Evaluation of the QuarkNet Program: Evaluation Report 2023-2024

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This report highlights cumulative evaluation efforts, which began in 2018-2022 and has continued during the current funding cycle from the National Science Foundation (NSF).[1] Portions of this report have drawn from annual evaluation reports prepared during the past grant period to reflect the continuity of these efforts (Race, 2019-2023). When a report section has not changed substantially over this time period, relevant information has been bundled and presented as an appendix. (The Executive Summary of this report begins on page 111.)

QuarkNet: Professional Development for HS Teachers

The QuarkNet Collaboration, referred to as QuarkNet, "is a long-term, national program that partners high school science teachers with particle physicists working in experiments at the scientific frontier." QuarkNet is a professional development program that "immerses teachers in authentic physics research and seeks to engage them in the development of instructional strategies and best practices that facilitate the implementation of these principles in their classrooms, delivering its professional development (PD) program in partnership with local centers" (Program Theory Model, PTM, 2019).

QuarkNet program efforts began in 1999; a brief history of the program is described in Appendix A. The QuarkNet program is not static but reflects changes in particle physics, such as neutrinos, and improved approaches to professional development over time. As noted by Beal and Young (2017), "For nearly two decades, QuarkNet has been fully engaged in establishing a national community of researchers and educators associated with particle physics experiments" drawing from the professional development literature. These past evaluators noted that QuarkNet has "evolved to reflect changes in the education context in which the program operates, and in response to findings from formative evaluation."

It is the current program that is the focus of present evaluation efforts, but we draw on the program's rich history when relevant.

Importance of Centers

In current form, QuarkNet[1] is "first and foremost, a teacher professional development program" (personal communication, email December 11, 2018), with 53 centers across the United States, where these centers "both form the essential backbone and are partners in the QuarkNet collaboration" (PTM, 2019). These centers are housed at a university

[1]QuarkNet has been co-sponsored by the National Science Foundation. Additional funding is provided by U.S CMS and U.S. ATLAS. In-kind support is provided by Fermilab through the Department of Energy.

or laboratory, serving primarily high school teachers who live in the nearby catchment area. Included in this number of in-person centers, there is the Virtual Center, which provides a home for teachers who do not live proximal to a particle physics research group. Experience conducting virtual workshops via the Virtual Center was instrumental in aiding program delivery through the COVID impacted program years of 2020 and 2021. At centers, program leaders include one or two physicists who serve as mentor(s) and team up with one or two lead teacher(s). Each center seeks to foster lasting relationships through collaboration at the local level and through engagement with the national program (PTM, 2019).

A center has been defined as “active” if it provides at least one day of teacher development and “semi-active” if the center and its teachers participate in only International Masterclasses, or another promotional event-program such as International Muon Week, Word Wide Data Day, International Cosmic Day or an equivalent activity (email blast sent by the PIs, email December 11, 2018). At the time of this writing there are 53 “active” QuarkNet centers, which will be listed later in this report. Two of these centers are new (e.g., started during the 2023 program year).

Program Goals

As articulated by the Principal Investigators (PIs) of the program and as stated in the Program Theory Model, the measurable program goals of QuarkNet are:

1. To continue a PD program that prepares teachers to provide opportunities for students to engage in scientific practices and discourse and to show evidence that they understand how scientists develop knowledge. To help teachers translate their experiences into instructional strategies, which reflect guided inquiry and NGSS science and engineering practices.

2. To sustain a national network of independent centers working to achieve similar goals. To provide financial support, research internships, an instructional toolkit, student programs and professional development workshops. To investigate additional funding sources to strengthen the overall program.

3. To reenergize teachers and aid their contributions to the quality and practice of colleagues in the field of science education.

4. To provide particle physics research groups with an opportunity for a broader impact in their communities.

Approach to Evaluation

The evaluation themes are: (1) (Develop and) Use a Program Theory Model (PTM); (2) Measure Outcomes (teacher, student and long-term); and (3) Measure Center-level Program Outcomes. During the previous grant period, new evaluation measures based on the PTM were created; these were combined with selected previous evaluation measures

Figure 1. Throughout the evaluation, program engagement (i.e., specifically exposure to core program strategies) provides the context in which assessment has occurred.

and efforts. These measures were implemented to assess teacher-level program outcomes, student-level, long-term outcomes, center-level outcomes and as well as program-center sustainability.

These outcome measures are supported by program-operations data obtained from program resource documents (such as agendas and annual reports) and, other teacher- and center-level information (such as teacher implementation plans and center feedback forms). This information is supported by virtual visits conducted by the external evaluator during implemented workshops. We drew from QuarkNet program and evaluation history when relevant (e.g., QuarkNet Proposal to NSF, 2018; 2023).

Key to the evaluation efforts, both quantitative assessment and qualitative assessment have sought to link program engagement to expected outcomes (see Figure 1).

(Develop and) Use Program Theory Model (PTM)

Because of the significance of the PTM and its role, previous reports provided at length the history and development of the model. We have bundled this description and present this in detail in Appendix B. In short, we drew from the relevant literature (characteristics of effective professional development, Darling-Hammond, et al., 2017); Next Generation Science Standards (especially the Practices); and defined our use of the term "Guided Inquiry." We developed the content of the model through structured interviews with key stakeholders; held a face-to-face meeting with past evaluators; and through working meetings with PIs and stakeholders developed a detailed, pictorial representation of the program.

Thus, QuarkNet's PTM:

1. Offers "an approximate fit" of the theory of the QuarkNet program as *designed.*
2. Allows for a comparison between the program as *designed* and as *implemented.*
3. Links core program strategies to program outcomes.
4. Directs evaluation efforts.

The PTM is intended to reflect that *context matters* in the implementation of the program and to provide a representative picture of how *change* is expected to happen.

Theory of Change

The Program Theory Model elaborates on how change is expected to occur, based on following QuarkNet Theory of Change:

By immersing teachers in doing authentic particle physics research and by engaging them in professional development that supports guided-inquiry and standards-aligned instructional practices and materials designed for the classroom, teachers become empowered to teach particle physics to their students in ways that model the actual practices of scientists and support instructional best practices suggested by the educational research literature. (Modified from Beal & Young, QuarkNet Summative Evaluation Report 2012-2017).

We continue to use this theory of change.

QuarkNet's Program Theory Model: What's New and What's Kept

QuarkNet's PTM was reviewed and revised (in small but important ways) to coincide with the current renewal grant. To this end, we had added: a new partner (i.e., the Institute for Research and Innovation in Software for High Energy Physics, IRIS-HEP); added new program components; and, reviewed, updated and revised descriptions of other program components, as needed.

The first two pages of the PTM are presented here (see Exhibit A and Exhibit B, next two pages); the full model is shown in Appendix C. The first two pages serve as an abbreviated version of the model and may be very useful depending upon the audience. The first page of the model presents the context in which the program operates identifying active partners and acknowledges the oversight responsibility of the program's Advisory Board. It also highlights additional outreach efforts associated with the program that extend beyond the program's core. The second page of the PTM provides a schematic overview of the program "a map" of the elements of the model suggesting how each may relate to the other. (Graphics created by L. Hudson.)

Who is the Audience*?* The audience for the PTM is someone who is or is not familiar with QuarkNet and who has an interest in or a stake in the program. The abbreviated model is likely to have the widest audience; an audience who may include individual teachers, mentors, participating centers, future funders, among others.

Details in the PTM regarding program strategies and its structure are offered as a guide for the stakeholders responsible for these program components and to help in program operations and revisions; and, to help guide reflections or assessments as to whether or not the program *as implemented* is aligned with the program *as designed* (i.e., its theory). For the external evaluator, the PTM has directed the outcomes-based evaluation.

QuarkNet Partners

NSF: The National Science Foundation is an independent federal agency created by Congress in 1950 "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…" NSF supports basic research and people to create knowledge that transforms the future. QuarkNet is funded through NSF's Integrative Activities in Physics Program.

Fermilab: America's particle physics and accelerator laboratory whose vision is to solve the mysteries of matter, energy, space and time for the benefit of all. Fermilab, a co-sponsor of QuarkNet, hosts Data Camp held each summer and supports the cosmic ray studies program. Fermilab hosts DUNE and the Long-Baseline Neutrino Facility. DUNE brings together over 1,000 scientists from more than 175 institutions in over 30 countries.

Broadening Participation and Community Outreach: QuarkNet works on multiple fronts to help broaden participation beyond the existing community, including teachers and students who are underrepresented in physics. Examples include center needs assessment workshops that serve to identify ways to reach out to these communities. QuarkNet partners with other STEM organizations to reach more teachers and students. Recent partners are *STEP UP, STEMarts Lab, and i.am.Angel Foundation.* Many Data Activities Portfolio activities have been translated into Spanish. Often, participating teachers develop classroom implementation plans that integrate culturally sensitive content. Centers integrate QuarkNet in their community outreach efforts, partnering to reach beyond existing QuarkNet schools to students traditionally underrepresented in STEM.

Advisory Board: Typically, eight to ten individuals both familiar with and new to the program meet annually to review QuarkNet program achievements and make recommendations for future plans and objectives. Members represent a diverse mix of high school physics teachers, education administrators, research physicists and physics outreach leaders.

QuarkNet: The QuarkNet Collaboration is a long-term, national program that *partners high school science teachers with particle physicists* working in experiments at the scientific frontier. A professional development program, QuarkNet immerses teachers in authentic physics research and seeks to engage them in the development of instructional strategies and best practices that facilitate the implementation of these principles in their classrooms.

QuarkNet Centers: Centers both form the essential backbone of and are partners in QuarkNet. A center is housed at a university or laboratory, serving high school physics and physical science teachers; active local centers number 50+.

IRIS-HEP: A software institute funded by the National Science Foundation. It aims to develop the state-of-the-art software cyberinfrastructure required for the challenges of data intensive scientific research at the High Luminosity Large Hadron Collider (HL-LHC) at CERN, and other planned HEP experiments of the 2020's. In partnership with IRIS-HEP, QuarkNet offers professional development opportunities for teachers to improve coding skills to enhance classroom implementation of particle physics instructional materials.

U.S. ATLAS: A collaboration of scientists from 45 U.S. institutions. ATLAS is one of two general-purpose detectors at the Large Hadron Collider in Geneva, Switzerland. The ATLAS experiment investigates a wide range of physics, from the search for the Higgs boson to extra dimensions and particles that could make up dark matter. U.S. ATLAS is a co-sponsor of QuarkNet.

U.S. CMS: A collaboration of more than 900 scientists from 50 U.S. institutions who make significant contributions to the Compact Muon Solenoid (CMS) detector. Discoveries from the CMS experiment are revolutionizing our understanding of the universe. USCMS is a co-sponsor of QuarkNet.

Broader Impacts: QuarkNet has led in facilitating the public use of large particle physics datasets. Working within the International Particle Physics Outreach group (IPPOG), QuarkNet shares the overall central coordination of International Masterclasses (IMC). QuarkNet schedules and coordinates ATLAS, CMS, MINERvA and NOvA International Masterclasses with videoconferences based at Fermilab. Also, QuarkNet develops and coordinates World Wide Data Day, an IMC extension, and shares leadership in the global cosmic ray studies project. QuarkNet provides a wealth of information for IPPOG members to consider in their own education and outreach programs. QuarkNet staff and teachers attend and present at meetings of the American Association of Physics Teachers and the American Physical Society. These presentations have highlighted how QuarkNet works, e-Labs, the Data Activities Portfolio and scientific discovery for students.

Exhibit A. The first page of the PTM highlighting key partners and outreach efforts.

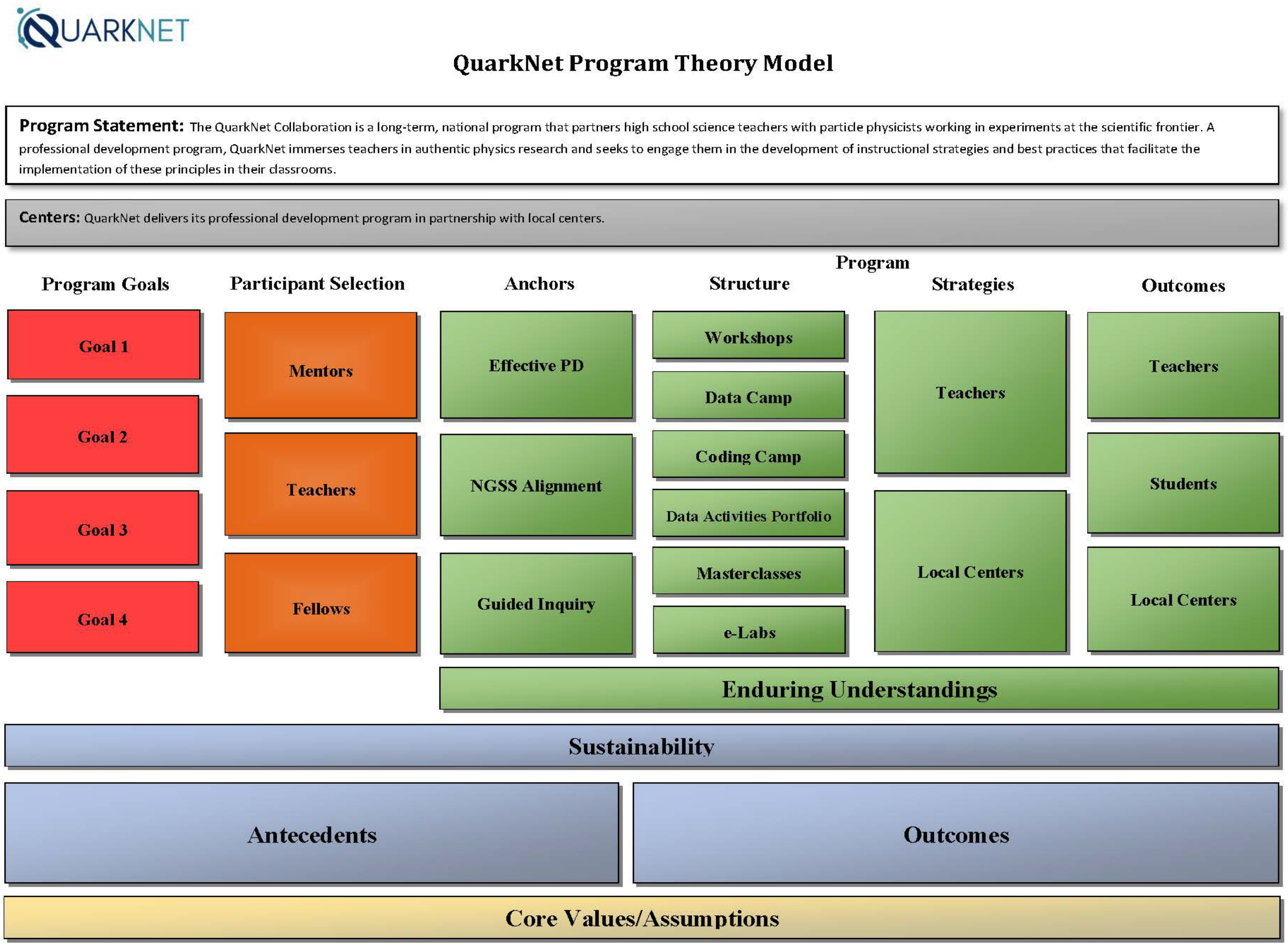


Exhibit B. The second page of the PTM which over views its component parts.

PTM: Three Program Anchors

The PTM is anchored by:

1. Drawing from the Literature: Effective Professional Development
2. Program Alignment with the Next Generation Science Standards
3. Program's Use of the Concept of Guided Inquiry

Effective Professional Development (PD)

In 2017, Darling-Hammond and her colleagues identified characteristics of effective professional development. Her work was based on the review of 35 studies that met their criteria of methodological rigor; studies, which they noted, built on an expansive body of prior research that has described positive outcomes based on teacher and student self-reports or observational studies. These reviewed studies showed a positive link between teacher professional development, teaching practices, and student outcomes (Darling-Hammond, Hyler & Gardner, 2017). Her work added to the contributions of Desimone (2009), which led to the identification of seven characteristics of effective PD. They posit that successful PD "will generally feature a number of these components simultaneously" (Darling-Hammond, Hyler & Gardner, 2017, p. 4). Table 1 provides a brief description of each of these characteristics.

As shown in this table, the seven characteristics of effective PD as proffered by Darling-Hammond, et al. (2017) are:

1. Is **content focused**.
2. Incorporates **active learning** utilizing adult learning theory.
3. Supports **collaboration**, typically in **job-embedded contexts**.
4. Uses **models and modeling** of effective practice.
5. Provides **coaching and expert support**.
6. Offers opportunities for **feedback and reflection**.
7. Is of **sustained duration**.

Given the overarching nature of this program anchor, Table 1 also briefly describes how each of these characteristics is integrated in the QuarkNet program. Similarly, Roudebush (2022) showed how these characteristics align with the Data Activities Portfolio activities of QuarkNet. Professional Learning Communities are seen by Darling-Hammond, Hyler and Gardner (2017) as an important means in which to embed these PD characteristics Later in this report, we will highlight how the implemented QuarkNet program facilitates building relationships among teachers, lead teachers, fellows, mentors, and other scientists through these collegial networks in pursuit of learning communities.

The remaining program anchors described in the PTM are introduced in this section as well; however, QuarkNet alignment with these anchors are presented in more detail in subsequent sections of this report.

Table 1
Brief Description of Characteristics of Effective Professional Development (PD)
Identified by Darling-Hammond, Hyler and Gardner (2017) and What Happens in QuarkNet

Characteristic of Effective PD	Brief Description[a]	What Happens in QuarkNet
Content Focused	PD that is focused on a discipline-specific curricula or instructional materials; that is "both content specific and classroom based;" that promotes inquiry-based learning in a structured sequence of ideas; and, supported by standards-based instruction and practice. Such PD will provide teachers with opportunities, for example, to study their students' work, test out new curriculum, and study a particular element of pedagogy or student learning in the content area. It is most often job embedded (i.e., situated in the classroom). (pp. 5-6)	All QuarkNet opportunities are content focused and are an integral part of the larger QuarkNet program whether a workshop, masterclass, e-Lab or something else (focused on specific content i.e., particle physics or more general physics). The Data Activities Portfolio (DAP) activities, content-specific instructional materials designed for classroom use, support QuarkNet opportunities and are designed for classroom use. Each activity encompasses standards-based instruction and practice; each aligns with specific Next Generation Science Standards science practices. Some instructional materials build skills necessary to support subsequent content area(s). The need for diversity and inclusion in physics is addressed through specific activities.
Active Learning	PD that addresses "*how* teachers learn as well as *what* teachers learn;" engages teachers directly in the practices they are learning, and is connected to teachers' classrooms and students; where teachers use "authentic artifacts, interactive activities and other strategies;" teachers engage as learners often engaging in the same activities that they are designing for their students; and, where learning opportunities reflect their own interests, needs and experience; and where reflection and inquiry are central. (p. 7)	QuarkNet provides opportunities for teachers to engage in QuarkNet as active learners. Active learning typically occurs through the engagement in DAP activities by teachers, experiencing these as students, during all nationally-led workshops, and during most center-led workshops. Teachers may try out Masterclass materials, as active learners, during a center meeting prior to implementing the activity with their students. At specific centers, teachers participate in on-going research projects as active researchers.
Collaboration	Seen as an important feature of well-designed PD programs where collaboration can span a host of configurations "from one-on-one or small group interactions to schoolwide collaborations to exchanges with other professionals beyond the school." (p. 9)	QuarkNet provides a full array of opportunities to collaborate whether one-on-one engagement between teachers; working in small groups while engaged in an activity; or collaborating between centers. Teachers become familiar with large, international collaborations through physics talks and activities such as virtual tours of the experiments at CERN. Teachers exchange ideas with other teachers or fellows on classroom implementation, including the necessary collaboration to conduct very large particle physics experiments. QuarkNet encourages teachers to share their QuarkNet opportunities, such as participating in Data Camp or a visit to CERN, with teachers upon their return to the center.
Use of Models and Modeling	PD that uses models of effective practice, where "curricular and instructional models and modeling of instruction help teachers have a vision of practice on which to anchor their own learning and growth." (p. 11)	QuarkNet supports professional development by focusing on cutting-edge particle physics and by modeling the instructional practices that teachers are encouraged to use in their classroom, supported with standards-based instructional materials. Workshop facilitators and QuarkNet staff support these practices using standards-based instructional materials found in the DAP. Teachers engage in QuarkNet as active participants with ample time for reflection, feedback, and collaborations with others.

Table 1 (con't.)
Brief Description of Characteristics of Effective Professional Development (PD)
Identified by Darling-Hammond, Hyler and Gardner (2017) and What Happens in QuarkNet

Characteristic of Effective PD	Brief Description[a]	What Happens in QuarkNet
Coaching and Expert Support	PD where experts help "to guide and facilitate teachers learning in the context of their practice" by "employing professional learning strategies" "such as modeling strong instructional practices, supporting group discussions," "share expertise about content and evidence-based practices;" "sharing their knowledge as workshop facilitators." Experts can range from "specially-trained master teachers and instructional leaders to research and university faculty." (pp.12-13)	There are a variety of ways in which QuarkNet draws on expert support, by a teacher reaching out to a mentor, to another teacher, to a lead teacher, fellow, or QuarkNet staff teacher. Often, these opportunities are a designated part of a workshop, or a meeting as documented in the agenda. Opportunities can occur more informally such as through emails and one-on-one conversations as needed by individual teachers. QuarkNet encourages teachers to develop and practice leadership skills. These skills are fostered through specific workshops to help lead-teachers and fellows define their role, including how/and in what ways they can contribute to workshops. Lead teachers are encouraged and supported in coordinating logistics, serving as facilitators, or in giving presentations. Fellows are encouraged and supported in developing agendas and in facilitating and leading workshops. Fellows and, at times, teachers are encouraged and supported to present at local, regional, and national professional conferences.
Feedback and Reflection	Effective PD incorporates two distinct practices feedback and reflection -- that are seen as "powerful tools" and each of which are "critical components of adult learning theory." Effective PD provides "built-in time for teachers to think about, receive input on, and make changes to their practice by provides intentional time for feedback and/or reflection." (p.14)	Specific time is allocated during workshops and other QuarkNet opportunities for meaningful discussions based on the needs of teachers. Often, these sessions or opportunities focus on ways to incorporate QuarkNet content or instructional materials into the classroom. Teachers have time to reflect "as students" followed by a debriefing at the end of an activity after their engagement. A significant portion of nationally-led workshop agendas is devoted to the development of implementation plans by teachers. Feedback can come from other teachers who have implemented a particular activity or from workshop facilitators. Other opportunities to exchange ideas can occur through "share-a-thon' sessions, which can include QuarkNet and other resources. For example, QuarkNet Educational Discussions (QED) started during COVID to provide a small-group forum for teachers to discuss issues related to online teaching and the return to the classroom. This has evolved to a more general discussion and support group forum.
Sustained Duration	"(M)eaningful professional learning requires time and quality implementation." Effective PD is sustained, providing multiple opportunities for teachers to engage in learning around a single set of concepts or practices; providing the time necessary for learning that is rigorous and cumulative. (p. 15)	Typically, centers have been involved in QuarkNet for many years and individual teachers within centers continue to meet over many years. These efforts are wrapped in a larger program. Centers may meet annually, and some meet throughout the school year. Engagement may include: a workshop, a masterclass, and/or using cosmic ray detectors to collect and analyze data. QuarkNet offers many opportunities for teachers to engage, and the teacher (and the center) can select, from among these, opportunities that best fit the teachers or center needs. Not all centers or teachers engaged in the full spectrum of QuarkNet opportunities, but the center serves to build a supportive network of teachers, nonetheless. For example, teachers are supported through team building, networking, and supporting the social needs (e.g., sharing stories) of participating teachers.

[a]Sources. Column two presents direct quotes and paraphrases descriptions proffered by Darling-Hammond, Hyler & Gardner (2017). The program descriptions of QuarkNet presented in column three were prepared by the QuarkNet PI, QuarkNet staff, and the evaluator (Roudebush, Bardeen, Cecire, Wood, LaMee, Pasero, Adams, Hoppert and Race). It is intended to provide a representative picture of the current program relative to these characteristics.

Program's Alignment with NGSS Standards

Clearly QuarkNet predated the release of the Next Generation Science Standards (1999 versus 2013). That said inquiry, specifically guided inquiry, and a claims-evidence-reasoning approach (McNeill & Krajcik, 2008) were evident as foundational to the program reflected in both its implementation and instructional materials before the emergence of these standards. To reflect both current thinking about best practices in the instruction of science and the implementation model embedded in the program, the Science and Engineering Practices of the NGSS (April 2013) were explicitly stated as program anchors in the PTM. The eight practices are:

1. Asking questions (for science) and defining problems (for engineering).
2. Developing and using models.
3. Planning and carrying out investigations.
4. Analyzing and interpreting data.
5. Using mathematics and computational thinking.
6. Constructing explanations (for science) and designing solutions (for engineering).
7. Engaging in argument from evidence.
8. Obtaining, evaluating, and communicating information.

As important, Crosscutting Concepts (NGSS) were included as well. These are:

1. Patterns
2. Cause and Effect
3. Scale, Proportion and Quantity
4. Systems and System Models
5. Energy and Matter in Systems
6. Structure and Function
7. Stability and Change of Systems (see NGSS at https://www.nextgenscience.org)

Program's Use of the Concept of Guided Inquiry

In the PTM and in the *implemented* program, guided inquiry is operationally defined using Herron's model of inquiry (Herron, 1971) as modified by Jan-Marie Kellow (2007). That is, as defined, guided inquiry is seen as to occur in situations where the teacher provides the problem or question; and for structured inquiry in situations where the teacher provides the problem and procedure. Further, as modified, in guided inquiry the solution is not already existing/known in advance and could vary from student to student. Students *either* investigate a teacher-presented question (usually open-ended) using student designed/selected procedures *or* investigate questions that are student formulated (usually open-ended) through a prescribed procedure (some parts of the procedure may be student/designed/selected) (Herron, 1971; Jan-Marie Kellow, 2007).

In QuarkNet's case, it is likely that the teacher may be a mentor or lead/associate/staff teacher; and the student(s) -- may be participating teacher(s) engaged in active learning as students--; or actual students engaged in activities from the Data Activity Portfolio.

QuarkNet's Program Theory Model: Program Structure

In its fully articulated form, the PTM describes the QuarkNet program *as designed* (as already stated). The model identifies program strategies framed within the specific program structure and components and seeks to describe how outcomes logically link to the program. In the model, a program statement, program centers, program goals, assumptions/core values, participant selection and key program components including anchors, the program's structure, core strategies and program outcomes are stated or described. In addition, enduring understandings and a sustainability framework are included.

The details reflected in the PTM are at the strategic level and are deliberatively not activity specific. The intent is to capture ideas core to the program or "its big ideas" as well as the supportive structure of the program in which these strategies are embedded. The component, *Enduring Understandings,* previously developed and revised by Young, Bardeen, Roudebush, Smith and Wayne (2019), was included in the PTM because it succinctly describes expectations about understandings -- that are core to the program and reflective of particle-physics science practices and good science practices in general. Ultimately, the PTM can be viewed as a "blueprint" as to how change is expected to happen through the program's underlying components and strategies (DuBow & Litzler, 2019).

At the program level, the information presented in the PTM is not intended to be prescriptive; an in-depth look at the program would likely be supported (and is) with other information; for example, details about the sequencing of Data Activities Portfolio activities and highlighting how these instructional materials align with other science standards such as AP or IB Physics Science Standards.

Exhibit C provides a graphic presentation of the program structure of QuarkNet. These program components are:

- Workshops
- Data Camp
- Coding Camp
- Data Activities Portfolio
- Masterclasses
- e-Labs (as well as cosmic ray studies, cosmic watches)

Program Structure

Data Camp: Offered annually at Fermilab, this 1-week summer program is an introductory workshop for teachers of physics and physical science who either have had little-to-no experience with particle physics and/or who have had little experience with quantitative analysis of LHC data. The camp emphasizes an authentic data analysis experience in which teachers engage as active learners (as students) of a challenging topic they may have known very little about. In the beginning of the week, teachers receive an authentic CMS dataset and work in small groups to determine the mass of particles produced during LHC proton-proton collisions. Successful completion of this phase of the workshop culminates in each group presenting and explaining their analyses. In the second half of the week, teachers explore various instructional materials in the Data Activities Portfolio that help incorporate particle physics concepts into their everyday lessons and propose an implementation plan for their classrooms. Throughout the week, teachers take tours and participate in seminars from theoretical and experimental physicists.

Coding Camp: A virtual 1-week program offered annually in the summer for teachers of physics and physical science with little-to-no experience in computer programming and/or incorporating computer science into their courses. The camp emphasizes an authentic data analysis experience in which teachers engage as active learners (as students) using common scientific programming software (e.g., Jupyter, Python, & SciPy) to analyze and visualize large datasets from various scientific disciplines, including particle physics, astronomy, and geology. Like Data Camp, during the first half of the week, teachers are learners of challenging content. In the second half, they use reformed pedagogy in planning how to integrate coding into their courses. Throughout the week, teachers participate in virtual seminars with scientists and programmers working in various fields.

Data Activities Portfolio: An online compendium of particle physics classroom instructional materials organized by data strand, level of student engagement, curriculum topics and NGSS Standards. Instructional materials conform to a specific instructional design and are aligned with NGSS and AP science standards (Physics 1 and Physics 2) as relevant. Materials are based on authentic experimental data used by teachers to give students an opportunity to learn how scientists make discoveries. Strands include LHC, Cosmic Ray Studies, and Neutrino. Level descriptions, 0 to 4, explain the data analysis skills that students apply at each level: tasks in Level 0 are simpler than those in Levels 1 and 2. While each level can be explored individually, students who start in one level and progress to more complex levels experience increasingly engaging and challenging tasks.

Each curriculum topic provides connections between topics routinely covered in physics class and particle physics content and methods. The drop-down menus identify activities related to desired content and student skill sets. Teacher, student resources and data sets are available for each activity. In the Curriculum Topic drop-down menu, Spanish Language versions are available for some activities. Also, coding activities are available.

Masterclass, QuarkNet Model: A one-day event in which students become "particle physicists for a day." Teachers and mentors participate in an orientation, either remote or in person, by QuarkNet staff or fellows. Teachers implement up to three hours of classroom activities prior to a masterclass. Then, during the masterclass that usually takes place at a center, mentors introduce students to particle physics, and teachers explain the measurements they will make using authentic particle physics data. Working in pairs, students analyze data from visual event displays, characterize the events, pool their data with peers, and draw conclusions. Students are helped by and discuss interpretation of data with one or more particle physicists and their peers and teachers. At the end of the day, students may gather by videoconference with students at other sites to discuss results with moderators, who are particle physicists, at Fermilab, CERN, or another high energy physics facility. Some masterclasses take place at school with teachers providing the particle physics and measurement information. QuarkNet Masterclasses are part of a larger program, International Masterclasses.

Workshops: The primary vehicle through which participating QuarkNet teachers receive professional development. Teachers engage in QuarkNet workshops when new to the program and often over multiple years.

Workshops are in-person events held at a center. (A virtual center accommodates teachers from a dispersed area.) QuarkNet staff work with individual centers to build this experience with considerable flexibility to organize workshops that meet local needs and interests. Workshops vary in length, from 1-to-5 days, typically occur during the summer, but many centers may meet during the summer and school year. Workshops can be locally led or nationally led and are often a combination of the two, thus varying in content and structure. Nationally-led workshops, conducted by QuarkNet staff and/or fellows, cover content including, for example, cosmic ray studies, LHC or neutrino data, coding in support of particle physics, and related activities from the Data Activities Portfolio. Nationally-led workshops support opportunities for teachers to engage as active learners, as students, engage in activities from the Data Activities Portfolio, collect and analyze data, work in a learning-community environment, learn and share ideas related to content and pedagogy, and build collegial relationships with other teachers, fellows and mentors. Of importance, teachers have time to develop and discuss classroom implementation plans. Often locally- led workshops mirror these components and offer opportunities for teachers to tour local research labs, participate in unique events, and/or hear presentations by local physicists and students.

Staff encourage centers to post their agendas and annual reports on the QuarkNet website to share this engagement with other centers. Often, centers collaborate with other centers (e.g., rotating host responsibilities from one year to the next), join together through shared interests or content needs and other opportunities for multi-center engagement.

e-Lab: A browser-based online platform in which students can access and analyze data in a guided-inquiry scientific investigation. An e-Lab provides a framework and pathway as well as resources for students to conduct their own investigations. e-Lab users share results through online plots and posters. In the CMS e-Lab, data are available from the Compact Muon Solenoid (CMS) experiment at CERN[2]'s Large Hadron Collider (LHC). In the Cosmic Ray e-Lab, users upload data from QuarkNet cosmic ray detectors located at high schools, and once uploaded, the data are available to any and all users.

[2] Conseil Européen pour la Recherche Nucléaire

Cosmic Ray Studies: Across most centers, QuarkNet supports a high school long-term collaboration based on the High Energy Physics model using particle detectors provided in kit form. In this hands-on learning opportunity, students assemble the parts into a working scientific instrument based on the design used in the Collider Detector at Fermilab. Students and their teachers use the detectors for inquiry-based learning involving authentic research tasks and experiments such as muon flux, muon lifetime, and speed of muons, using data they collect themselves. Their data can be uploaded to the cosmic ray e-Lab for analysis, creating graphed plots to display results.

Cosmic Watches: Smaller more portable particle detectors, cosmic watches extend the reach of authentic research activity to all students, not just research groups, by moving cosmic ray studies into classrooms increasing the number of teachers using cosmic rays to teach about elementary particles and observing the invisible.

Exhibit C. Program Structure of QuarkNet's Program Model as described on page 3 of the model.

Table 2
Data Activities Portfolio: Level Definitions

Level	Description of Expected Student Engagement
0	Students build background skills and knowledge needed to do a Level 1 activity. Students analyze one variable or they determine patterns, organize data into a table or graphical representation and draw qualitative conclusions based on the representation of these data.
1	Students use background skills developed in Level 0. They calculate descriptive statistics, seek patterns, identify outliers, confounding variables, and perform calculations to reach findings; they may also create graphical representations of the data. Datasets are small in size. The data models come from particle physics experimentation.
2	Students use skills from Level 1 but must apply a greater level of interpretation. The analysis tasks are directed toward specific investigations. Datasets are large enough that hand calculation is not practical, and the use of statistics becomes central to understanding the physics. They perform many of the same analysis tasks but must apply a greater level of interpretation.
3	Students use the skills from Level 2. They develop and implement a research plan utilizing large datasets. They have choices about which analyses they do and which data they use; they plan their own investigations.
4	Students use the skills from Level 3. They identity datasets and develop code for computational analysis tools for the investigation of their own research plan.

Note: A new Level 4 activity has been added into the mix. (D. Roudebush, 2023)

Data Activities Portfolio

The Data Activities Portfolio (DAP) is an online compendium of particle physics classroom instructional materials organized by Data Strand, Level of student engagement, Curriculum Topics and NGSS standards (https://quarknet.org/data-portfolio). This compendium is an important component of the program connected to the national program's Data Camp as well as to other national and center-run workshops and programs where teachers have opportunities to explore these sequenced lessons and to develop classroom implementation plans. These instructional materials are based on authentic experimental data used by teachers to give students an opportunity to learn how scientists make discoveries. Strands include LHC, Cosmic Ray, and Neutrino data. Curriculum topics include, for example, activities related to conservation laws; and electricity and magnetism. Activities increase in complexity, sophistication and expected student engagement from Levels 0 to 4. Draft instructional materials are reviewed by QuarkNet staff based on specified instructional design guidelines and are aligned with NGSS, IB, and AP science standards (Physics 1 and Physics 2) as relevant.

Through guidance from teachers, students are provided the opportunities shown in Table 2, which shows five instructional levels of these instructional materials; (level 0 and level 4 are new to this award period). Masterclasses and e-Labs offer additional options at levels 3 and 4 with project maps offered as guidance for Masterclass implementations. By selecting activities from across available levels, teachers can develop a sequence of lessons or activities appropriate for their students and to help build student skills-sets by moving from simple to more complex. Teachers can also search for activities by a specific NGSS Practice or across all applicable practices.

Linking Program Strategies to Outcomes

The principal intent of the PTM is to logically link core strategies to program outcomes. Tables 3 and 4 reflect this alignment, first by showing the alignment of program anchors, -- that is, effective professional development, NGSS standards and guided inquiry, -- with core strategies (Table 3). This table (and this section of the PTM) presents the grounding of these program strategies as suggested by the educational research literature.

The overarching strategy of the program is the recognition that QuarkNet is not static but evolves to reflect changes in particle physics and the education context in which it operates. Two big-picture strategies relate to opportunities for teachers to be exposed to instructional strategies that model active, that is, guided-inquiry learning, and big ideas in science and enduring understandings. Strategies directed toward teachers include: *Engage as active learners, as students;* and *Discuss the concept of uncertainty in particle physics.* There are two strategies relate to local centers, these are: *Interact with other scientists and collaborate with each other*; and *Build a local (or regional) learning community*. More will be said about centers latter in this report.

Table 4 shows the logical links between core strategies and program outcomes. As shown, these outcomes are organized by "target audience," including Teachers, their Students, and Local Centers. Of importance, teacher outcomes are directed toward how teachers translate their experiences into instructional strategies, which reflect guided inquiry and NGSS science and engineering practices and other science standards such as AP, as applicable and to the extent possible in their school setting. These outcomes include: *Discuss and explain concepts in particle physics;* and, *Use instructional practices that model scientific research.* Outcomes directed toward their students include: *Use, analyze and interpret authentic data; draw conclusions based on these data.*

Outcomes directed toward local centers include Teachers as Leaders, such as: *Act in leadership roles in local centers and in their school (and school districts) and within the science education community.* There are outcomes directed toward Mentors, such as: *Become the nexus of a community that can improve their teaching, enrich their research and provide broader impacts for their university*; and Teachers and Mentors such as: *Form lasting collegial relationships through interactions and collaborations at the local level and through engagement in the national program.*

As will be seen in subsequent sections of this report, program outcomes directed toward teachers are measured by a Full Teacher Survey (followed by a short update) distributed on an annual basis. And program outcomes related to mentors and interactions between mentors and teachers have been captured in a Center Feedback Template (as well as sustainability outcomes). The Center Feedback Template serves a dual-role, to provide the context in which teachers receive the implemented program; and, to serve as a center-level outcome measure in its own right. These principal evaluation measures are supported, for example, by links to program operations data such as implemented workshop agendas and implementation plans developed by participating teachers (when available). In addition, the external evaluator conducts virtual visits of workshop

Table 3. QuarkNet: Aligning Program Anchors and Core Strategies

<table>
<tr><th>Program Anchors: Effective Professional Development and Best Practices</th><th>Core Strategies: What Happens in QuarkNet?</th></tr>
<tr><td>Characteristics of Effective Professional Development[1]
• Is content focused
• Incorporates active learning utilizing, adult learning theory
• Supports collaboration, typically in job-embedded contexts
• Uses models and modeling of effective practice
• Provides coaching and expert support
• Offers opportunities for feedback and reflection
• Is of sustained duration.
[1] Darling-Hammond, L., Hyler, M.E., & Gardner, M. (2017, June). Effective teacher professional development. Palo Alto, CA: Learning Policy Institute.</td><td rowspan="2">QuarkNet is not static but evolves to reflect changes in particle physics and the education context in which it operates.

Teachers
Provide opportunities for teachers to be exposed to:
• Instructional strategies that model active, guided-inquiry learning (see NGSS science practices).
• Big Idea(s) in Science (cutting-edge research) and Enduring Understandings (in particle physics).

Provide opportunities for teachers to:
• Engage as active learners, as students.
• Do science the way scientists do science.
• Engage in authentic particle physics investigations (that may or may not involve phenomenon known by scientists).
• Engage in authentic data analysis experience(s) using large data sets.
• Develop explanations of particle physics content.
• Discuss the concept of uncertainty in particle physics.
• Engage in project-based learning that models guided-inquiry strategies.
• Share ideas related to content and pedagogy.
• Review and select particle physics examples from the Data Activities Portfolio instructional materials.
• Use the pathways, suggested in the Data Activities Portfolio, to help design implementation plan(s).
• Construct classroom implementation plan(s), incorporating their experience(s) and Data Activities Portfolio instructional materials.
• Become aware of resources outside of their classroom.

Local Centers (Each center seeks to foster lasting relationships through collaboration at the local level and through engagement with the national program.)

In addition, through sustained engagement provide opportunities for teachers and mentors to:
• Interact with other scientists and collaborate with each other.
• Build a local (or regional) learning community.</td></tr>
<tr><td>Pedagogical and Instructional Best Practices
Aligns with the Science and Engineering Practices of the NGSS APPENDIX F – Science and Engineering Practices in the NGSS (2013, April). As suggested, these practices are intended to better specify what is meant by inquiry in science.
https://www.nextgenscience.org
1. Asking questions (for science) and defining problems (for engineering).
2. Developing and using models.
3. Planning and carrying out investigations.
4. Analyzing and interpreting data.
5. Using mathematics and computational thinking.
6. Constructing explanations (for science) and designing solutions (for engineering).
7. Engaging in argument from evidence.
8. Obtaining, evaluating, and communicating information.

Content addresses Disciplinary Core Ideas and Crosscutting Concepts (NGSS):
1. Patterns
2. Cause and Effect
3. Scale, Proportion and Quantity
4. Systems and System Models
5. Energy and Matter in Systems
6. Structure and Function
7. Stability and Change of Systems

Guided Inquiry
Guided inquiry (teacher provides problem or question) and Structured inquiry (where teacher provides problem and procedure) [Herron, M.D. (1971). The nature of scientific enquiry. School Review, 79(2), 171- 212.] Guided Inquiry - The solution is not already existing/ known in advance and could vary from student to student. Students EITHER investigate a teacher-presented question (usually open-ended) using student designed/selected procedures OR investigate questions that are student formulated (usually open-ended) through a prescribed procedure (some parts of the procedure may be student designed/ selected). (2007 Jan-Marie Kellow)]</td></tr>
</table>

Table 4. QuarkNet: Aligning Core Strategies and Program Outcomes

Core Strategies: What Happens in QuarkNet?	Program Outcomes
QuarkNet is not static but evolves to reflect changes in particle physics and the education context in which it operates. ***Teachers:*** *Provide opportunities for teachers to be exposed to:* • Instructional strategies that model active, guided-inquiry learning (see NGSS science practices). • Big Idea(s) in Science (cutting-edge research) and Enduring Understandings (in particle physics). *Provide opportunities for teachers to:* • Engage as active learners, as students. • Do science the way scientists do science. • Engage in authentic particle physics investigations (that may or may not involve phenomenon known by scientists). • Engage in authentic data analysis experience(s) using large data sets. • Develop explanations of particle physics content. • Discuss the concept of uncertainty in particle physics. • Engage in project-based learning that models guided-inquiry strategies. • Share ideas related to content and pedagogy. • Review and select particle physics examples from the Data Activities Portfolio instructional materials. • Use the pathways, suggested in the Data Activities Portfolio, to help design implementation plan(s). • Construct classroom implementation plan(s), incorporating their experience(s) and Data Activities Portfolio instructional materials. • Become aware of resources outside of their classroom. **Local Centers** (Each center seeks to foster lasting relationships through collaboration at the local level and through engagement with the national program.) *In addition, through sustained engagement provide opportunities for teachers and mentors to:* • Interact with other scientists and collaborate with each other. • Build a local (or regional) learning community.	**Teachers** *Translate their experiences into instructional strategies, which reflect guided inquiry and NGSS science and engineering practice and other science standards as applicable. Specifically:* • Discuss and explain concepts in particle physics. • Engage in scientific practices and discourse. • Use particle physics examples, including authentic data, when teaching subjects such as momentum and energy. • Review and use instructional materials from the Data Activities Portfolio, selecting lessons guided by the suggested pathways. • Facilitate student investigations that incorporate scientific practices. • Use active, guided-inquiry instructional practices in their classrooms that align with NGSS and other science standards. • Use instructional practices that model scientific research. • Illustrate how scientists make discoveries. • Use, analyze and interpret authentic data; draw conclusions based on these data. • Become more comfortable teaching inquiry-based science. • Use resources (including QuarkNet resources) to supplement their knowledge and instructional materials and practices. • Increase their science proficiency. • Develop collegial relationships with scientists and other teachers. • Are life-long learners. **(And their) Students will be able to:** • Discuss and explain particle physics content. • Discuss and explain how scientists develop knowledge. • Engage in scientific practices and discourse. • Use, analyze and interpret authentic data; draw conclusions based on these data. • Become more comfortable with inquiry-based science. **Local Centers** • Model active, guided-inquiry instructional practices that align with NGSS and other science standards that model scientific research. *Through engagement in local centers* ***Teachers as Leaders:*** • Act in leadership roles in local centers and in their school (and school districts) and within the science education community. • Attend and/or participate in regional and national professional conferences sharing their ideas and experiences. ***Mentors:*** • Become the nexus of a community that can improve their teaching, enrich their research and provide broader impacts for their university. ***Teachers and Mentors:*** • Form lasting collegial relationships through interactions and collaborations at the local level and through engagement with the national program.

discussions by teachers on proposed implementation plans and how QuarkNet content and materials may be used in their classrooms.

Finally, it is important to note that the designed and ultimately the implemented program are strategy-based in part because of the recognized need for flexibility in conducting workshops and events across 50+ centers (currently 53 centers). Program strategies offer guidelines and guard rails encouraging program versatility within these. There is not a prescriptive "recipe" of specific workshops/events and classroom activities but rather a family of workshop options and classroom-activities engagement (first by teachers and then their students through the Data Activities Portfolio) that can be implemented. Strategies increase the likelihood of providing teachers with professional development that reflects their individual -- as well as center -- needs and at the same time provide a framework that aligns with effective practices reflected in the educational research literature.

Enduring Understandings

Table 5 presents the Enduring Understandings of Particle Physics developed by Young, Bardeen, Roudebush, Smith and Wayne (originally in 2015 and revised in 2019). These were incorporated into the PTM because of their fundamental relevance to expected understandings of big ideas associated with participation in QuarkNet; and, because these are integral to the design and implementation of instructional materials contained in the Data Activities Portfolio.

Accordingly, these Enduring Understandings are in keeping with Wiggins and McTighe's (2005), *Understanding by Design,* who describe backward design as a three-stage process in which the teacher first identifies the desired results; then determines what would count as evidence to determine whether or not the students did or did not reach those results; and then designs the learning experience around these desired results and evidence. In this way, Wiggins and McTighe recommended four criteria, i.e., to what extent does the idea, topic or process:

1. Represent a "big idea" having enduring value beyond the classroom?
2. Reside at the heart of the discipline?
3. Require uncoverage?
4. Offer potential for engaging students?

Sample (2011) noted that uncoverage implies depth over breath; determining how much material to cover; how deep to go and how deeply to dig down into core principles or processes of a given discipline to gain a lasting understanding. Thus, *enduring understandings* are defined as "statements summarizing important ideas and core processed that are central to a discipline and have lasting value beyond the classroom. They synthesize what students should understand – not just know or do – as a result of studying a particular content area." (Wiggins and McTighe, 2003; http:/Enduring Understandings | iTeachU (uaf.edu)]

Table 5
Enduring Understandings of Particle Physics

1. Scientists make a claim based on data that comprise the evidence for the claim.
2. Scientists use models to make predictions about and explain natural phenomena.
3. Scientists can use data to develop models based on patterns in the data.
4. Particle physicists use data to determine conservation rules.
5. Indirect evidence provides data to study phenomena that cannot be directly observed.
6. Scientists can analyze data more effectively when they are properly organized; charts and histograms provide methods of finding patterns in large datasets.
7. Scientists form and refine research questions, experiments and models using patterns in large data sets.
8. The Standard Model[1] provides a framework for our understanding of matter at its most fundamental level.
9. The fundamental particles are organized according to their characteristics in the Standard Model[1].
10. Particle physicists use conservation of energy and momentum to measure the mass of fundamental particles.
11. Fundamental particles display both wave and particle properties, and both must be taken into account to fully understand them.
12. Particle physicists continuously check the performance of their instruments by performing calibration runs using particles with well-known characteristics.
13. Well-understood particle properties such as charge, mass, momentum and energy provide data to calibrate detectors.
14. Particles that decay do so in a predictable way, but the time for any single particle to decay, and the identity of its decay products, are both probabilistic in nature.
15. Particle physicists must identify and subtract background events in order to identify the signal of interest.
16. Scientists must account for uncertainty in measurement when reporting results.

Note. Developed by Young, Bardeen, Roudebush, Smith & Wayne, 2019
[1]The Standard Model of Particle Physics: the current theoretical framework that describes elementary particles and their forces (six leptons, six quarks and four force carriers). Physicists (and other scientists) can understand every phenomenon observed in nature by the interplay of the elementary particles and forces of the Standard Model. The search beyond the Standard Model of Particle Physics may lead to a larger, more elegant "theory of everything."
(http://www.fnal.gov/pub/science/inquiring/matter/ww_discoveries/index.html)

Sustainability Framework

Atypical of PTM's, a sustainability framework has been included. Its inclusion seems particularly warranted given the longevity of the program, and the multiple centers that serve as partners and the "essential backbone" of the program. Of importance, this framework is intended to help us think about sustaining a program beyond its funding period – asking how and in what ways this may be possible and to what end. This framework, shown in Table 6, is based on the work of Scheirer and Dearing (2011) and has been modified as recommended by Schierer, Santos, Tagai, Bowie, Slade, Carter and Holt (2017) to better reflect the QuarkNet program. We have adopted Scheirer and Dearing's definition as well, "Sustainability is the continued use of program components and activities for the continued achievement of desirable program and populations outcomes" (2011, p.2060).

Stated in a different way, the sustainability framework identifies long-term outcomes, often articulated in a PTM. At the same time, it attempts to distill the program components that might have the greatest influences on sustainability (referred to as antecedents).

As will be seen in subsequent sections of this report, the sustainability framework is used to guide the assessment of the engagement of centers in the QuarkNet program and how factors related to this activity may help in the longevity of the center's broader impacts. It may also serve to better illuminate the context in which teachers engage in the QuarkNet program.

Before embarking on a discussion of measured teacher-level and center-level outcomes and preliminary results, it is important to briefly highlight a picture of the *implemented* program.

QuarkNet Program Implementation

An overview of the roles and responsibilities of key QuarkNet stakeholders is shown in Figure 2. Also shown is a depiction of a typical center that is comprised of a mentor(s) and teachers with support from QuarkNet staff and fellows. As already stated, these centers are housed at a university or laboratory; serving primarily teachers who live within reasonable commuting distances. Initially, mentors interested in QuarkNet submitted a proposed research project, identified a mentor team, and described previous outreach experience.

As part of the implementation of the QuarkNet program, staff members hold weekly meetings, that is, a staff-wide meeting focused on program-wide issues and discussions; meetings with IT QuarkNet developers focused on IT needs and updates; and a curriculum development team focused on workshop content and activity development of the Data Activities Portfolio (personal communication, email M. Bardeen, April 17, 2019). These are on-going as well as development team and IT team meetings also held weekly.

Table 6
PTM: QuarkNet Sustainability Framework[a]

Antecedents	Outcomes
Characteristics of the Specific Program 1. Fidelity to PTM core strategies as implemented (national or center-level).[b] 2. Evidence of flexibility/adaptability at the center level (if/as needed). 3. Evidence of effectiveness. **Organizational Setting at the Center-level Program**[c] 1. (Good) fit of program with host's organization and operations. 2. Presence of an internal champion(s) to advocate for the program. 3. Existing capacity and leadership of the organization to support program. 4. Program's key staff or clients believe in the program (believe it to be beneficial). **Specific Factors Related to the Center-level Program** 1. Existing supportive partnerships of local organizations (beyond internal staff). 2. Potentially available/existing funders or funding. 3. Manageable costs (resources and personal; supported by volunteers).[d]	1. Program components or strategies are continued (sustained fidelity in full or in part).[e] 2. Benefits or outcomes for target audience(s) are continued.[e] 3. Local/center-level partnerships are maintained.[f] 4. Organizational practices, procedures and policies in support of program are maintained. 5. Commitment/attention to the center-level program and its purpose is sustained.[f] 6. Program diffusion, replication (in other sites) and/or classroom adaptation occur.[f]

[a]This framework is based on the work of Scheirer and Dearing (2011); adopting their definition of sustainability, as well: "Sustainability is the continued use of program components and activities for the continued achievement of desirable program and population outcomes" (p. 2060). The QuarkNet Sustainability Framework has been modified to better reflective the QuarkNet program (as recommended by Scheirer, et al., 2017). (See notes below.)
[b]Program fidelity, as *implemented*, has been added as a program characteristic.
[c]The language used to describe these organizational characteristics has been modified slightly to better fit the QuarkNet program.
[d]This cost component was moved to environmental or contextual concerns of the specific program.
[e]The order of these two outcomes are reversed from the original.
[f]The language of this characteristic was modified to better fit the QuarkNet program.

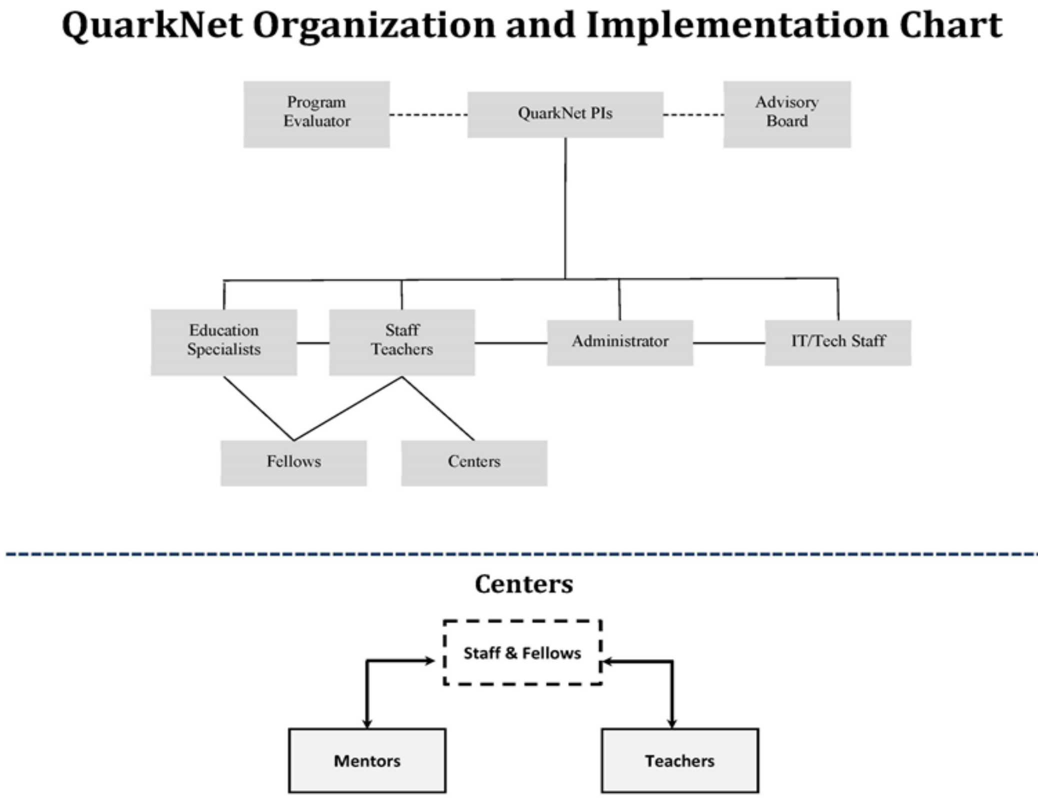


Figure 2. An overview of the organization and implementation of the QuarkNet Program.

Centers

Typically, at centers, as already noted, program leaders include one or two physicists who serve as mentor(s) who team up with one or two lead teacher(s). Teachers, whether a lead teacher or participant, are high school physics or physical science teachers who express interest in QuarkNet and who may be invited to participate through staff, fellows, or mentor/center teachers. Mentors often know high school teachers who are good additions to their research teams and/or who may become lead teachers at the center. Fellows are teachers who are invited by staff to become fellows based on participants' experiences working with a local center or on national program such as Data Camp (PTM, 2023). Fellows may interact with any of the centers. As already stated, the primary vehicle through which participating QuarkNet teachers receive professional development is a workshop conducted through the national program or that is center run.

In an email distributed by the co-PIs (Wayne, Bardeen and Swartz, December 2018) and already noted, a center is operationally defined as active "if they provide at least one day of teacher development (not in a student workshop) and 'semi-active' if they and their teachers participate only in International Masterclasses, International Muon Week, World Wide Data Day, International Cosmic Day, or an equivalent activity which they indicate." (See Table 7.)

Table 7
QuarkNet Centers through Program Years 2019-2023: 53 Total

Single or combined[a]	Center	Single or combined[a]	Center
1	Black Hills State University		~~University of California – Riverside~~
2	Boston/Brown University/ Northeastern University	1	University of California at Santa Cruz
2	Brookhaven National Laboratory/Stony Brook University	1	University of Cincinnati
1	The Catholic University of America	1	University of Florida
1	Colorado State University	1	University of Hawai'i
2	Fermilab/University of Chicago/College of DuPage	2	University of Illinois at Chicago/ Chicago State University
	~~Florida Institute of Technology~~	2	University of Iowa/Iowa State University
1	Florida International University	1	University of Kansas
1	Florida State University	1	University of Minnesota
1	Idaho State University	1	University of Mississippi
2	Johns Hopkins University	1	University of New Mexico
1	Kansas State University	1	University of Notre Dame
1	Lawrence Berkeley National Laboratory	1	University of Oklahoma
1	Northern Illinois University	1	University of Oregon
1	Oklahoma State University		~~University of Pennsylvania~~
1	Purdue University	1	University of Puerto Rico at Mayaguez
1	Purdue University Northwest		~~University of Rochester~~
1	Queensborough Community College	1	University of South Dakota
			~~University of Tennessee~~
2	Rice University/University of Houston	1	University of Washington
1	Rutgers University	1	University of Wisconsin –Madison
1	Southern Methodist University	1	Vanderbilt University
1	Syracuse University	1	Virginia Center (Hampton, George Mason, William & Mary Universities)
1	Texas Tech University	1	Virginia Tech
1	University of Alabama		
1	University at Buffalo – SUNY	1	Virtual Center
1	University of California -- Irvine		~~Wayne State University~~

[a]A center is noted as a combined center if two (or more) centers work together to hold a QuarkNet workshop or event. Combined centers receive additional funds to support more teachers and/or more days to hold these events. ~~Center~~ denotes a center that is no longer active (as of April 2023).

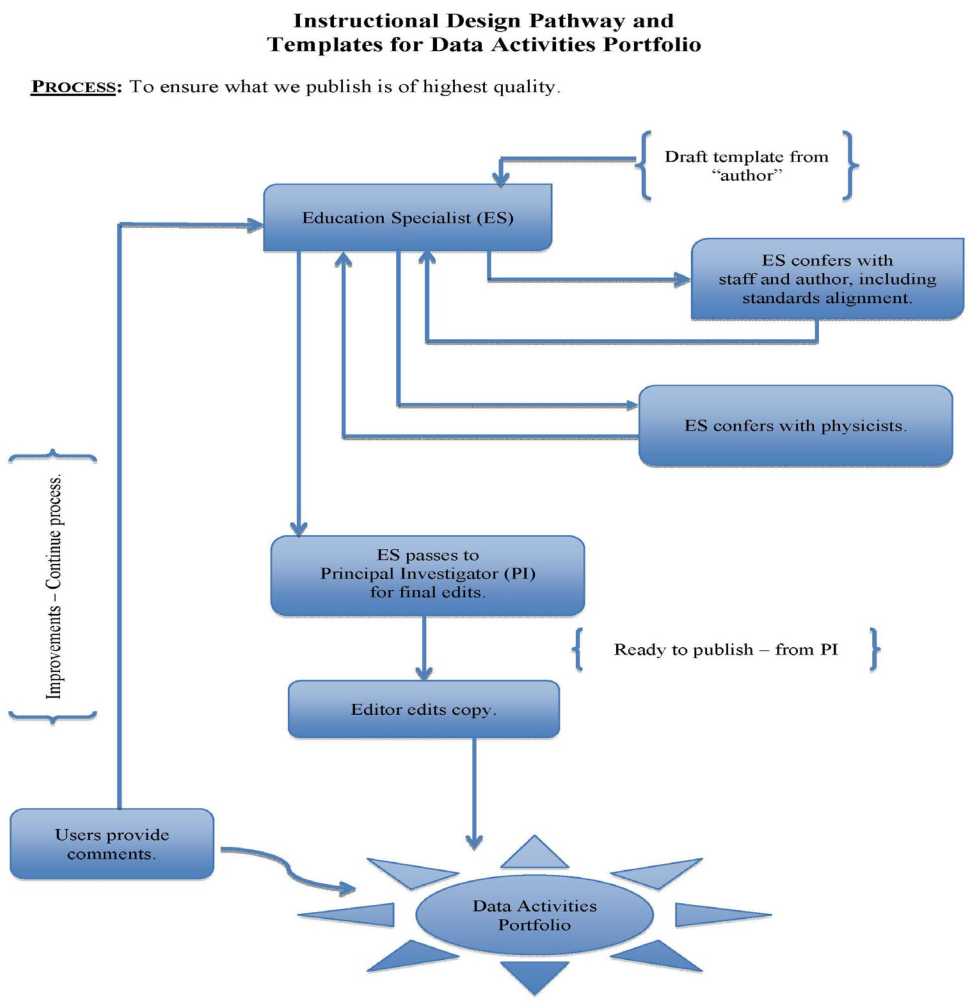


Figure 3. Instructional Design Pathway for Data Activities Portfolio (created by Young, Roudebush & Bardeen, 2019)

Data Activities Portfolio: Instructional Design and Review of Activities

Figure 3 shows the process used to develop and review activities for inclusion in the Data Activities Portfolio; this process follows the design recommendations by Wiggins and McTighe (2005) as already noted. This process has evolved since the start of QuarkNet, outlined in 2015, by Young, Roudebush and Bardeen; and later updated in 2019. Its intent is to help ensure the quality of developed activities; to align these with the science practices of NGSS; and to provide a standardized template and format. The complete document is shown in Appendix D along with the review protocol. Over the course of the QuarkNet program, the development (and review) of activities in the Data Activities Portfolio has been a dynamic process. This has included making sure that all activities, in particular older activities, were reviewed or re-reviewed before posting on the website; and that these aligned with the review guidelines just discussed. Other activities, for example, were split to accommodate either the required student-skills level (introducing level 0) or split because the content suggested the need for this (e.g., masterclasses split by data strand such as ATLAS Z-path or CMS-WZH-path). As the science (or availability of data) evolved, physicists helped to add activities (e.g., 3-D puzzle activity and creating a simulation) and to advise on existing ones. In addition, over the course of the previous grant period, curriculum topics were created to help teachers envision and plan for sequencing lessons (and helping to ensure that their students develop the required skills-set). This effort revealed possible gaps in student skills-sets; thus, additional activities were created to help fill these gaps.

Current on-going efforts have included the re-review of previously posted activities; filling in gaps for improved sequencing; developing neutrino materials; and creating activities at level 4. New activities have been added, and several have been translated into Spanish as well. A brief history of the Data Activities Portfolio is highlighted in Appendix E.

Data Activities Portfolio: Activities, Masterclasses and e-Labs

The criteria used to determine the alignment of DAP activities with the Next Generation Science Standards: Science Practices (Appendix F, NGSS April 2013) are shown in Table 8.

Table 9 provides a list of the current activities in the Data Activities Portfolio (DAP); 38 activities are listed in this table. This represents: 9 activities at Level 0; 15 activities at Level 1; 11 activities at Level 2; 2 activities at Level 3; and 1 activity at Level 4.

As noted, there are three activities that are not included in Table 9. These activities were developed through a partnership with STEP UP focused on Diversity and Inclusion. These activities are: QuarkNet: Changing the Culture (Level 0); QuarkNet STEP UP: Careers in Physics (Level 1); and QuarkNet STEP UP Women in Physics (Level 2). And, these three activities align with the NGSS All Standards, All Students" commitment to making NGSS accessible to all students (Appendix D, NGSS, April 2013).

Thus, the total number of DAP activities is 41 (as of May 2024).

In comparison during the 2012-2017 program grant years, there were 14 activities at the conclusion of that time period. (See Exhibit D created by D. Roudebush, May 2023 and used with permission). Also shown in Exhibit E is a listing of DAP activities developed for online use, an effort that occurred during COVID to support these efforts during this turbulent period. Currently, nine DAP activities have been translated into Spanish (as of March 2023).

Table 8
Criteria Used to Align Data Activity Portfolio Activities with the
Science and Engineering Practices in the Next Generation Science Standards (NGSS)

NGSS Practice	Alignment Criteria (Provide opportunity for required/ recommended engagement by students)
1. Asking questions (for science) and defining problems (for engineering)	• Students must determine the problem for which questions and answers lead to solutions.
2. Developing and using models	• Students must use data to develop a qualitative or quantitative model that explains the data and predicts subsequent data.
3. Planning and carrying out investigations	• Students may receive a research question for which they must develop and carry out a plan for their own investigation. Or the students may receive preliminary data from which they develop and carry out a plan for their investigation.
4. Analyzing and interpreting data	• Students must either collect data or receive data which they analyze qualitatively or quantitatively.
5. Using mathematics and computational thinking	• Students must use mathematical techniques for interpreting graphs and histograms including linearization and correct histogram uncertainties.
6. Constructing explanations and designing solutions	• Students must gather and analyze data and report out either to their group, the teacher or the class.
7. Engaging in argument from evidence	• Students must justify their claims with evidence and reasoning that is derived from the data.
8. Obtaining, evaluating, and communicating information	• Students must gather and analyze data and report out either to their group, the teacher or the class.

Criteria articulated by D. Roudebush and M. Bardeen August 18, 2020.

Table 9
Instructional Materials in the Data Activities Portfolio

Level	Activity	Data Strand	NGSS Practices
0	Mass of U. S. Pennies	Cosmic Ray, LHC	1,2,3,4,6,7,8
0	Quark Workbench 2D/3D	Cosmic Ray, LHC	1,2,4,5,6,7
0	Dice, Histogram and Probability	Cosmic Ray, LHC	1,2,3,4,5,6,7,8
0	Shuffling the Particle Deck	LHC	1,2,4,5,6,7
0	Mapping the Poles	LHC	2,4,6,7
0	Signal and Noise: The Basics	Cosmic Ray, LHC	4,5,6,7,8
0	Histograms: The Basics	Cosmic Ray, LHC, Neutrino	4,5,7
0	Making Tracks I	Cosmic Ray, LHC, Neutrino	1,2,4,6,7
0	Introduction to Coding Using Jupyter	Cosmic Ray, LHC, Neutrino	1,2,4
1	What Heisenberg Knew	Neutrino	2,4,5,6,7,8
1	The Case of the Hidden Neutrino	LHC, Neutrino	2,4,5,6,7
1	Making it ‘Round the Bend – Qualitative	LHC	1,2,3,4,6,7
1	Rolling with Rutherford	Cosmic Ray, LHC	1,3,4,5,7
1	Calculate the Z Mass	LHC	1,2,4,5,6,7,8
1	Calculate the Top Quark Mass	Cosmic Ray, LHC	1,4,5,7
1	Signal and Noise: Cosmic Muons	Cosmic Ray	4,5,6,7,8
1	Mean Lifetime Part 1: Dice	Cosmic Ray, LHC	2,4,5,7
1	Histograms: Uncertainty	Cosmic Ray, LHC, Neutrino	4,5
1	Energy, Momentum, and Mass	Cosmic Ray, LHC, Neutrino	2,4,5,7,8
1	Making Tracks II	Cosmic Ray, LHC, Neutrino	1,2,4,6,7
1	Particle Transformations	Cosmic Ray, LHC, Neutrino	1,2,4,6,7
1	Angles and Dimuons	Cosmic Ray, LHC	2,4,5,6,7,8
1	How Speedy are These Muons?	Cosmic Ray	2,3,4,5,7,8
1	TOTEM 1	LHC	4,5,8
2	Making it ‘Round the Bend – Quantitative	LHC	1,2,3,4,5,6,7,8
2	CMS Data Express	LHC	1,2,4,5,7,8
2	TOTEM 2	LHC	2,4,5,6,7,8
2	ATLAS Z-path Masterclass	LHC	1,2,4,5,6,7,8
2	CMS Masterclass WZH-path	LHC	1,2,4,5,6,7,8
2	Mean Lifetime Part 2: Cosmic Muons	Cosmic Ray	2,3,4,5,7,8
2	Mean Lifetime Part 3: MINVERvA	Cosmic Ray, Neutrino	2,3,4,5,7,8
2	ATLAS Data Express	LHC	1,2,4,5,7,8
2	ATLAS W-path Masterclass	LHC	1,2,4,5,6,7,8
2	CMS Masterclass J/Psi	LHC	1,2,4,5,6,7,8
2	Z Mass Spreadsheet Extension	LHC	2,3,4,5,6,7,8
3	Cosmic Ray e-Lab	Cosmic Ray	1,2,3,4,5,6,7,8
3	CMS e-Lab	LHC	1,2,3,4,5,6,7,8
4	Research Using Coding	Cosmic Ray, LHC, Neutrino	1,2,3,4,5,6,7,8

Note: List of activities taken from QuarkNet website https://quarknet.org/data-portfolio. (As of April 2024). Does not include three STEP UP activities: QuarkNet: Changing the Culture (0): QuarkNet STEP UP; Careers in Physics (1); and QuarkNet STEP UP Women in Physics (2). (As of March 2023.) NGSS Practices: 1. Asking questions and defining problems. 2. Developing and using models. 3. Planning and carrying out investigations. 4. Analyzing and interpreting data. 5. Using mathematics and computational thinking. 6. Constructing explanations and designing solutions. 7. Engaging in argument from evident. 8. Obtaining, evaluating, and communicating information. (https://www.nextgenscience.org/)

2012-2017 Grant Period	As of March 2024
14 Activities	40 Activities
Variety of structures	Specific structure
No Protocol	Protocol Aligned with PD Criteria
Level 1-3	Level 0 - 4
No Teacher Answer Key	Teacher Answer Key Provided
No Coding Activities	2 Coding Activities
No Spanish Language Versions	Spanish Language Posted for 9 Activities

Exhibit D. Comparison of the Data Activities Portfolio from past to current grant. (Created by D. Roudebush, May 2023 and used with permission.) Online activities, developed during COVID, are shown below in Exhibit E (for use for remote, online teaching or as homework assignments).

Activity	Level	Activity	Level	Activity	Level
Quark Workbench	0	Calculate the Z Mass	1	Mean Lifetime Part 2: Cosmic Muons	2
Shuffling the Particle Deck	0	Mean Lifetime Part 1: Dice	1	Atlas Data Express	2
Dice, Histograms, and Probability	0	What Heisenberg Knew	1	Making it 'Round the Bend -Quantitative	2
Histograms: the Basics	0	Histograms: Uncertainty	1	Mean Lifetime Part 3: MINERvA	2
Making it 'Round the Bend - Qualitative	0	Energy, Momentum, and Mass	1	Cosmic Racy e-Lab	3
Rolling with Rutherford	1	CMS Data Express	2	CMS e-Lab	3

Note. Adapted from: https://quarknet.org/content/comments-adapting-data-activities-teaching-online.

Exhibit E. DAP activities developed for online use (as well as in-person).

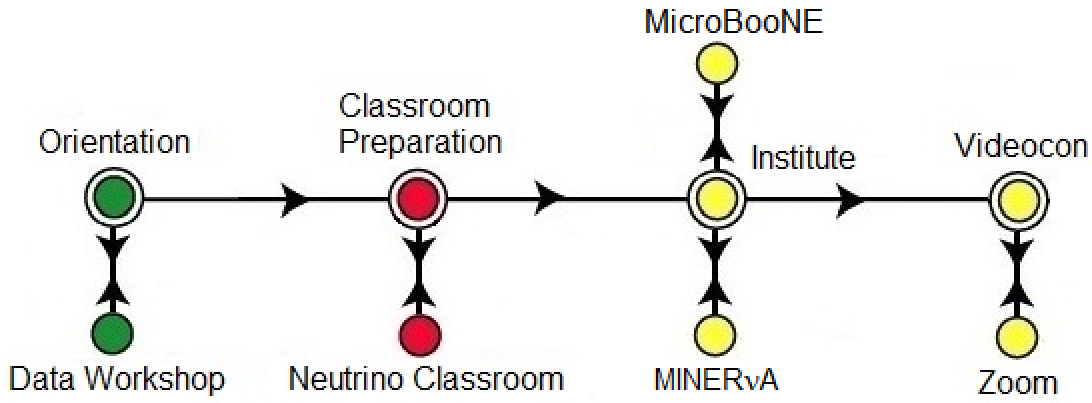


Figure 4. Neutrino Masterclass Project Map 2019 (developed by Cecire, Bilow and Wood); https://quarknet.org/content/neutrino-masterclass-project-map-2020).

Each activity in the DAP is available through the QuarkNet website, https://quarknet.org/data-portfolio. These activities can be searched whether logged into the website or not; and instructions are provided as to how to search for desired examples. Activities can be searched by manually scrolling through the web pages (progressing from simple to complex); or, to facilitate searches these are organized by Data Strand (Cosmic Ray, LHC, and Neutrino); Level (0-4), Curriculum Topics, (e.g., Conservation Laws; Electricity; Quantum Mechanics; Half-Life/Mean Lifetime.); and NGSS Science Practices. An individual can search by one or all of these organizational categories. In support of these activities are Teacher Notes; Student Guide files (and at times other support materials); and information on technology requirements. Estimated class time to implement is also provided.

The word "activity/activities" is frequently used by QuarkNet staff and staff teachers as well as participating QuarkNet teachers. We have adapted this language as well but note that when used we are referring to the full set of teacher and student resources and active learning opportunities that are associated with each.

Level 3 activities, which are contained in the Data Activities Portfolio, are supported by masterclasses and e-Labs. Masterclass instructional materials are organized by three project maps (LHC Project Map, Neutrino Project Map, and World Wide Data Day), which offer a sequence of planning, orientation, and classroom preparation to help teachers get their students ready for this engagement. And e-Labs include resources to support a series of investigations into high-energy Cosmic Rays; and, to support a student research project using CMS authentic data and analytical tools.

An example of a Project Map is shown in Figure 4. As noted on the website, The Project Map "is arranged in the typical chronological order in which a masterclass is prepared and then carried out. The order is more descriptive than prescriptive. This Project Map has 4 'metro stops' plus associated branches. The main metro stops are: **Orientation** explains orienting of teachers and physicists to run a masterclass and provides schedule information. **Classroom Preparation** details how teachers get their students ready for the masterclass. **Institute** and **Videocon** with their branches cover the main elements of the masterclass day. These make up the heart of the Project Map."

Links to MINERvA resources (MINERvA is the name of an experiment at Fermilab that is collecting data on how neutrinos interact with matter) including classroom information, data sets and the MINERvA web event display are also provided.

In addition, information about e-Labs is available in its own pull-down menu (https://quarknet.org/ content/about-e-labs) and offers overview and resource information links (http://www.i2u2.org/elab/) as well. As stated on the website, "e-Labs provide opportunities for students to: Organize and conduct authentic **research**; Experience the environment of scientific **collaborations**; and Analyze **authentic data** from large experiments." Students are able to explore data with other students and experts "to share results and publish **original work** to a world wide audience; discover and extend the research of other students, model the processes of modern, large-scale research projects; and access distributed computing techniques employed by **professional researchers**. Students may contribute to and access shared data which can come from professional research databases; and use common **analysis tools**, store their work and use metadata to discover, replicate and confirm the research of others." Through this collaboration students "correspond with other research groups, post comments and questions, prepare summary reports and participate in the part of scientific research that is often left out of classroom experiments" (https://quarknet.org/content/about-e-labs).

DAP Activities: Alignment with the Enduring Understandings of Particle Physics

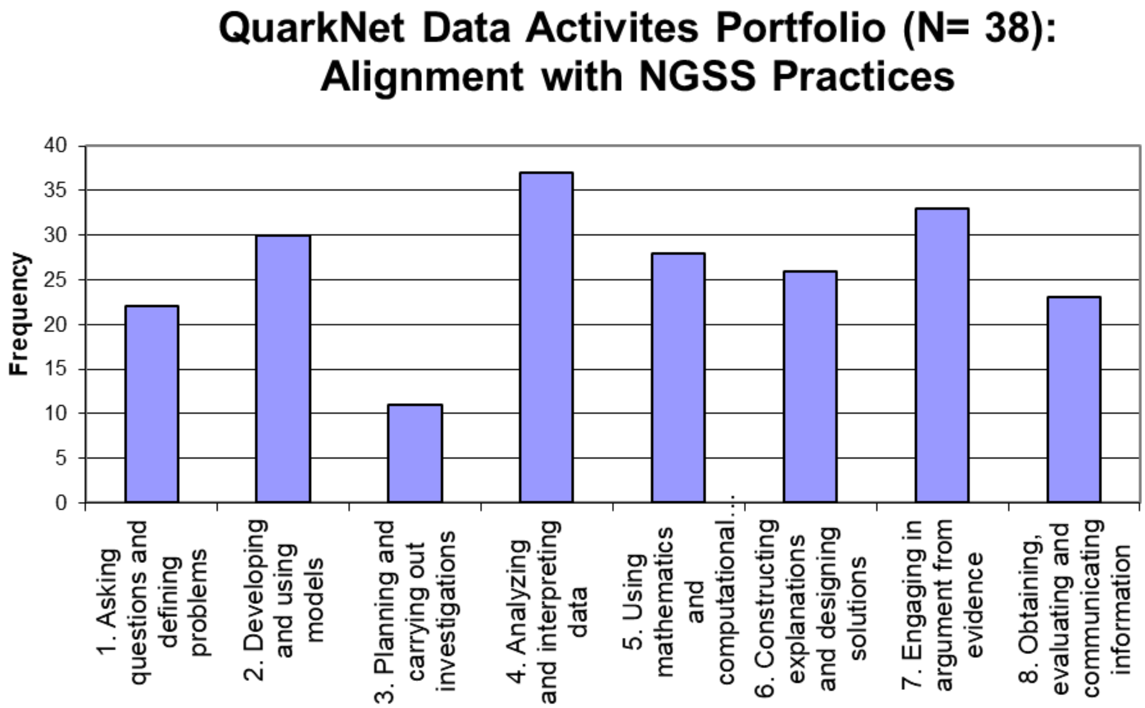
Table 10 shows the alignment of the Data Activities Portfolio with the Enduring Understandings of Particle Physics that are an integral part of the PTM and the implemented program. As shown, typically one activity focuses on one Enduring Understanding as suggested by Wiggins and McTighe (2005) covering content in depth over breath. Masterclasses and e-Labs, along with a few other activities, are notable exceptions because these require prior preparation to fully engage in these. Also, it should be noted that when a given activity is embedded in a national-led or center-led program it is used to support the particle physics content contained within a workshop; thus, an Enduring Understanding(s) is sequenced into a workshop as well. Of importance, DAP activities provide a vehicle as to how this content may be incorporated into the classrooms of participating teachers.

DAP Activities: Alignment with the Next Generation Science Standard Practices

Two points seem evident from the distribution shown in Figure 5 that shows the alignment of the activities from the Data Activities Portfolio (DAP) with the Next Generation Science Standards, Science and Engineering Practices. First, at the program level a strength of these activities is how well these collectively align with these Practices.

Table 10
Enduring Understandings: Alignment of Activities in the Data Activities Portfolio

Enduring Understandings	QuarkNet Activity	Level
1. Scientists make a claim based on data that comprise the evidence for the claim.	• ATLAS Z-path Masterclass • CMS Masterclass WZH-path • How Speedy are These Muons>	2 2 1
2. Scientists use models to make predictions about and explain natural phenomena.	• Cosmic Ray e-Lab • CMS e-Lab	3 3
3. Scientists can use data to develop models based on patterns in the data.	• Mapping the Poles • Making it 'Round the Bend – Qualitative • Making it 'Round the Bend – Quantitative • Mean Lifetime Part 1: Dice • Mean Lifetime Part 3: MINERvA • Introduction to Coding Using Jupyter • Angles and Dimuons • Mean Lifetime 2: Cosmic Muons	0 0 2 1 2 0 1 2
4. Particle physicists use data to determine conservation rules.	• Making Tracks I • Making Tracks II • Rolling with Rutherford • The Case of the Hidden Neutrino • ATLAS Z-path Masterclass • TOTEM 1	0 1 1 1 2 1
5. Indirect evidence provides data to study phenomena that cannot be directly observed.	• Making Tracks I • Making Traces II • Rolling with Rutherford • The Case of the Hidden Neutrino • ATLAS Z-path Masterclass	0 1 1 1 2
6. Scientists can analyze data more effectively when they are properly organized; charts and histograms provide methods of finding patterns in large datasets.	• Mass of U.S. Pennies • Dice, Histograms & Probability • Histograms: The Basics • Z Mass Spreadsheet Extension	0 0 0 2
7. Scientists form and refine research questions, experiments and models using observed patterns in large data sets.	• Cosmic e-Lab • CMS e-Lab • Research Using Coding	3 3 4
8. The Standard Model provides a framework for our understanding of matter at its most fundamental level.	• Quark Workbench 2D/3D • Particle Transformations • Cosmic e-Lab • CMS e-Lab	0 1 3 3
9. The fundamental particles are organized according to their characteristics in the Standard Model.	• Shuffling the Particle Deck	0
10. Particle physicists use conservation of energy and momentum to measure the mass of fundamental particles.	• Calculate the Z Mass • Calculate the Top Quark Mass • Energy, Momentum, and Mass • CMS Masterclass WZH-path • CMS Masterclass J/Psi	1 1 1 2 2
11. Fundamental particles display both wave and particle properties and both must be taken into account to fully understand them.	• TOTEM 2 • ATLAS Data Express	2 2
12. Particle physicists continuously check the performance of their instruments by performing calibration runs using particles with well-known characteristics.	• CMS Data Express	2
13. Well-understood particle properties such as charge, mass, momentum and energy provide data to calibrate detectors.	• Calculate the Z Mass	1
14. Particles that decay do so in a predictable way, but the time for any single particle to decay, and the identity of its decay products, are both probabilistic in nature.	• Mean Lifetime Part 1: Dice • Mean Lifetime Part 3: MINERvA • Mean Lifetime Part 2: Cosmic Muons	1 2 2
15. Particle physicists must identify and subtract background events in order to identify the signal of interest.	• Signal and Noise: The Basics • Signal and Noise: Cosmic Muons • CMS Masterclass J/Psi	0 1 2
16. Scientists must account for uncertainty in measurements when reporting results.	• What Heisenberg Knew • Histograms: Uncertainty	1 1



Science and Engineering Practices in the Next Generation Science Standards

Figure 5. Alignment of Data Activities Portfolio activities with NGSS Science Practices. (Note: The three Step-Up activities are not included in this graph.) (As of 4/24/2024.)

This is especially the case for Practices 4, 5, 6 and 7 (that is, 4. Analyzing and Interpreting Data; 5. Using Mathematics and Computational Thinking.; 6. Constructing Explanations and Designing Solutions; and 7. Engaging in Argument from Evidence). For example, all activities require analyzing and interpreting data (Practice #4). And, of importance this engagement is based on authentic data, often using large data sets involving cutting-edge physics, especially for higher level activities (e.g., Level 2 and 3 activities).

Second, the less frequently noted first three practices (1. Asking questions and defining problems. 2. Developing and Using Models. 3. Planning and Carrying Out Investigations.) suggest that these activities are largely guided-inquiry engagement (where the teacher provides the question) reflective of the complexity of the concepts covered in these activities.

The Program's Website

As already suggested, with or without a user account (a guest user account is available) a visitor to the QuarkNet website (https://quarknet.org/) can access all of the activities just described (Data Activities Portfolio, Masterclasses, and e-Labs) along with supportive documents and resources. There are also listings and links to QuarkNet centers.

Groups have been created, where on the website center-wide information is shared by a specific center (such as agendas, annual reports) or, where information about a specific need or activity is provided (e.g., Planning the Masterclass 2019). Expectations for mentors are provided; as well as a summary of award support (e.g., stipends for teachers); and how mentors and teachers can become involved in the program. National workshops opportunities for QuarkNet centers and mentor "must-do lists" are posted. Teachers and students can upload data and conduct analyses. There is contact information for key program stakeholders; a place to post questions or problems with the website; and testimonials from teachers, students and international partners reflecting their engagement in the program.

Thus, the website offers teachers, students, and research groups a rich resource of information, whether or not the individual and/or the group are directly engaged in the QuarkNet program.

Implementation of QuarkNet: 2019 through 2023 Program Years

Throughout the implementation of the current program, each center has been encouraged to apply annually for a budgeted 30 teacher-days; for a merged or combined center (two or more) this budgeted amount is set at 45 teachers-days. This is done through an RFP (Request for Proposal) process which will be described shortly (personal communication, email). There are various ways in which this budgeted 30 teacher-days commitment can be broken down. As explained in an annual email (January 18, 2019; February 3, 2020; March 1, 2021; January 24, 2022; and January 19, 2023), this could mean, for example, 6 teachers for 5 days or 15 teacher-days for 2 days. To help centers plan for a given program year (with most activities starting in the summer), centers are offered a list of national workshop opportunities along with sample agendas to aid in planning and implementation https://quarknet.org/page/ summer-workshop-opportunities-quarknet-centers) as well as a staff-member representative list (see for example https://quarknet.org/content/ quarknet-center-staff-assignments-january-2020).

As usual in the planning of a given program year, centers are asked to complete a short RFP, requesting contact information (individual's name, email address, and center name); plans for workshops in the program year; expected number of days; anticipated dates; expected number of teachers; which nationally-led workshop if desired; and additional information as needed (see for example, https://quarknet.org/content/summer-2023-rfp). Staff teachers then have followed up with centers via emails and/or phone calls as a reminder and/or to help clarify any questions. As reported by QuarkNet staff teachers, typically these center-level workshop requests are initially confirmed; and finalized with an official follow-up funding letter that stipulates the maximum dollar amounts allocated for that center. Staff teachers also tracked requests for national workshop engagement and accommodate these requests to the extent to which their schedule permits (personal communication, email March 15, 2019).

This process was implemented in the 2018 program year and has been repeated for the 2019 through 2023 program years starting with an annual email blast distributed with a link to support information (as already described).

A series of tables are presented in Appendix F that summarizes QuarkNet Workshops held during past program years. For 2018, there are two tables where Table F-1 shows the national workshops run by QuarkNet staff; and Table F-2 lists the meetings and workshops held at QuarkNet Centers and led by the individual centers. (Data Camp was implemented at Fermilab on July 16-20, 2018.) In subsequent program years, there is one table per program year where nationally-led workshops are highlighted in a bold-face font. (Workshops cancelled in 2020 and 2021 because of COVID are crossed out in these tables -- not deleted -- to help reflect the impact that COVID had on delivered programs at centers.)

Program Years 2019-2022

Starting with the rollout of the 2019-2020 program year, QuarkNet staff provided mentors and workshop facilitators with examples of agendas for nationally-led workshops (as already described), which can and have been modified for workshops led by individual centers, if desired. During nationally-led workshops, these agendas often are modified in real time providing a straightforward way of documenting content and schedule changes. Once a workshop is completed, the updated agenda serves to memorialize the scheduled events, including main topics of presentation and discussion, activities from the Data Activities Portfolio, and implementation plan development. Another benefit of this approach is that it may help centers complete their annual reports; with details regarding the workshop or meeting captured in one or both of these documents.

Nationally-led workshops are implemented within a standard template and reflect the program strategies articulated in the Program Theory Model. That said, each center has and does take advantage of locally-available resources. This is reflected in presentations by scientists related to, for example, computing in particle physics, understanding neutrinos, measuring Muon g-2; tutorials on using cosmic ray detectors; masterclass walkthroughs and access to large data sets; as well as presentations by students related to their research, for example, using cosmic ray detectors, or machine learning. A tour of local laboratories and research centers has often been an integral part of the workshop; or involve unique-opportunity research (e.g., building a cosmic ray detector and using it to collect data on the National Basilica of the Shrine of the Immaculate Conception in Washington, DC; or a presentation on cosmic ray detection and the 2017 Solar Eclipse).

The Neutrino Workshop, pilot tested during the 2018-2019 program year, was incorporated fully into the 2019-2020 QuarkNet program year. And STEP-UP was incorporated into designated workshops as well (STEP UP is a national movement to provide high school physics teachers with resources to reduce barriers and inspire young women and minorities to major in physics.) Coding Camp, added in the 2019-2020 program year, was pilot tested as a workshop in the 2020-2021 program year and expanded during the 2021-2022 and the 2002-2023 program years.

Of note, QuarkNet staff added many online-available resources in response to challenges due to the coronavirus starting in March 2020 including a of program modifications were made to help adapt QuarkNet to online teaching venues. Additional teacher support for online resources were added including for example, remote online simulations and online lessons; and how to use Cosmic Ray detectors remotely for data collection and analyses.

Program Year 2022-2023

The implemented workshops during the 2022-2023 QuarkNet program year are shown in Table 11. Centers could choose among a list of available nationally led workshops, including: Higgs@11; Just in Time W2D2; ATLAS Workshop; ATLAS Workshop Update; CMS Data Workshop; CMS Data Workshop Update; Neutrino Data Workshop; CMS e-Lab Workshop; Cosmic Ray e-ab Workshop; Muon Study Workshop; Workshop X; Intro to STEP-UP Workshop; New Questions in Particle Physics.

Table 11 focuses on Data Activities Portfolio (DAP) activities included in the workshops as these are a direct means to bring QuarkNet content into the classroom. The content of this table is not intended to give a full summary of the engagements and events that occurred during these programs (such as, select talks on cutting edge topics in particle physics; or tours or experiments/laboratory research associated with the center). DAP activities implemented during the workshops are documented, as well, because these are a frequent and integral part of a workshop, especially for nationally led workshops. This focus – and its documentation – coincides with the improved rigor and robust increase in the number of activities included in the DAP (since 2017). By design, the embedded DAP activities align with the workshop content, often at multiple student-skills levels (Levels 0-4). Teachers engaged in these activities as active learners – as students -- and, at times, can select from optional examples of activities during the workshop to enhance this engagement. Experiencing these activities as active learners may give teachers insight as to how and in what ways their students may engage in these activities and subsequent comprehension. This is in line with effective teacher professional development practices outlined by Darling-Hammond, et al., (2017). Of importance, teachers are given time to reflect on how they might use these activities in their class-room – a primary purpose of the DAP -- and incorporate these in implementation plans.

During the 2022-2023 program year, among the most frequently DAP activities embedded within held workshops were: *Shuffling the Particle Deck* (Level 0); Rolling with Rutherford (Level 1); and Calculate the Z Mass (Level 1).

Table 11

2023 QuarkNet Workshops and Meetings: National- and Center-led (December 2022-October 2023)

Center	**2023 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Black Hills State University	July 5-8	**BHSU/SURF Workshop**	Introduction to Jupyter (0) Review from coding 1 Advanced applications for data analysis Creating a data activity for your classroom Dark Masterclass Cloud Chamber Radiation Shielding CRMD
	May 12	Science Day @Cheyenne-Eagle Butte School	Data Activities Portfolio: Particle Cards (0) Rolling with Rutherford (1) Building a Neutrino Detector
	May 13	Women in Science & Neutrino/ NOvA Masterclass	NOvA Analysis Near Detector Events – Using Coding Notebooks
Boston Area/Brown University/ Northeastern University[a]	December 8, 2022	Winter Meeting Projects in Physics Class	Various projects were highlighted including a constructed photoelectric apparatus; data to measure the Sgr A* supermassive black holes; a sound speed measurement; an egg crash project using a double pendulum to regulate speed; a Rube Golberg construction project to demonstration energy conversion; a constructed periscope to help under mirror reflections; particle quest project where student created an imaginative fact or fiction story involving the particle; project where construct parachutes from readily available materials to test Aristotle's theory that the speed of fall is proportional to weight.
	March 11	CMS Masterclass	Thirty-one high school students and five QuarkNet teachers from Massachusetts, Rhode Island, and Vermont participated; Agenda items included get-acquainted exercises; talk on particle physics; talk on analysis of CMS proton collision images; opportunity to talk with physics grad students at lunch; and a visit to lab where a small liquid argon time project chamber is being built. Students and teachers met via a video conference with students from Williamsburg VA, Mexico and Columbia and physicists and fellows at Fermilab.
	June 8	Spring Meeting	Teachers worked in pairs to calculate physical and angular measurements related to black holes and their shadow images engaged as active learners, as students.
	August 9-10	Summer Workshop Questions and Clues in Particle Physics	Standard Model of Particle Physics and its limitations; the importance of doubt 5 σ criterion in physics; muon g-2 experiments; σ and β decay; Dune and other neutrino adventures; and W bosons 2 mass.

Table 11
2023 QuarkNet Workshops and Meetings: National- and Center-led (December 2022-October 2023)

Center	2023 Dates (All dates except where noted)	Workshop/Meeting	Brief Summary of Activities and Data Activities Portfolio (Level) [and/or classroom use/implementation plans]
Brookhaven National Laboratory – Stony Brook University[a]	June 26-29	**Summer Workshop Neutrinos**	Data Activities Portfolio Activities: What Heisenberg Knew (1) The Case of the Hidden Neutrino (1) Coding with Phyton Teachers prepared and shared implementation plans
	June 29	**NOvA Masterclass**	NoVA masterclass measurement
Catholic University of America	July 17-21	**Summer Workshop**	QuarkNet Data Activities Presentations (e/g/. Physics at JLab; Comic Ray Archaeology) Tour of National Accelerator Facility Presentations (e.g., CERN research) and Exploration (e.g., cosmic watches) Implementation Plans and Presentations
Colorado State University	March 4	**Masterclass**	Students interacted with the Data Activities Portfolio activities. Analyzed data from MINVERa experiment. Shared experience via videoconference with two other masterclasses.
	October 13-17	**Annual Workshop**	Four-day trip to Los Alamos, NM to align with solar eclipse; engaged in cosmic ray flux study with two telescopes with different filters. Tour of Los Alamos National Lab Share-a-thon presentations and discussion
Fermilab/University of Chicago/College of DuPage[a]	August 1-3	**QuarkNet Teachers Workshop**	Series of presentations by scientists, teachers and students; a number of activities working toward the introduction of statistical analysis of data while learning physics Data Activities Portfolio Activities: Particle Transformations (1) Energy Momentum and Mass (1) Coding Activity: Invariant Mass of the Muon Shuffling the Particle Deck (0) NOvA Masterclass Measurement Teachers developed plans toward integrating physics research data into their classrooms.

Table 11 (con't.)

2023 QuarkNet Workshops and Meetings: National- and Center-led (December 2022-October 2023)

Center	**2023 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Florida International University	No activity		
Florida State University	July 26~~-28~~	**FSU Summer Workshop**	Shuffling the Particle Deck (0) Mapping the Poles (0) Totem 2 (2)
Idaho State University	July 24-27	Idaho State QuarkNet Summer Workshop	Shuffling the Particle Deck Measuring Z Calculating W-bosons 1,2 Muon g-2 experiment Implementation Plans
Johns Hopkins University	July 24-28	2023 JHU Workshop	Half-day Morning Coding Sessions Introduction to Jupyter Probability Position graphs Other notebooks Scaffolded Notebook Best Practices for Coding with Python Modifying an existing notebook Share out implementation plans
	March	LHC Masterclass	Teachers and about 35 students participated
Kansas State University	June 5-7	Workshop	Various tours and NREL workshop
	March 31	Masterclass	Six teachers and their students participated
	March 4	Masterclass Orientation	Eight teachers participated
	No date	Research Project	Twelve CRMD teacher worked with students to correlate muon rates with atmospheric temperature and pressure changes (from NASA data)

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.

[a]Combined QuarkNet center

Table 11 (con't.)
2023 QuarkNet Workshops and Meetings: National- and Center-led (December 2022-October 2023)

Center	**2023 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Lawrence Berkeley National Laboratory	June 23 June 26	**Particle Physics Data Activities**	Particle Cards (0) Quark Workbench (0) Search for Higgs in CMS data Z Mass Measurement (1)
	June 20-30	Physics in and through the Cosmology Two Week Virtual Workshop (3 hours per weekday)	A total of 6 teachers and 49 students participated. Discussion on a variety of topics and students worked in groups for an Interview a Scientist Project. Presentation by Nobel Prize winner Saul Perlmutter
Northern Illinois University	No activity		
Oklahoma State University/University of Oklahoma[a]	July 24-26	**Summer Workshop**	The Case of the Missing Neutrino (1) What does the Muon g-2 experiment tell us NOvA masterclass measurement Share-a-thon Implementation Plans
	3 events (no dates)	**Atlas Masterclasses**	
Purdue University	July 28-29	Neutrino Workshop	Shuffling the Particle Deck (0) Mean Lifetime Dice (1) Mean Lifetime MINERvA (3) Neutrino Masterclass Measurement Coding Activities Implementation Plans
	February	Masterclass Orientation	1 teacher and 12 students participated
Purdue University Northwest	June27-30	Summer Workshop: Computation in the Classroom	Workshop topics: Solving problems computationally Python for beginners Using Python in the classroom with Jupyter Notebooks and Google Colab Introduction to Particle Physics QuarkNet DAP activities Use and analysis of cosmic ray data and LHC Data Introduction to Machine Learning

Table 11 (con't.)

2023 QuarkNet Workshops and Meetings: National- and Center-led (December 2022-October 2023)

Center	**2023 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Queensborough Community College	August 14-18	Testing and Characterizing Cosmic Ray Scintillating Courses	Individual projects presented on website [Queensborough Community College QuarkNet Center | QuarkNet]
Rice University/University of Houston[a]	June 22-23	**World Wide Data Day and New Questions Workshop**	Shuffling the Particle Deck (0) Making Tracks (0) New Questions
	June 19-21	**IRIS-HEP Coding Workshop**	Teachers created 13 coding activities that they can take back to their classrooms and their students
Rutgers University	2-weeks	Summer Program on Fundamental Physics	24 students analyzed data from MINERvA experiment and gave presentations to an audience of family, friends and the general public.
Southern Methodist University	June 26-28	**3-Day Coding Workshop**	Intro to Colab Intro to Coding Other Notebooks Explore and work through notebook examples Particle Physics CMS Particle Analysis Implementation Plans
	June 29-30	**Dark Matter** **New Questions in Particle Physics**	The physics of g-2 Dice activity
Syracuse University	August 14-16	Summer Workshop	Shuffling the Particle Deck (0) Rolling with Rutherford (1) Feynman Diagrams Making Tracks I (0) Mass of the Top Quark (1) World Wide Data Day measurement MINERvA Masterclass measurement
Texas Tech University	No activity		
University of Alabama	June 5-7	Coding Workshop (First year in QuarkNet)	Each participating teacher created a coding project for a total of five.

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.

[a]Combined QuarkNet center

Table 11 (con't.)

2023 QuarkNet Workshops and Meetings: National- and Center-led (December 2022-October 2023)

Center	**2023 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
University at Buffalo -SUNY	August 17-18	Summer Workshop	Presentations by mentors Demonstrations (e.g., Cloud Chamber, Cosmic Ray detector) Analysis of NOvA experiment data: Coding activity Shuffling the Particle Deck (0) Implementation plan discussions
University of California – Irvine	July 12-14	**Summer Workshop**	Intro to Colab Notebook Intro to Colab with Python Experience Explore and work through notebook examples Work on a notebook Bringing Coding into the Classroom Coding Share out Shuffling the Particle Deck (0) NOvA Video Cosmic Ray Muon Detector Phyton Near Event Analysis
	March 25	**Neutrino Masterclass**	NOvA masterclass measurement 1 NOvA masterclass measurement 2
University of California -Santa Cruz	March 4	Masterclass	61 registered students of which most attended in person; followed up with a classroom BAMA activity at a local school on May 22.
University of Cincinnati	June 20-22	Workshop	Shuffling the Particle Deck (0) Introduction to Coding/Probability and Histograms/Muon Mass STEP UP: Careers in Physics (Lesson 2) (1) STEP UP: Women in Physics (Lesson 3) (2) Calculate the Z mass (1) Implementation plan discussion

Table 11 (con't.)
2023 QuarkNet Workshops and Meetings: National- and Center-led (December 2022-October 2023)

Center	**2023 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
University of Florida	No activity		
University of Hawai`i	March 21	CMS Masterclass	21 students participated Rolling with Rutherford (1) or Quark Puzzle Analyzed CMS multi-lepton data
University of Illinois at Chicago/Chicago State University[a]		Eight Half-day Meetings (Oct 30, 2022; Dec 4, Jan 8, Feb 12, Mar 19, Aug 23, Sept 3)	Analyses for the Moon Shadow experiment
	June 14-16	**Workshop**	Analyses for the Moon Shadow experiment (measure the shadow of the moon cats in muon at the earth's surface)
University of Iowa/Iowa State University[a]	July 25-29	Summer Teacher Institute	Shuffling the Particle Deck (0) Particle Adventure Quark Workbench (0) Rolling with Rutherford (1) Mass of the Z Boson (1) Mass of the Top Quark (1) Making Tracks 1 () Making Tracks 2 (1) Energy Momentum and Mass (1) Implementation Plans
University of Kansas	May 10, 2023 Apr 12, 2023 Nov 8, 2022 Oct 26, 2022	Cosmic Ray Zoom Series	Kansas flux/storm project
University of Minnesota	August 9-10	**Summer Workshop**	Shuffling the Particle Deck (0) QuarkNet Work Bench (0) Making Tracks (0) Rolling with Rutherford (1) Mass of Z (1)
	March 11	**NOvA Masterclass**	NOvA measurement Part 1 & 2

Table 11 (con't.)
2023 QuarkNet Workshops and Meetings: National- and Center-led (December 2022-October 2023)

Center	**2023 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
University of Mississippi	July 17	Belle II Data Workshop Pilot	Public workshop to test Belle II becoming an official QuarkNet Masterclass Shuffling the Particle Deck (0)
	March 24	Belle II Masterclass	
University of New Mexico	October 11-12	**Classroom Visit**	Shuffling the Particle Deck (0): Student Work Rolling with Rutherford (1)
	July 26-29	**Cosmic Ray Muon & STEAM Workshop**	Shuffling the Particle Deck (0) Mean Lifetime Part 1 Dice Mean Lifetime Part 2 Cosmic Muons Analyze Cosmic Ray Data Implementation discussion
University of Notre Dame		Summer	Cosmic Ray studies with CRMDs and Cosmic Watches and Project GRAND. Other projects included Astrophysics, magnetic phenomena, building and testing CO_2 sensors (with Indiana University South Bend), and CMS Data.
		Regular Monday Afternoon Hybrid Meetings	World Wide Data Day International Cosmic Day International Muon Day
	Feb 28	Masterclass	
University of Oregon	No activity		
University of Puerto Rico - Mayaguez	November 21	Neutrino Data Workshop	Sharing advanced work from NOvA masterclass
	March 25	MINERvA Masterclass	
	March 4	Masterclass Orientation	

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.
[a]Combined QuarkNet center

Table 11 (con't.)

2023 QuarkNet Workshops and Meetings: National- and Center-led (December 2022-October 2023)

Center	2023 Dates (All dates except where noted)	Workshop/Meeting	Brief Summary of Activities and Data Activities Portfolio (Level) [and/or classroom use/implementation plans]
University of South Dakota	July 17-18	STEM Workshop	Mass of US Pennies (0) Quark Workbench (0) Rolling with Rutherford (1) LHC Masterclass measurement
University of Washington	July 10	IRIS-HEP Workshop	Very limited participation Attempting to re-energize center
University of Wisconsin – Madison	April 20	Five 2-hour sessions over the course of 6 weeks	Teachers work to develop an engaging activity for high school students on the IceCube Project; pilot tested during summer over a 2-week enrichment program with students.
Vanderbilt University	June 19-23	Workshop	Workshop focused on developing YouTube style videos to support imparting particle physics content with support from Python coding Implementation Plan development and discussion
Virginia Center (Hampton University, the William and Mary, and the George Mason University)[a]	October 28	Fall Workshop	Making Tracks II (1)
	August 2-4	Summer Workshop	Shuffling the Particle Deck (0) Making Tracks I (0) Rolling with Rutherford (1) Calculating the Z Mass (1)
	March 11	Masterclass	
Virginia Tech University	August 4	New Questions Workshop	Last day of workshop co-implemented with Virtual Center Particle Cards (0) Measuring the Z (1) The physics of g-2
	August 2-3	Workshop	Assembling, commissioning and collecting data from a muon detector

Note. National led QuarkNet workshops are in a bold face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.
aCounted as a double center.

Table 11 (con't.)

2023 QuarkNet Workshops and Meetings: National- and Center-led (December 2022-October 2023)

Center	**2023 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Virtual Center	August 4	New Questions Workshop	Last day of workshop co-implemented with Virginia Tech Particle Cards (0) Measuring the Z (1) The physics of g-2
	August 2-3	Workshop	Diffraction data Z Mass spreadsheet (2)
Coding Camp 1	June 26-30	Five Day Coding Camp (Virtual Event)	24 participating teachers 22 coding projects created by participating teachers
Data Camp	July 9 – 14		Dice Histograms CMS Calibration Analysis Time to independently explore the Data Activities Portfolio

Note. National led QuarkNet workshops are in a bold face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.
aCounted as a double center.

Sources of Outcomes Data

Teacher Full Survey
Primary Focus: Quantitative analyses of teacher, student, and long-term outcomes
Update Survey
Primary Focus: Qualitative analyses of QN content and material use in classrooms
Center Feedback Process and Template
Primary Focus: Comparing center-level and teacher-level responses
Virtual Workshop Visits by Evaluator
Primary Focus: Implementation plan discussions

Multiple Sources of Information: Evidence of Program Engagement/ Alignment with PTM

Workshop Summary Table compiled from:
Workshop Agendas
Annual Reports from Centers
Data Activities Portfolio alignment with:
NGSS Science Practices
Workshop Engagement
Enduring Understandings
Acknowledge and Review other Information
(e.g., cosmic ray studies, use of comic watches, professional presentations; masterclasses; student-collected data)

Exhibit F. Summary and Overview of Evaluation Measures and Program Engagement

Development of Evaluation Measures and Evaluation Plan

The evaluation measures used to assess teacher-level, student-level and long-term outcomes were developed or adopted to align with the measurable outcomes listed in the PTM. Evaluation measures were supported by program operations data, annual reports submitted by participating centers, virtual site visits by the evaluator during implementation plan discussions at workshops, posted implementation plans, and examples of teacher and/or student work when available to help provide the context in which this assessment has occurred. (See Exhibit F.)

To this end, a Teacher Survey (in two versions full and in an abbreviated update) and a Center Feedback Template were developed; these evaluation efforts began in September 2018 to coincide with the 2018-2019 program year, where most QuarkNet workshops and meetings at participating centers occur over the summer (as already noted). The Teacher Survey (full version) was rolled out to coincide with summer 2019 activities. (This aligns with Goal 2: assess teacher-level outcomes as well as student and long-term outcomes). A pilot test of the Center Feedback Template began in November

2019 and was rolled-out during the 2019-2020, 2020-2021 and 2021-2022 program years. This coincided with assess center-level outcomes (Goal 3) and served to provide a context for teacher-level responses. In anticipation of obtaining a renewal grant period, the full Teacher Survey was modified slightly to include additional QuarkNet options for teachers to select when querying past/current program engagement and a few skip functions for new teachers. This survey version was rolled out to coincide with the 2023 QuarkNet program.

Serving both program and evaluation needs, QuarkNet staff teachers (Wood, Cecire) and the education specialist (Roudebush) posted on the QuarkNet website a *Guide to Teacher Implementation Plan Development* to help teachers think through classroom implementation. Rolled out during the 2019-2020 program year, this involved a more structured approach to implementation where a specific time slot was allocated as a required activity for nationally-led workshops. This activity has been strongly recommended for center-run workshops as well. And, to coincide with the 2020-2021 program year, a template was created to help teachers think through the components of these plans. Often these classroom implementation plans are posted on the QuarkNet's website or linked within the posted workshop agenda.

To complement this effort, an Update: Teacher Survey was integrated into the process starting in spring of the 2019-2020 program year to help capture classroom implementation plans proposed by teachers. The Update: Teacher Survey will again be rolled out, as an option for teachers, during the 2024 program year. Finally, workshop observations (most done remotely) have been incorporated into this process.

We first describe the evaluation measures; then, present preliminary results based on the implementation of these methods and measures.

Assessment of Program Outcomes at the National and Center Levels: Full Teacher Survey

The Full Teacher Survey was developed to assess teacher-level program outcomes at the national and center levels as perceived by participating teachers. As implied, the unit of measure is the individual teacher (see Table 12). The full survey is shown in Appendices G and H (in a PDF format) for the original and modified versions; the update survey is shown in Appendix I.

There are six segments to the full survey, questions about: 1) who is completing it; 2) level of QuarkNet participation; 3) classroom use of activities from the Data Activities Portfolio; 4) opportunities to be exposed to QuarkNet program strategies, including big-picture and community-building strategies; 5) teacher-level outcomes and the degree to which QuarkNet may have influenced these; and 6) (their) student-level outcomes and the degree to which QuarkNet may have influenced this engagement.

As the survey method and content (although tweaked in 2023) each has remained the same, a more detailed description of method and its content is provided in Appendix G.

Table 12
Teacher Survey: Teacher Perceptions of Exposure to Program Core Strategies and Assessment of Program Outcomes

Core Strategies	Outcomes	Evaluation Measure
Provide opportunities for teachers to be exposed to: • Instructional strategies that model active, guided-inquiry learning (see NGSS science practices). • Big Idea(s) in Science (cutting-edge research) and Enduring Understandings (in particle physics). *Provide opportunities for teachers to:* • Engage as active learners, as students. • Do science the way scientists do science. • Engage in authentic particle physics investigations (that may or may not involve phenomenon known by scientists). • Engage in authentic data analysis experience(s) using large data sets. • Develop explanations of particle physics content. • Discuss the concept of uncertainty in particle physics. • Engage in project-based learning that models guided-inquiry strategies. • Share ideas related to content and pedagogy. • Review and select particle physics examples from the Data Activities Portfolio instructional materials. • Use the pathways, suggested in the Data Activities Portfolio, to help design implementation plan(s). • Construct classroom implementation plan(s), incorporating their experience(s) and Data Activities Portfolio instructional materials. • Become aware of resources outside of their classroom. **Local Centers** (Each center seeks to foster lasting relationship through collaboration at the local level and through engagement with the national program.) *In addition, through sustained engagement provide opportunities for teachers and mentors to:* • Interact with other scientists and collaborate with each other. • Build a local (or regional) learning community.	***Teachers:*** *Translate their experiences into instructional strategies, which reflect guided inquiry and NGSS science and engineering practice and other science standards as applicable. Specifically:* • Discuss and explain concepts in particle physics. • Engage in scientific practices and discourse. • Use particle physics examples, including authentic data, when teaching subjects such as momentum and energy. • Review and use instructional materials from the Data Activities Portfolio, selecting lessons guided by the suggested pathways. • Facilitate student investigations that incorporate scientific practices. • Use active, guided-inquiry instructional practices in their classrooms that align with NGSS and other science standards. • Use instructional practices that model scientific research. • Illustrate how scientists make discoveries. • Use, analyze and interpret authentic data; draw conclusions based on these data. • Become more comfortable teaching inquiry-based science. • Use resources (including QuarkNet resources) to supplement their knowledge and instructional materials and practices. • Increase their science proficiency. • Develop collegial relationships with scientists and other teachers. • Are life-long learners. ***(And their) Students will be able to:*** • Discuss and explain particle physics content. • Discuss and explain how scientists develop knowledge. • Engage in scientific practices and discourse. • Use, analyze and interpret authentic data; draw conclusions based on these data. • Become more comfortable with inquiry-based science.	The Teacher Survey is intended to assess teachers' perceptions related to their exposure to core strategies (as *implemented*); and their perceptions regarding teacher and student outcomes. (See Appendices G and H for a copy of the survey.) The unit of measure for this survey is the individual teacher. The intent is to complete the survey during their on-site program engagement. The survey is conducted via SurveyMonkey. An annual event. Teachers are asked to complete a much shorter survey (Update) the following year they complete the full survey; focused on use of activities in the use of QuarkNet content and DAP activities in their classroom; teacher-level and student-level outcomes. (See Appendix I.)

Table 13
Center Feedback Template: Linking Core Strategies and Center-level Outcomes

<table>
<tr><th>Core Strategies</th><th>Outcomes</th><th>Evaluation Measure</th></tr>
<tr><td>Provide opportunities for teachers to be exposed to: Instructional strategies that model active, guided-inquiry learning (see NGSS science practices).
1. Asking questions (for science) and defining problems (for engineering).
2. Developing and using models
3. Planning and carrying out investigations.
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information.</td>
<td rowspan="3">Local Centers
• Model active, guided-inquiry instructional practices that align with NGSS and other science standards that model scientific research.

Through engagement in local centers
Teachers as Leaders:
• Act in leadership roles in local centers and in their school (and school districts) and within the science education community.
• Attend and/or participate in regional and national professional conferences sharing their ideas and experiences.

Mentors:
Become the nexus of a community that can improve their teaching, enrich their research and provide broader impacts for their university.

Teachers and Mentors:
Form lasting collegial relationships through interactions and collaborations at the local level and through engagement with the national program.</td>
<td rowspan="3">The Center Feedback Template is intended to serve as a guide or protocol to capture center-level information related to implemented program strategies and well as key center-level outcomes. (See Appendix J for a copy of this protocol.)

The unit of measure for this evaluation effort is the center. The narrative of this report explains the plan for how this template has been distributed and in what ways centers are offered assistance in completing it based on staff teacher aid and/or assistance from the evaluator.

This template also addresses sustainability outcomes, which are presented in Table 14.</td></tr>
<tr><td>Program provides opportunities for a strong mentor.
(Mentor provides leadership skills mainly of content and/or technical expertise; understands education and professional development -- working with teacher leaders as needed; models research.)</td></tr>
<tr><td>Local Centers: In addition, through sustained engagement provide opportunities for teachers and mentors to:
• Interact with other scientists and collaborate with each other.
• Build a local (or regional) learning community</td></tr>
</table>

The survey is a planned annual event; however, a given teacher is asked to complete the full survey only once during a grant period. Starting in spring 2020, if a teacher had completed the Full Teacher Survey, he or she was asked to complete the short Update: Teacher Survey (see Appendix I). The update survey focuses on the use (or planned use) of activities in the Data Activities Portfolio in the classroom; teacher-level outcomes and their perceptions about (their) student outcomes. The update was rolled out to coincide with the 2019-2020 program year and continued during each subsequent program year. (There is also a Spanish language version.) Teachers access it through a SurveyMonkey link with an estimated 6-minute completion time. Time to complete this update is also incorporated into the agenda.

Table 14
Center Feedback Template: Sustainability Outcomes and Success Factors[a]

Sustainability Outcomes[b]	Success Factors[a]
1. Program components or strategies are continued (sustained fidelity in full or in part). 2. Benefits or outcomes for target audience(s) are continued. 3. Local/Center-level partnerships are maintained.[c] 4. Organizational practices, procedures and policies in support of program are maintained. 5. Commitment/attention to the center-level program and its purpose is sustained.[c] 6. Program diffusion, replication (in other sites) and/or classroom adaptation occur.[c]	1. *Program provides opportunities for a* ***strong teacher leader****.* (Teacher provides leadership in areas of content and/or is a technical expert; models exemplary pedagogical skills; able to provide organizational skills. These characteristics may be present in one or a team of teacher leaders.) 2. *Program provides opportunities for a* ***strong mentor****.* (Mentor provides leadership skills mainly of content and/or technical expertise; understands education and professional development -- working with teacher leaders as needed; models research.) 3. *Participants meet regularly*. (QuarkNet model is for a summer session with follow-up during the academic year or sessions during the academic year. Follow up includes working with the national staff and collaboration within and across centers. Mentors and teachers have flexibility to set the annual program locally.) 4. *Meaningful activities* (The standard for meaningful activities is focusing topics in modern physics, discussing how to implement this content in classrooms, conducting research and discussing scientific inquiry methods; using Data Activities Portfolio instructional materials.) 5. *Directly addresses classroom implementation of instructional materials for all teachers.* (Time for teachers to discuss Data Activities Portfolio instructional materials and pathways; to consider NGSS, AP, IB or other science standards; presentation(s) from veteran teachers on classroom implementation experiences or similar engagement.) *6. Program is able to provide regular contact and support with teachers*. (Specific support and or follow up from staff; staff teachers are available and/or volunteers who support teachers, especially related to classroom implementation.) *7. Money for additional activities or additional grants.* (Seeking additional funding to fulfill the mission/ objectives of the center; providing supplemental or complementary support for QuarkNet e.g., providing transportation, lodging, buying equipment; providing food.) *8. Stable participant base.*(A stable participant base can provide an expert group that can help other teachers, support outreach, and provide organizational leadership.) *9. Addresses teacher professionalism.* (The standard is to provide opportunities for at least a few teachers to attend professional meetings; support teachers taking leadership roles in their school, school districts, outreach, and highlight PD opportunities for continuing development.) *10. Establish a learning community.* (The standard is forming a cohesive group where teachers learn from one another; engage with mentors and other scientists; provide outreach to other teachers.)

[a] M.J. Young & Associates (2017, September). *QuarkNet: Matrix of Effective Practices*
[b]This framework is based on the work of Scheirer and Dearing (2011); adopting their definition of sustainability, as well: “Sustainability is the continued use of program components and activities for the continued achievement of desirable program and population outcomes” (p. 2060). The language has been modified slightly to better fit the QuarkNet program.
[c]The language of this characteristic was modified to better fit the QuarkNet program.

Table 15
Summary of QuarkNet Teacher Enrollment and Survey Response Rate
by Program Year

Program Year[f]	Number of Enrolled Teachers	Number of Completed Surveys	Total
2023	330	257[e]	78%
2022	281	224[d]	80%
2021	242	192[c]	79%
2020	251	181[b]	72%
2019	311	242[a]	78%

[a]An additional 78 teachers who participated in QuarkNet in 2018 *but not* in 2019 were contacted via email and asked to participant in the survey. A total of 22 of these teachers completed the survey for a response rate of 28%. (These totals are not reflected in the above table.) Thus, a total of 264 teachers responded to the survey.
[b]In 2020, 91 teachers completed the full survey and 90 teachers completed the update survey.
[c]In 2021, 68 teachers completed the full survey and 124 teachers completed the update survey.
[d]In 2022, 76 teachers completed the full survey and 148 teachers completed the update survey.
[e]All teachers completed the full survey to coincide with the renewal grant award.
[f]Program year numbers are unique for each program year.

Assessment of the Sustainability of Program Centers: Based on Center-level and Sustainability Outcomes – Center Feedback Template

Given that most teachers experience the QuarkNet program through their engagement of the program at a specific center, the center provides an important context in which the teachers experience the program and at the same time, centers are a source of outcomes in their own right. To this end, the Center Feedback Template was designed to assess this program context, assess center-level outcomes (see Table 13); and gather information on success factors as a means to assess sustainability outcomes (see Table 14).

The Center Feedback Template is a 4-page form divided into four sections (see Appendix J). Information about the Center (who is participating in this effort and who is completing this form) is requested in Section I. Section II asks about program events over the past two years. Section III gathers information about center-level outcomes (described in Table 13); and Section IV is focused on the Success Factors listed in Table 14. Finally, there is an optional fifth page for Centers to add any additional comments, if desired. The protocol used to implement this approach is also described in Appendix J.

QuarkNet Participant: Teacher Survey (2019-2023)

A summary of enrollment numbers and survey response rates is shown in Table 15. For each year, participating teachers completed the survey at the time of the workshop/ program; or, after one email reminder. We believe the reason behind the high response rate for participating teachers is that the survey was administered face-to-face during 2019 workshops and programs; at the time of the workshop or program mostly in a virtual environment for 2020 and 2021; and, again in 2022 and 2023 during in-person workshops. (See for example footnote a in Table 15 for a comparison of response rates for 2018 vs. 2019 that supports this claim.) Thus, the credit for this high response rate is due to the commitment by the staff and facilitators of QuarkNet; we are thankful for it.

Raw Data

For each program year, raw data were downloaded from Survey Monkey via an Excel spreadsheet and exported to SPSS (Statistical Package for the Social Sciences, Version 28) for subsequent analyses. Although the survey is accessible to teachers by a link, raw data are only accessible via a specific Survey Monkey account.

Data were reviewed, cleaned, and new variables were created to facilitate data analysis, when necessary. (These data manipulations are described in the analysis sections of this report.) When a teacher self-identified and completed both surveys (full and update) 2019 through 2023 survey responses were linked so that year-to-year comparisons for these teachers could be made.

A total of 611 QuarkNet teachers completed their full survey; this represents a unique count of teachers across the 2019-2023 program year period. As this is a unique count, this does not represent the number of teachers who participated in a given program across multiple years. An estimate of the total number of teachers who engaged in QuarkNet during this time period – and under the umbrella of survey outreach is at least 1,400 program participants (some teachers are likely counted multiple times).

In addition to completed full surveys, 362 Update Surveys were completed across a 3-year period of 2020-2023. Of these, 327 (or 90%) were linked to full survey responses so that multiple-year comparisons can and have been made. This represents a unique count of 208 teachers who completed their update survey at least once during at least once during this time period.

In program year 2023, a total of 257 teachers participated in QuarkNet and completed their survey. Of these 105 of these teachers were *new* to the survey process.

Before teacher-level (and their students) and long-term outcomes are explored, a brief look is provided as to who are these teachers.

Teacher Demographics: Gender

Using a unique count of the total number of QuarkNet teachers who participated during the 2019-2023 program years, the gender of participants is broken down in Table 16. A total of 583 teachers responded to this question -- 28 teachers did not indicate their gender – for a total of 611 teachers. Survey responses labeled as 2020, 2021, 2022 and 2023 reflect teachers who were *new* to QuarkNet survey (starting in 2019). These teachers may or may not be new to the QuarkNet program per se as will be discussed in the next section.

Table 16
Full Teacher Survey: Gender of QuarkNet Teachers

Program Year: Unique Count	Gender		Total
	Men	Women	
(new to survey) 2023	45 (43%)	60 (57%)	105 (100%)
(new to survey) 2022	42 (55%)	34 (45%)	76 (100%)
(new to survey) 2021	41 (63%)	24 (37%)	65 (100%)
(new to survey) 2020	34 (42.5%)	46 (57.5%)	80 (100%)
2019	157 (61%)	100 (39%)	257 (100%)
Total	319 (55%)	264 (45%)	583 (100%)

Note. Please note that this represents a unique count of teachers. Numbers in 2020, 2021, 2022 and 2023 do not represent the total number of teachers who participated in QuarkNet for each of these program years. *New* means new to the survey process not necessarily new to QuarkNet. A total of 28 survey respondents did not specify their gender.
$\chi^2_{(4,\ 583)} = 16.83$, $p < .002$ (comparing gender across program years).

In program year 2023, a total of 257 teachers participated in QuarkNet and completed their survey. Of these teachers, 120 are men (46.7%) and 114 are women (44.4%). A total of 23 individuals (8.9%) did not specify their gender.

Teachers *New* to QuarkNet

Table 17 represents a unique count of teachers who reported that they were new to the QuarkNet program during the 2019-2022 program years by center. And it includes a similar breakdown for the 2023 program year. These counts are based on survey responses for a unique count total of 611. These data were based on a question, framed in an open-ended format, teachers were asked, *For how many years (approximately) have you participated in QuarkNet (including today or your most recent participation)?*

Most often, teachers new to the program either indicated that they were new; or had participated for one year or less in the program. When describing their participation as in and around one year, teachers frequently indicated that the workshop in question was their first. For this reason, the table includes both "new" and "1-year" responses as a representative number of new teachers. As indicated, these counts are broken down by QuarkNet center.

A total of 36% of teachers who participated in QuarkNet during the 2019-2022 program were new/1-year in the program. In the 2023 program year, 33% of participants were new/1-year in the program.

Years Teaching and Years at Current School and Years in QuarkNet

Figure Set 6 displays the number of years teaching, years at current school compared to years in QuarkNet for participating teachers. The mean number of years in QuarkNet was 4.89 years (Standard Deviation, SD = 5.60), with a median of 2.0 years (50^{th} percentile).

Table 17
Unique Count of *New* Teachers at QuarkNet Centers: Across Several Program Years

Single or combined[a]	Summary from Previous Grant 2019-2022 Program Years				2023 Program Year		
	Center	Number of *New* Teachers		Total Number of Teachers	Number of *New* Teachers		Total Number of Teachers[c]
		New	1 year in QuarkNet		New	1 year in QuarkNet	
1	Black Hills State University	2	3	10	1	1	4
2	Boston/Brown University/Northeastern University	0	4	15	3	0	3
2	Brookhaven National Laboratory/Stony Brook University	3	2	13	0	2	5
1	The Catholic University of America	0	6	11	0	1	5
1	Colorado State University	3	1	12	--	--	3
2	Fermilab/University of Chicago/College of DuPage	12	9	42	1	1	3
	~~Florida Institute of Technology~~ (Central Florida)	3	3	6	0	1	1
1	Florida International University	1	1	8	--	--	0
1	Florida State University	0	1	13	2	0	5
1	Idaho State University	2	4	13	--	--	0
2	Johns Hopkins University	0	0	15	4	2	7
1	Kansas State University	3	0	16	--	--	0
1	Lawrence Berkeley National Laboratory	1	7	20	0	1	2
1	Northern Illinois University	0	0	2	--	--	0
2	Oklahoma State University/Oklahoma State	1	0	17	3	9	15
1	Purdue University	0	0	0	1	2	3
1	Purdue University Northwest	0	1	5	--	--	0
1	Queensborough Community College	0	0	2	--	--	0
2	Rice University/ University of Houston	1	4	19	3	1	7
1	Rutgers University	0	0	3	--	--	0
1	Southern Methodist University	5	8	24	--	--	0
1	Syracuse University	3	4	22	3	2	6
1	Texas Tech University	1	1	3	--	--	0
1	University of Alabama[b]	0	0	0	0	1	1

Table 17 (con't.)
Unique Count of *New* Teachers at QuarkNet Centers: Across Several Program Years

Single or com-bined[a]	Summary from Previous Grant 2019-2022 Program Years				2023 Program Year		
	Center	Number of *New* Teachers		Total Number of Teachers	Number of *New* Teachers		Total Number of Teachers[c]
		New	1 year in QuarkNet		New	1 year in QuarkNet	
1	University at Buffalo -- SUNY	2	0	6	--	--	0
1	University of California – Irvine	6	1	8	6	3	9
	~~University of California – Riverside~~	0	0	0			
1	University of California at Santa Cruz	0	0	1	--	--	1
1	University of Cincinnati	4	8	18	4	0	5
1	University of Florida	1	3	5	--	--	0
1	University of Hawai'i	2	2	6	0	1	1
2	University of Illinois at Chicago/ Chicago State University	0	3	10	--	--	0
2	University of Iowa/Iowa State University	1	3	14	0	5	7
1	University of Kansas	0	1	5	--	--	0
1	University of Minnesota	1	2	13	2	1	4
1	University of Mississippi	1	0	4	--	--	2
1	University of New Mexico	10	7	19	0	1	1
1	University of Notre Dame	0	1	19	1	0	2
1	University of Oregon	0	1	5	0	1	1
	~~University of Pennsylvania~~	0	0	0			
1	University of Puerto Rico at Mayaguez	3	1	16	3	3	9
	~~University of Rochester~~	0	0	3			1
1	University of South Dakota[b]	0	0	0	1	0	1
	~~University of Tennessee~~			2			
1	University of Washington	0	0	0	1	2	3
1	University of Wisconsin - Madison	0	0	1	--	--	1

Table 17 (con't.)
Unique Count of *New* Teachers at QuarkNet Centers: Across Several Program Years

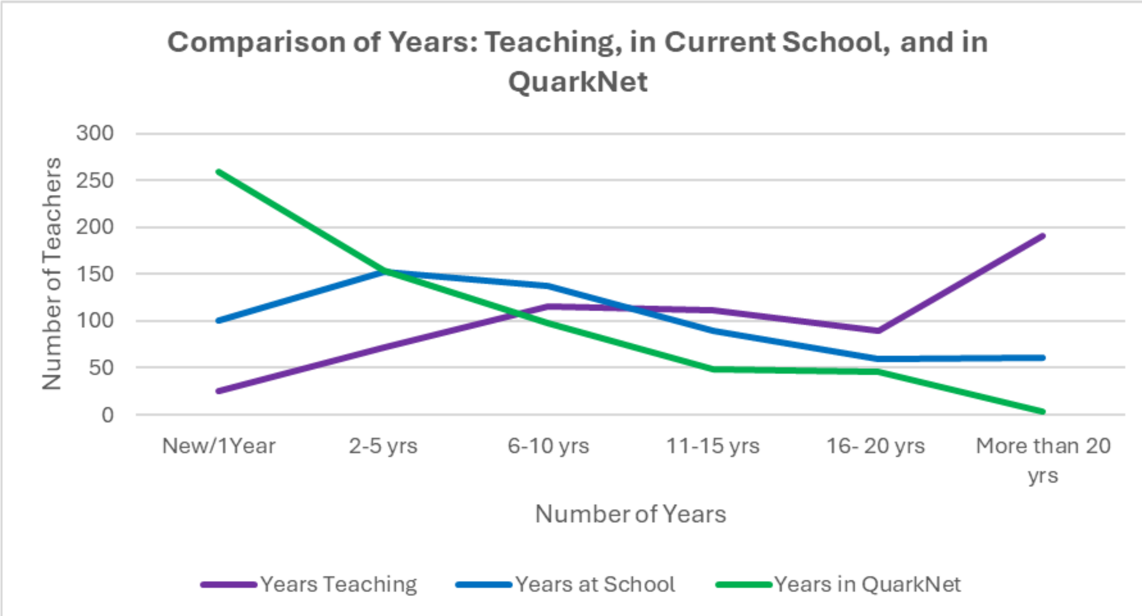
Single or com-bined[a]	Summary from Previous Grant 2019-2022 Program Years				2023 Program Year		
	Center	Number of *New* Teachers		Total Number of Teachers	Number of *New* Teachers		Total Number of Teachers[c]
		New	1 year in QuarkNet		New	1 year in QuarkNet	
1	Vanderbilt University	0	3	11	--	--	2
1	Virginia Center (Hampton, George Mason, William & Mary Universities)	0	2	11	2	4	8
1	Virginia Tech	1	1	9	--	--	0
1	Virtual Center	1	1	13	--	--	0
	~~Wayne State University~~	0	0	0			
	Missing	0	0	2			
53	Total	74 (15.3%)	99 (20.5%)	483	41 (15.9%)	45 (17.5%)	128[c] / 257

Note. This table represents a unique count of teachers participating in QuarkNet's Teacher Survey over the program years presented in this table. The data in this table should **not** be used as a count of the number of teachers who have participated in QuarkNet in a given program year (e.g., 2023). In 2023, a total of 257 teachers completed their survey; of these teachers 128 (nearly 50%) were new to the survey process. Thus, an entry of "--" means a center did not have any new/1 year teachers for the 2023 program year. And similarly, an entry of "0" means that no teacher who participated in 2023 was new to the survey process.

[a]A center is noted as a combined center if two (or more) centers work together to hold a QuarkNet workshop or event. Combined centers receive additional funds to support more teachers and/or more days to hold these events. ~~Center~~ denotes a center that is no longer active (as of April 2023).
[b]University of Alabama, and University of South Dakota are new centers.
[c]Represents a unique count of teachers. A total of 257 teachers participated in survey in 2023 many of whom had participated in QuarkNet and captured in the survey in previous years.

Collectively, these teachers had a mean number of years teaching of 16.18 years (SD= 10.14) (median 15.0 years); and a mean of 9.17 years at his/her school (SD = 7.95) (7.0 median years); with a few participating teachers who are retired.

The number of years a teacher has participated in QuarkNet is statistically related to teacher's gender and the program year in which a survey is captured. In a 2 x 5 Analysis of Variance (ANOVA), male teachers reported a higher mean number of years in QuarkNet (5.68; SD = 5.85) compared to female teachers (Mean = 3.93; SD =5.00) [$F_{(1, 571)} = 8.11$, $p < .005$]. Regarding program year, teachers reporting in program years 2022 and 2023 indicated a fewer number of years of QuarkNet participation (Mean = 2.89 SD = 4.53 in program year 2022; and Mean = 2.75 SD = 4.46 in program year 2023) compared to teachers who completed their surveys in 2019, 2020, or 2021 [$F_{(4, 571)} = 11.62$, $p < .001$]. (See Figure 7.)



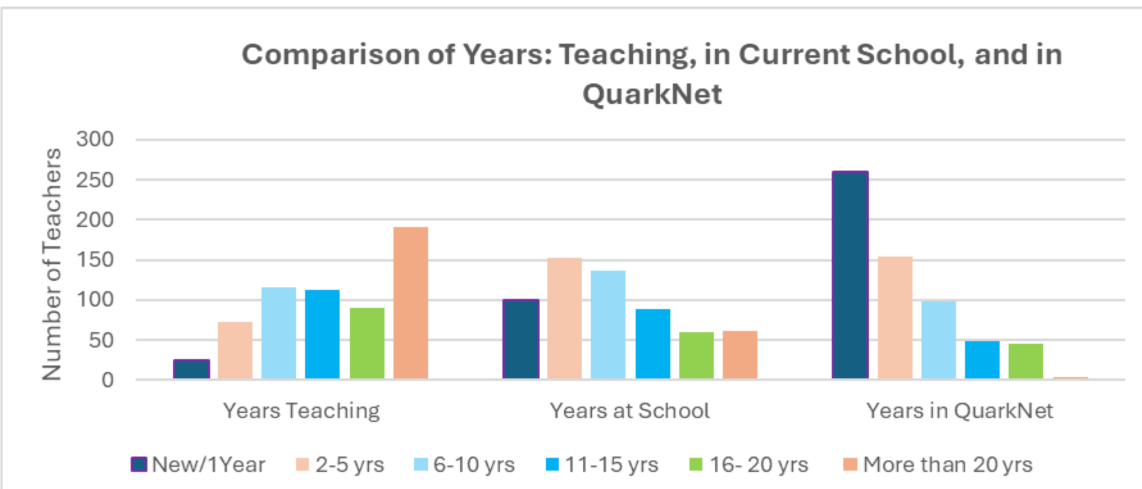


Figure Set 6. Comparison of the number of years: Teaching; at current school; and participating in QuarkNet (at the time the teacher completed his or her full survey).

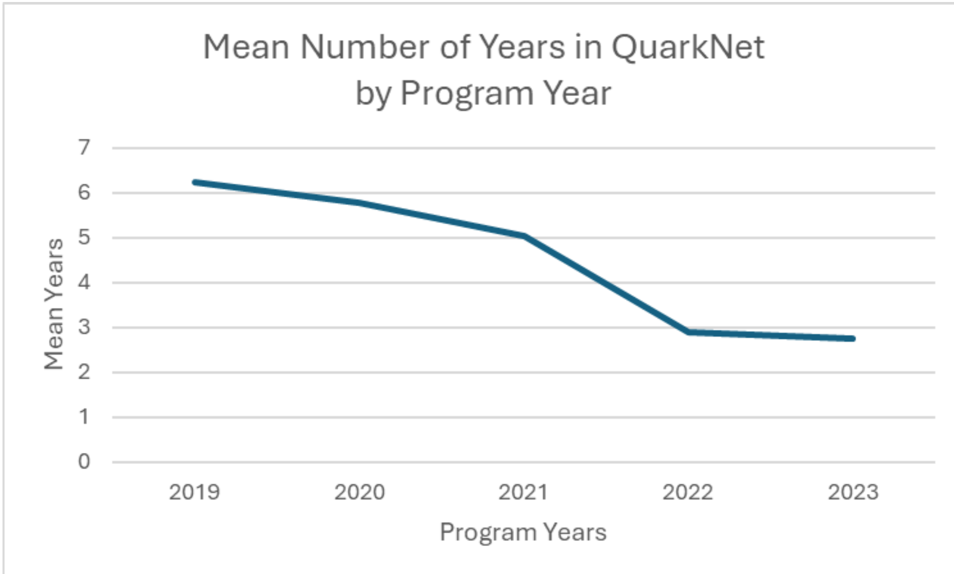


Figure 7. Over several program years, QuarkNet has been trending toward bringing in *new* teachers to the program (based on a unique count of teachers each year for a total of 611 teachers).

Relative to the number of years teaching, male teachers reported a mean number of years of 20.01 (SD= 11.68) compared to female teachers (Mean = 16.10; SD = 9.33) a statistically significant difference [$F_{(1, 567)} = 8.20$, $p < .005$]. Number of years teaching was not statistically related to the program year in which the teacher's survey was captured. Number of years at their current a school was statistically related to the gender but not program year [Male teachers Mean = 11.27, SD = 8.98; Female teachers Mean = 8.81, SD = 7.65; ($F_{(1, 562)} = 3.97$, $p < .05$)].

As one would expect, the number of years teaching and years at current school is positively correlated and notably high (r = .64); slightly lower but still high was the positive correlation between years teaching and QuarkNet experience (r = .47); and, years at current school and QuarkNet experience (r = .43).

<u>School Location</u>

Teachers were asked the best descriptor for the location of the school they represented. As shown in Table 18 most often participating teachers represented schools in suburban areas (198 or 32.9%); followed by urban, central city (198 or 27.0%); urban (128 or 21.2%); or rural (114 or 18.9%). Over the course of several program years, it is important to note that QuarkNet teachers are trending toward representing urban and urban center city locations and less so from schools in suburban locations, a trend that is statistically significant [$\chi^2_{(12, 602)} = 125.14$, $p < .001$].

School location was not statistically related to the gender of teachers.

Table 18
QuarkNet Teachers: School Location and Teaching Physics

Demographic	Program Year: Unique Count					
	2019	2020	2021	2022	2023	Total
School Location						
Rural	48 (19.0%)	15 (19.2%)	16 (23.9%)	12 (15.6%)	23 (18.1%)	114 (18.9%)
Suburban	124 (49.0%)	38 (48.7%)	12 (17.9%)	8 (10.4%)	16 (12.6%)	198 (32.9%)
Urban	49 (19.4%)	15 (19.2%)	7 (10.4%)	25 (32.5%)	32 (25.2%)	128 (21.2%)
Urban, Central City	32 (12.6%)	10 (12.8%)	32 (47.8%)	32 (41.5%)	56 (44.1%)	162 (27.0%)
Total	253 (100%)	78 (100%)	67 (100%)	77 (100%)	127 (100%)	602 (100%)
Teach Physics?						
Yes	223 (87.5%)	58 (73.4%)	47 (69.1%)	59 (77.6%)	89 (70.1%)	476 (78.7%)
No	32 (12.5)	21 (26.6%)	21 (30.9%)	17 (22.4%)	38 (29.9%)	129 (21.3%)
Total	255 (100%)	79 (100%)	68 (100%)	76 (100%)	127 (100%)	605 (100%)

Please note that this represents a unique count of teachers. Numbers in 2020, 2021, 2022,and 2023 **do not** represent the total number of teachers who participated in QuarkNet for each of these program years. *New* means new to the survey process not necessarily new to QuarkNet. Eight teachers did not indicate the location of their school. And five teachers did not indicate whether or not they are teaching physics.

To take a deeper dive into the schools represented by QuarkNet participating teachers a large-scale case study was undertaken to explore the student demographics represented by these schools. This was undertaken based on teachers registered for the 2022 QuarkNet program year – the results are based on 21 Centers (27 combined) and the inclusion of approximately 250 teachers from about 120 schools. Some teachers represented the same school but please keep in mind that QuarkNet program engages individual teachers and does not represent a school-wide or science-department level of professional development.

We have organized this information by center. The summary provided the name and city, state location of the school, school-level student demographics including school enrollment size; gender breakdown of students (by percents); ethnicity of students (by percents); and the percent of students who are eligible for free or reduced lunch programs. We based this summary on publicly available information, and we have accepted information at face value. (Presented as a separate report.)

What have we learned from this review? That the schools represented by QuarkNet teachers are varied; representing mostly public schools both large and small; and, to a lesser extent, private schools. Some centers show evidence that students represented by schools are diverse in ethnicity and represent notable percents of low-income students (e.g., free or reduced lunch eligibility). Other centers less so. As mentioned, we have organized this information by center in the hope that such organization would help facilitate its usefulness. It is likely most helpful if used by and for the local centers especially in discussions as to how to draw new teachers into QuarkNet to improve representation by teachers who teach at schools with under-represented student populations, as needed.

Teaching Physics

As reflected in Table 18 across program years, a total of 78.7% of teachers reported that they teach physics. During this time, there was a tendency for more teachers to report that they are not teaching physics [$\chi^2_{(4, 605)} = 22.36$, $p < .001$] from a percent high of 88% to a low of 70%. Slightly more female teachers do not teach physics as compared to male teachers [$\chi^2_{(1, 577)} = 19.11$, $p < .001$].

It is important to note that these survey results present a snapshot in time as to where and what a given teacher is teaching. Given that teachers often participate in QuarkNet frequently over the course of many program years, these data and results do not reflect this fluidity (e.g., scheduling changes for a given teacher at the same school over school years; or a change of schools during this time period). Changes, when they occur, are at times reflected in open-ended comments teachers have made during completion of the shorter, update surveys; but even here these changes are likely under-reported and reflect a moment in time.

QuarkNet Participation

Teachers were asked to select the QuarkNet workshops or programs where they were participants. These responses are summarized in Table 19. Clearly, a workshop (workshops collectively) is the most frequently mentioned QuarkNet program. Given that multiple responses are allowed, summing these numbers would not provide a unique count of teachers (although each total is based on a unique count of teachers, except for coding events). As to specific programs, most often, teachers indicated that they had participated in Data Camp (205) and Cosmic Ray e-Lab introduction (192). Participation in (a variety of) workshops and masterclasses is noteworthy.

It is important to note that the value of Table 19 is in our ability to gauge the type and degree of QuarkNet engagement by teachers as this relates to their perceived assessment of exposure to strategies core to the program. Another way to say this is, at the time that they evaluated their exposure to core program strategies what had their past (and immediately present) engagement in QuarkNet looked like. Table 19 *is not* a program operations data table indicating participation totals for a particular program year or across this grant period.

QuarkNet Participation Beyond the Survey: Masterclasses and e-Labs. It is noteworthy that workshops are the principal vehicle in which professional development is provided to participating QuarkNet teachers (supported by other opportunities as well); it is also the principal means by which survey responses are collected. Thus, these data may

Table 19
Which Workshop or Program?

Workshop/Program	Num. Teachers	Workshop/Program	Num. Teachers
Data Camp	205	Cosmic Ray e-Lab Advanced Topics	37
ATLAS	53	Neutrino Data Workshop	128
CMS Data Workshop	109	ATLAS Masterclass	62
CMS e-Lab Workshop	93	CMS Masterclass	125
Cosmic Ray e-Lab Intro	192	Neutrino Masterclass	58
Other QuarkNet Events			
International Muon Week	39[a]	International Cosmic Day	34[a]
CERN	53	International Muon Week	40[a]
Greece Trip	13	World Wide Data Day	24[a]
Coding Workshops/ Coding Camp 1 and Coding Camp 2[b]			188[b]

Note. Multiple responses were allowed.
[a]Since the main vehicle for gathering survey responses from teachers is through workshop participation, it is likely that some of these counts underestimate the actual number of teachers who participate in other programs, such as masterclasses or special events.
[b]Early exposure to coding was embedded in workshops that also included other physics content such as neutrino data and/or CMS updates (2020-2023). The number of participants in coding events **does not** represent a unique count of teachers and was taken from Race, September 2023. Portions of these events was sponsored by IRIS-HEP.

overrepresent workshop participation and undercount engagement in other types of QuarkNet events.

To offer a sense of the wider uses of QuarkNet programs and materials we present the following. As to likely undercounts, survey responses on coding program engagement was not representative of actual participation levels. Thus, as noted, we report the participant level as reflected in a report to IRIS-HEP on this engagement (Race, September 2023); although this is not a unique count of teachers.

A graph created by Cecire, (see Figure 7 displayed here with permission) shows the number of QuarkNet masterclasses held over the course of the current grant. Although the number of events and not teachers are provided, this graph offers a more accurate picture of the possible opportunities for QuarkNet teachers to engage in QuarkNet masterclasses across the current grant period.

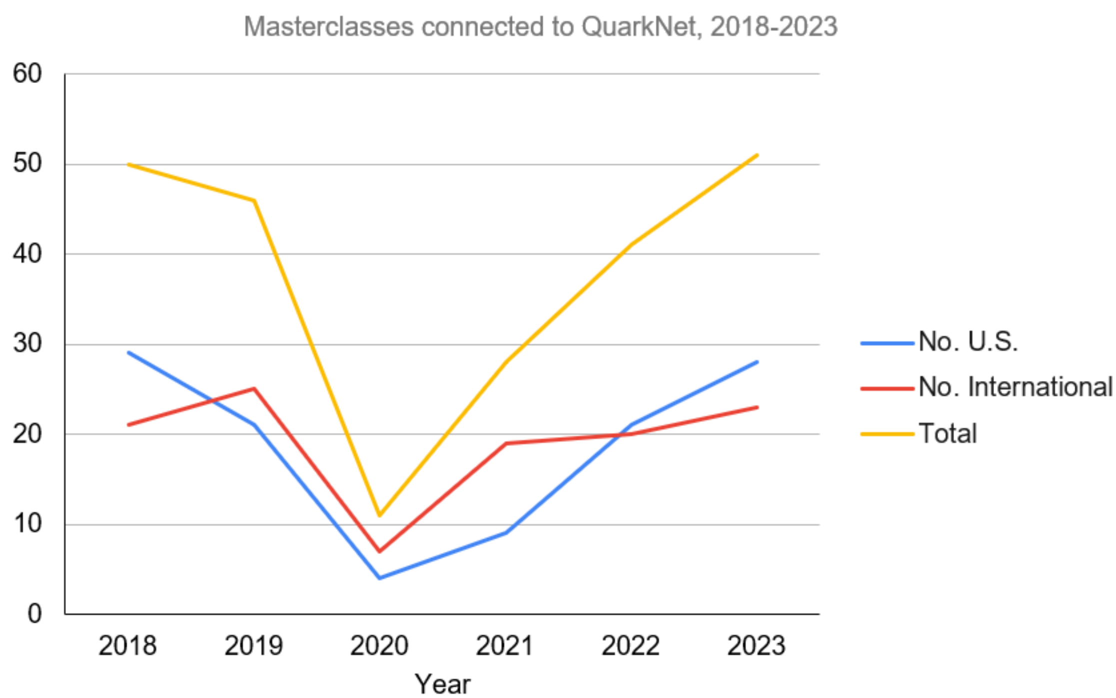


Figure 7. QuarkNet Masterclasses by program year (data from K. Cecire, 2024).

Table 20

High School Long-term Collaboration Using
High Energy Physics Model

Time Period	DAQs (Data Acquisitions)[a]	Uploads	Analyses Run
Apr-Oct 2019	66	2,173	--
Apr-Oct 2020[b]	27	2,733	2,182 (from 26 DAQs)
Apr-Oct 2021	42	2,871	4,300 (from 30 DAQs)
Apr-Oct 2022	55	3,513	5,055 (from 34 DAQs)

Note. Data compiled by M. Adams used with permission (email Adams 1/31/23)
[a]DAQ measurement/experiments using Cosmic Ray Muon Detectors.
[b]During COVID.

As to e-Lab activities, QuarkNet teacher engagement is measured in various ways. For example, information compiled by Adams (and used here with permission) suggests that there are over 2,000 teacher accounts. These teachers support approximately 1,400 student accounts (with a single student account representing one to many students).

Table 20 shows the number of uploads during 2019 through 2022; and the number of analyses run during 2020 through 2022. A total of 382 e-Lab plots were saved in 2022. (Historic totals for plots and file uploads are 26,115 and 119,213, respectively.)

Table 21
QuarkNet Participation by Program Year (Responses from Full Surveys)

QuarkNet Program	Program Year					Total
	2019	2020	2021	2022	2023	
Data Camp[a]						
Yes	112	33	14	24	22	205
No	146	47	54	53	106	406
Total	258	80	68	77	128	611
Variety of Prior Workshops[b]						
None	79	37	35	46	88	285
One workshop	79	19	20	17	29	164
Two or more	100	24	13	14	11	162
Total	258	80	68	77	128	611
Masterclasses[c]						
None	147	56	52	69	105	429
One or more	111	24	26	8	23	182
Total	258	80	68	77	128	611

[a][$\chi^2_{(4, 611)} = 34.07$, $p < .001$]
[b][$\chi^2_{(8, 611)} = 65.33$, $p < .001$]
[c][$\chi^2_{(4, 611)} = 45.29$, $p < .001$]

QuarkNet Participation and Program Year

Returning to QuarkNet participation as gauged by the Teacher Survey, please keep in mind that teachers were asked about their current and past QuarkNet participation. When doing so, engagement in QuarkNet by type of opportunity was found to be related to the program year in which they responded to the full survey (see Table 21).

Participation by program year differences may likely be linked to the onset of COVID which altered the implementation of QuarkNet especially during the 2020 and 2021 program years. For example, Data Camp (fundamentally an in-person event) was implemented only in 2019 and returned again in 2022 and 2023. Those teachers who indicated that they had participated in Data Camp, as reflected in program years 2020 and 2021, were reporting past engagement in QuarkNet and not the program year when their survey responses were gathered. That said, analysis suggests that more than expected teachers reported having participated in Data Camp in 2019 as compared to 2020-2023 program years. This was also the case of the variety of prior workshop engagement during 2019 (more teachers than expected reported engaging in prior workshops) as compared to 2020-2023 program years. And the number of masterclasses was more than expected engaging in masterclasses in 2019 as compared to 2020-2023 program years.

In subsequent sections of this report, program-year participation will be reported only if found to be statistically related to exposure to core strategies and/or program outcomes.

Overview of Analyses: Teacher (and their Students) and Long-term Outcomes

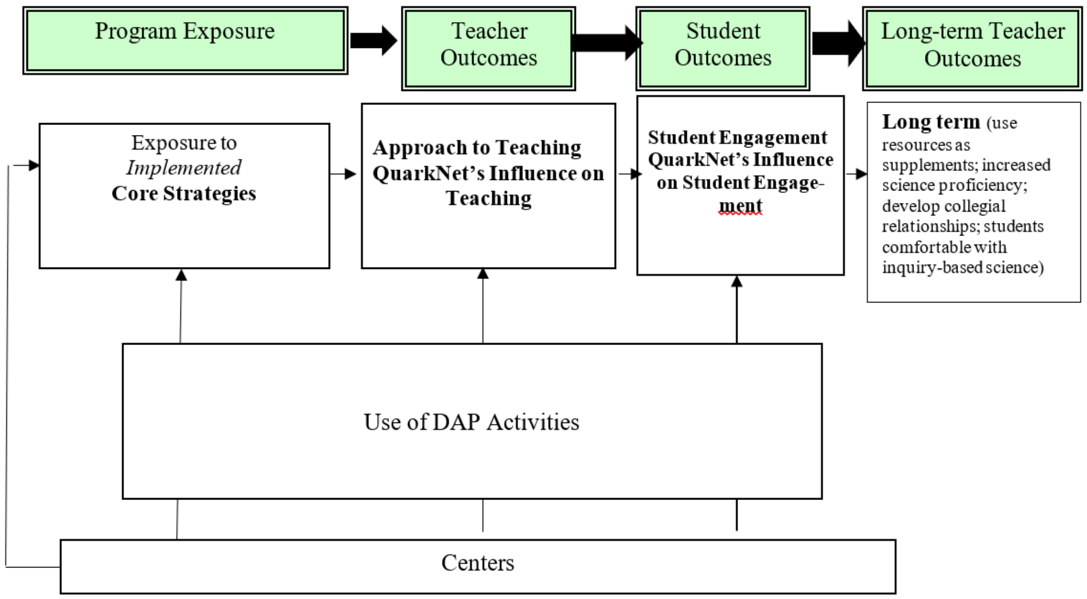


Figure 8. Teacher (and their Students) and Long-term Outcomes: Overview of Analyses

Quantitative analyses of outcomes began by exploring the relationship between engagement in QuarkNet and exposure to core program strategies; and subsequently the potential impact this involvement may have on teacher outcomes, student engagement outcomes, and long-term outcomes. We have analyzed responses from the 2019 through 2023 Full Teacher Surveys and have conducted a descriptive look at responses from the 2020 through 2022 Update Teacher Surveys (the latter of which will be discussed in subsequent sections).

At times, a given measure serves as the dependent measure in a set of analyses; and in turn, a given measure may be used as a "predictor" variable as we build models toward understanding teachers' approach to teaching (both teacher and student-level outcomes) and use of activities in the Data Activities Portfolio. Because of this complexity, Figure 8 provides an overview of these analyses as a means of offering a road map to their logic. Each analysis is presented and discussed separately in the next several sections. To help simplify these analyses and to use data with measured reliability (internal consistency), several scale scores were created (which will be explained shortly).

Please be mindful that these analyses explore the association of exposure to core strategies through QuarkNet programs and outcomes; and are not intended to imply causality. Multiple models are proffered as a means of helping us understand these relationships. *The weight of the evidence suggests a strong association between program participation and exposure to core strategies. In turn, exposure to core strategies and measured outcomes are positively and statistically related.* We reserve judgment as to the best model(s) to use at this time because these analyses are preliminary. Additional data added into this mix over the course of the past and current grant period have permitted the incorporation of center-level data into these models, when statistically feasible. We had used qualitative analyses to describe how teachers have incorporated QuarkNet content and materials in their classrooms within the context of center-level program engagement. The inclusion of center-level effects (i.e., nested teachers) in these analyses has strengthened our confidence in the interpretation of these results of these models.

Scale Score Development to Measure Exposure to Program and Teacher (and their Students) and Long-term Outcomes

The following scale scores were developed in support of these analyses: Core Strategies (assess program exposure); Approach to Teaching; QuarkNet's Influence on Teaching; Student Engagement; and QuarkNet's Influence on Student Engagement. A *new* scale score has been added, that is, Long-term Outcomes: Teachers. All scale scores are based on teacher self-reported responses to the Full Teacher Survey.

To help understand the content of these scales, the individual survey items, included in each of these scale scores, are shown in Table 22. In all cases, the responses to a given item set (scale) are summed with the *higher* the score, the more positive response, based on individual 5-point Likert-like response categories. Descriptive statistics and the reliability coefficient for each scale are shown in Table 23. Scale-building results have been stable across survey years. We provide more descriptive details about these scales in Appendix K.

Unique Contributions of QuarkNet Program Components

At the suggestion of NSF based on project and proposal review, we have conducted a series of statistical analyses where each of the following QuarkNet program components, that is, Data Camp participation, Variety of Workshop engagement, and MasterClass participation, are analyzed simultaneously. In these analyses, each comprised of a 2x3x2 Analysis of Variance (ANOVA), the contribution of each QuarkNet component is simulatenoutsly assessed using the following as a dependent measure: Core Strategies (level of exposure to key instructional strategies), reported Approach to Teaching, the perceived influence QuarkNet has had on teaching in the classroom, reported Student Engagement of their students (as assessed by teachers), the influence of QuarkNet on this reported Student Engagement, and Long-term Outcomes.

The results of these analyses are summarized in Table 24. (Table 25 provides the statistical details including means, standard deviations, number of teachers included in each analysis and reported statistical significance levels.) *These analyses suggest that Data Camp and Variety of Workshops each contribute to teachers' reported engagement in Core Strategies, and that each major program component of QuarkNet contributes uniquely to at least one or more outcome measures: Approach to Teaching; QuarkNet's*

Table 22
Items Used to Form Scale Scores

Scale	Survey Instructions	Individual Items
Core Strategies[a]	*Please rate the following strategies based on your current QuarkNet program experience and, if applicable, on your previous involvement in Quark-Net programs to date. If you have participated in QuarkNet for many years, please respond based on what you think the cumulative effect of this participation has been over the past two years.*	**Exposure to QuarkNet Strategies** *QuarkNet provides opportunities for me to:* 21a. Engage as an active learner as a student. b. Do science the way scientists do science. c. Engage in authentic particle physics investigations. d. Engage in authentic data analysis experiments using large data sets. e. Develop explanations of particle physics content. f. Discuss the concept of uncertainty in particle physics. *QuarkNet provides opportunities for me to:* 22a. Engage in project-based learning that models guided-inquiry strategies. b. Share ideas related to content and pedagogy. c. Review and select particle physics examples from the Data Activities Portfolio instructional materials. d. Use the pathways, suggested by the Data Activities Portfolio, to help design classroom instructional plan(s). e. Construct classroom implementation plan(s) incorporating experience(s) and Data Activities Portfolio instructional materials. f. Become aware of resources beyond my classroom.
Approach to Teaching[b]	*In thinking about your approach to teaching, please rate the frequency in which you engage in each of the following in your classroom.*	**Approach to Teaching Outcomes** 27a. Discuss and explain concepts in particle physics. b. Engage in scientific practices and discourse. c. Use physics examples including authentic data when teaching subjects such as momentum and energy. d. Review and use instructional materials from the Data Activities Portfolio. e. Selecting these lessons guided by the suggested pathways. f. Facilitate student investigations that incorporate scientific practices. 29a. Use active guided-inquiry instructional practices that align with science practices standards (NGSS and other standards). b. Use instructional practices that model scientific research. c. Illustrate how scientists make discoveries. d. Demonstrate how to use, analyze and interpret authentic data. e. Demonstrate how to draw conclusions based on these data. f. Become more comfortable teaching inquiry-based science.

[a] Response categories: 1= Poor, 2 = Fair, 3= Average, 4 = Good, and 5= Excellent.
[b] Response categories: 5= Almost Always, 4 = Very Often, 3= Sometimes, 2= Not Very Often, and 1= Rarely

Table 22 (con't.)
Items Used to Form Scale Scores

Scale	Survey Instructions	Individual Items
QuarkNet's Influence on Teaching[c]	*Now, indicate the degree to which you think QuarkNet has contributed to your implementation of these instructional strategies in your classroom.*	**QuarkNet's Influence on Teaching** 28a. Discuss and explain concepts in particle physics. b. Engage in scientific practices and discourse. c. Use physics examples including authentic data when teaching subjects such as momentum and energy. d. Review and use instructional materials from the Data Activities Portfolio. e. Selecting these lessons guided by the suggested pathways. f. Facilitate student investigations that incorporate scientific practices. 30a. Use active guided-inquiry instructional practices that align with science practices standards (NGSS and other standards). b. Use instructional practices that model scientific research. c. Illustrate how scientists make discoveries. d. Demonstrate how to use, analyze and interpret authentic data. e. Demonstrate how to draw conclusions based on these data. f. Become more comfortable teaching inquiry-based science.
Student Engagement[d]	*This last set of questions asks about your students' classroom engagement and how QuarkNet may have influenced (through your participation and/or your students) this engagement. In your judgment, please indicate ...*	**Student Engagement (***My students are able to …***)** 32a. Discuss and explain concepts in particle physics. b. Discuss and explain how scientists develop knowledge. c. Engage in scientific practices and discourse. d. Use, analyze and interpret authentic data. e. Draw conclusions based on these data.
QuarkNet's Influence on Student Engagement[e]	*Now, indicate the degree to which QuarkNet (either because of your participation of theirs) have contributed to your students' engagement.*	**QuarkNet has helped my students to:** 33a. Discuss and explain concepts in particle physics. b. Discuss and explain how scientists develop knowledge. c. Engage in scientific practices and discourse. d. Use, analyze and interpret authentic data. e. Draw conclusions based on these data.
Long-term Outcomes: Teachers[f]	*Please respond to the following statements.*	**Long-term Outcomes: Teachers** 31a. I use resources (including QuarkNet resources) to supplement my knowledge and instructional materials and practices. b. I have increased my science proficiency. c. I have developed collegial relationships with scientists and other teachers. d. I think my students have become more comfortable with inquiry-based science.

[c]Response categories: 5= Very High, 4 = High, 3= Moderate, 2 = Low, 1= Very Low)
[d]Response categories: 5= Almost Always, 4 = Very Often, 3= Sometimes, 2= Not Very Often, and 1= Rarely.
[e]Response categories: 5= Very High, 4 = High, 3= Moderate, 2= Not Very Often, and 1= Rarely.
[f]Response categories: 5 = Strongly Agree, 4 = Agree, 3 =Neutral, 2 = Disagree, and 1 = Strongly Disagree.

Table 23
Summary of Scale Development and Supportive Statistics

Scale	What's Measured	# of Items	N	Mean	Standard Deviation	Cronbach's Alpha
Core Strategies	Teachers' perceived exposure to program core strategies articulated in PTM	12	574	53.94	6.96	**0.85**
Approach to Teaching	Perceived assessment of QN teacher outcomes	12	528	42.24	8.66	**0.87**
QN's Influence on Teaching	Perceived assessment of how QN has influenced teaching practices and content	12	470	47.41	10.36	**0.93**
Student Engagement (SE)	Teachers' perceptions of student engagement in their classroom	5	498	18.17	3.72	**0.83**
QN's Influence on SE	How QN has influenced this student *engagement*	5	415	18.98	5.16	**0.94**
Long-term Outcomes: Teachers	Teachers' perceptions related to long-term behaviors such as: use resources as supple-ments; increase science proficiency; develop collegial relationships; and students more comfortable with inquiry-based science.	4	531	17.45	2.49	**0.81**

[a]Measure of reliability (internal consistency). (Factor analyses suggest one factor solutions for each.) This summary is based on 2019-202e Full Teacher Survey responses. Note. The smaller mean values for student engagement (SE), QN"s Influence on SE, and Long-term Teacher Outcomes are due to the smaller number of items that comprise each of these scales.

Influence on Teaching, Student Engagement (as reported by teachers), QuarkNet's Influence on Student Engagement; and Long-term Teacher Outcomes. Thus, these analyses suggest that each of the major components of QuarkNet contribute *uniquely* to outcomes as measured.

These analyses, although encouraging, are limited in that each *does not* take into consideration that teachers are nested within their individual QuarkNet center. To be shown shortly, centers contribute significantly to QuarkNet's reported impact.

Table 24
Analyses Comparing Individual QuarkNet Components:
Unique Contributions of Each

<table>
<tr><th>QuarkNet Program Component</th><th>Statistical Results</th><th>Other Relationships</th><th>Long-term Teachers: Outcomes</th></tr>
<tr><td>Data Camp</td><td>Data Camp experience was shown to be statistically significantly related to higher Core Strategies[a] scores and Approach to Teaching scores (on average) by participating teachers.</td><td>Workshop experience was also statistically significantly related to higher Approach to Teaching scores (on average).</td><td rowspan="3">All QuarkNet components Data Camp, Variety of Workshops, and Masterclass participation were statistically significantly related to higher Long-term Teacher Outcomes[a] scores (on average).</td></tr>
<tr><td>Variety of Workshops</td><td>Participation in workshops (two or more) as reported by teachers was statistically significantly related to higher scores (on average) for Core Strategies,[a] Approach to Teaching, QN's Influence on Teaching,[a] and Student Engagement.</td><td>Higher Student Engagement scores (on average) were also statistically significantly related to teachers' participation in Masterclass.</td></tr>
<tr><td>Masterclass</td><td>Participation in Masterclasses (one or more) as reported by teachers was statistically significantly related to Student Engagement, and QN's Influence on Student Engagement scores.</td><td>Higher Student Engagement scores were also statistically significantly related to reported workshop participation.</td></tr>
</table>

Note: This table summarizes the results of a series of ANOVA analyses where each of the listed QuarkNet program components are treated simultaneously as independent variables, and where in separate analyses Core Strategies, Approach to Teaching; QN's Influence on Teaching, Student Engagement, QN's Influence on Student Engagement, and Long-term Teacher Outcomes scores each is treated as the dependent variable. Long-term outcomes include survey items that address: 1. Use resources as supplements. 2. Increased science proficiency; 3. Develop collegial relationships; and 4. Students are more comfortable with inquiry-based sciences. [a]Unequal variance was noted as well.
Based on scale scores created from survey responses from 2019 through 2023 program years.

Table 25
Summary of Analyses: Unique Contribution of Each Major QuarkNet Program Component

	Program Exposure and Teacher and Student Outcomes																	
QN Program Component	Core Strategies[a] (A)			Approach to Teaching[b] (B)			QN's Influence on Teaching[c] (C)			Student Engagement[d] (D)			QN's Influence on Student Engagement[e] (E)			Long-term Oucomes[f] (F)		
	Score Range 12-60			Score Range 12-60			Score Range 12-60			Score Range 5-25			Score Range 5-25			Score Range 4-20		
Data Camp																		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
No	**52.27**	**7.44**	**377**	**40.76**	**8.74**	**339**	46.54	10.98	284	17.65	3.77	311	19.16	4.30	228	**17.07**	**2.62**	**339**
Yes	**55.24**	**5.75**	**197**	**44.88**	**7.89**	**189**	48.74	9.20	186	19.03	3.49	187	19.93	3.92	176	**18.13**	**2.09**	**192**
Variety of Workshops																		
No	**52.27**	**8.09**	**257**	**40.45**	**8.60**	**231**	**45.19**	**11.70**	**195**	**17.56**	**3.53**	**212**	18.95	4.32	153	**16.99**	**2.77**	**231**
One Workshop	**54.70**	**5.88**	**162**	**41.80**	**9.09**	**147**	**47.80**	**10.20**	**126**	**17.57**	**4.25**	**136**	19.30	4.32	111	**17.37**	**2.50**	**146**
Two or More	**55.94**	**5.12**	**155**	**45.43**	**7.42**	**150**	**49.98**	**7.71**	**149**	**19.57**	**3.09**	**150**	20.24	3.73	140	**18.83**	**1.76**	**154**
Masterclasses																		
No	53.25	7.35	396	41.13	8.91	357	46.40	11.22	303	**17.59**	**3.79**	**330**	**18.86**	**4.37**	**244**	**17.03**	**2.59**	**356**
One or More	55.49	5.73	178	44.55	7.66	171	49.24	8.31	167	**19.30**	**3.33**	**168**	**20.45**	**3.60**	**160**	**18.31**	**2.03**	**175**

Note: This table summarizes the results of a series of ANOVA analyses where each of the listed QuarkNet program components are treated *simultaneously* as independent variables; where in separate analyses Core Strategies, Approach to Teaching; QN's Influence on Teaching, Student Engagement, QN's Influence on Student Engagement and Long-term Outcomes each is treated as the dependent variable. **Bold face comparisons (and shaded) reflect statistically significant findings**. Student Engagement/QN Influence on Student Engagement and Long-term Outcomes measured on a different scale. [For columns A-C, range of scores is 12 to 60; for columns D and E the range of scores is 5 to 25; and the range of possible scores for column F is 4 to 20.] Includes survey responses from 2019-2023.

[a]**Core Strategies**
When an Analysis of Variance (ANOVA) analysis was conducted with Data Camp, Variety of Workshops, and Masterclass simultaneously analyzed with Core Strategies as the dependent variable, with unequal variance based on Levene's Test [$F_{(11, 562)} = 5.15$, $p < .001$], Data Camp [$F_{(1, 562)} = 4.12$, $p < .05$] and the experience of two or more workshops was statistically related to higher Core Strategies scores [$F_{(2, 567)} = 4.75$, $p < .001$].

[b]**Approach to Teaching**
When an Analysis of Variance (ANOVA) analysis was conducted with Data Camp, Variety of Workshops, and Masterclass simultaneously analyzed with Approach to Teaching as the dependent variable, Data Camp [$F_{(1, 516)} = 11.19.47$, $p < .001$] and the experience of two or more workshops [$F_{(2, 516)} = 7.89$, $p < .0013$].were statistically related to higher Approach to Teaching scores.

[c]**QN's Influence on Teaching**
When an Analysis of Variance (ANOVA) analysis was conducted with Data Camp, Variety of Workshops, and Masterclass simultaneously analyzed with QN's Influence on Teaching as the dependent variable, with unequal variance based on Levene's Test [$F_{(11, 458)} = 3.50$, $p < .001$], the experience of two or more workshop was statistically related to higher QN's Influence on Teaching [$F_{(2, 458)} = 4.85$, $p < .01$].

[d]**Student Engagement**
When an Analysis of Variance (ANOVA) analysis was conducted with Data Camp, Variety of Workshops, and Masterclass simultaneously analyzed with Student Engagement as the dependent variable, the experience of two or more workshops [$F_{(2, 486)} = 7.81$, $p < .001$] , and the experience of Masterclass (one or more) [$F_{(1, 486)} = 7.91$, $p < .01$] were statistically related to higher Student Engagement scores.

[e]**QN's Influence on Student Engagement**
When an Analysis of Variance (ANOVA) analysis was conducted with Data Camp, Variety of Workshops, and Masterclass simultaneously analyzed with QN's Influence on Student Engagement as the dependent variable the experience of Masterclass (one or more) [$F_{(1, 392)} = 8.26$, $p < .01$] was statistically related to higher QN's Influence on Student Engagement scores.

[f]**Long-term Outcomes**
When an Analysis of Variance (ANOVA) analysis was conducted with Data Camp, Variety of Workshops, and Masterclass simultaneously analyzed with Long-term Outcomes as the dependent variable, with unequal variance based on Levene's Test [$F_{(11, 519)} = 4.53$, $p < .001$, Data Camp [$F_{(1, 519)} = 9.34$, $p < .01$], the experience of two or more workshops [$F_{(2, 519)} = 3.8$, $p < .03$], and the experience of Masterclass [$F_{(1, 519)} = 9.84$, $p < .01$] were statistically related to higher Long-term Outcomes scores.

How QuarkNet Engagement is Related to Approach to Teaching: QuarkNet Centers *Matter*

In the main, and already stated, teachers participate in QuarkNet through their local center. Thus, statistically it is plausible and likely that center-related variance is systematic and not random (that is, not independent as required in a simple multiple regression analysis or in the ANOVA analyses just highlighted). Or said in another way, it is likely that teachers within a given center are more like other teachers within that center than compared to other QuarkNet teacher who participate in the program at other centers; at least in terms of how we measure their exposure to the program and outcomes.

In these analyses, Core Strategies scores are used as a surrogate measure for the type and level of QuarkNet program engagement. The relationship between participation in individual QuarkNet components and the measurement of Core Strategies is shown in Figure 9.

Several statistical steps were necessary before we could explore the influence that individual centers contribute to teacher-level, student-level and long-term outcomes and specifically teacher-level outcomes which are discussed in this section. First to meet analysis requirements, only centers where at least 10 teachers (who engaged in QuarkNet and who responded to the full Teacher Survey) were included in the analysis. This sampling requirement resulted in the inclusion of 26 centers (34 combined centers); this represents nearly two-thirds of participating centers. Data from a total of 504 teachers were potentially eligible for analysis inclusion, representing slightly more than 80% of participating teachers who completed their surveys. In practice, however, the number of teachers included in these analyses reduced to about two-thirds of the teacher data that we have in order to meet full data-set requirements.

A hierarchical linear regression analysis based on these 26 centers (34 combined) explored the relationship between core program strategies, perceived influence QuarkNet has had on classroom teaching practices and implemented instructional practices (Approach to Teaching). The results of this analysis are modeled in Figure 10 where QuarkNet's Influence on Teaching, Core Strategies and Centers (as measured by mean Approach to Teaching Scores) are shown to be positively related to teacher use of content and instructional practices in their classrooms (i.e., Approach to Teaching). As indicated, these results are statistically significant [$F_{(3, 388)} = 73.85$, $p < .001$]. Figure 11 shows details the survey items that comprise each of these scale scores.

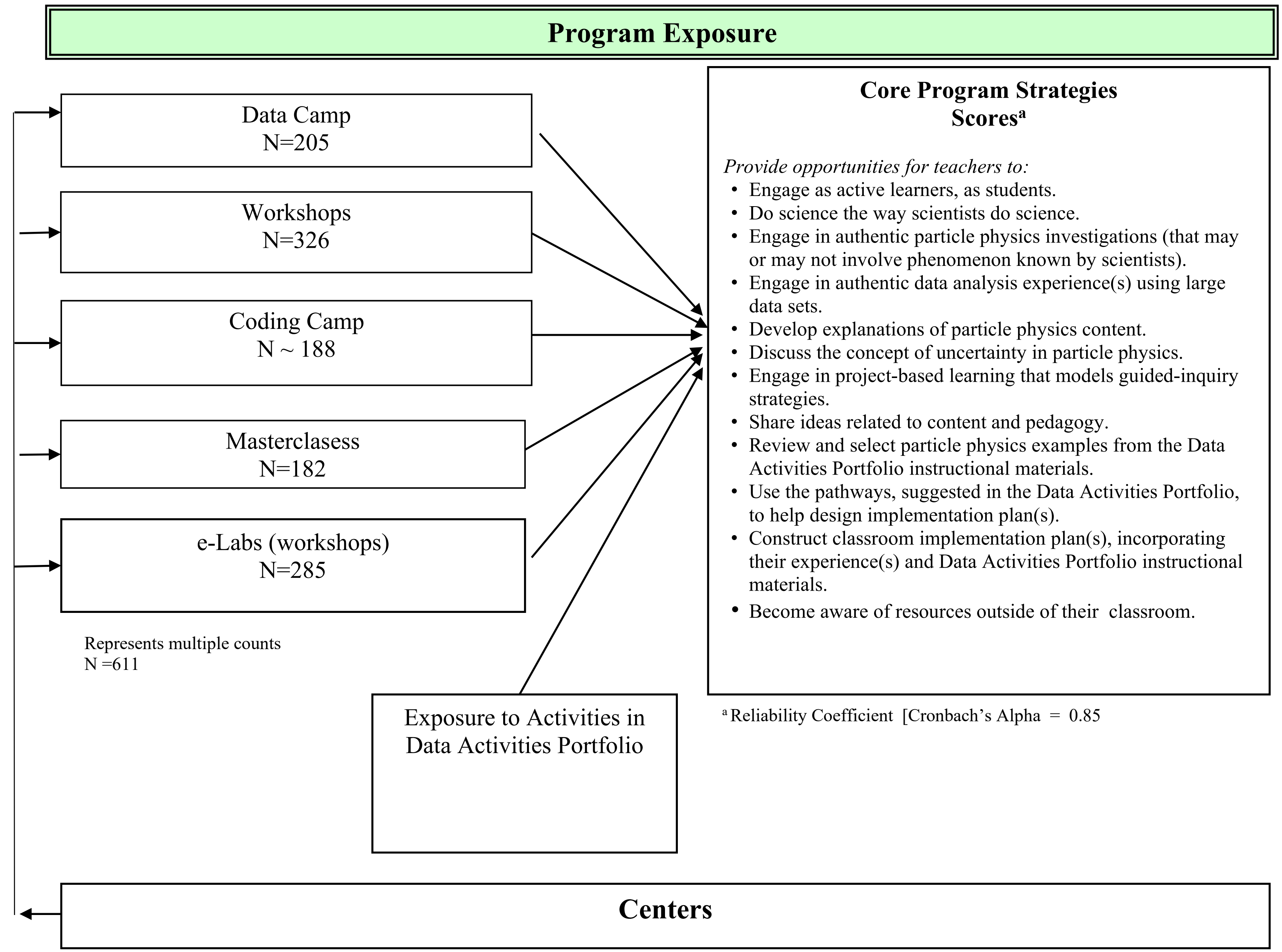
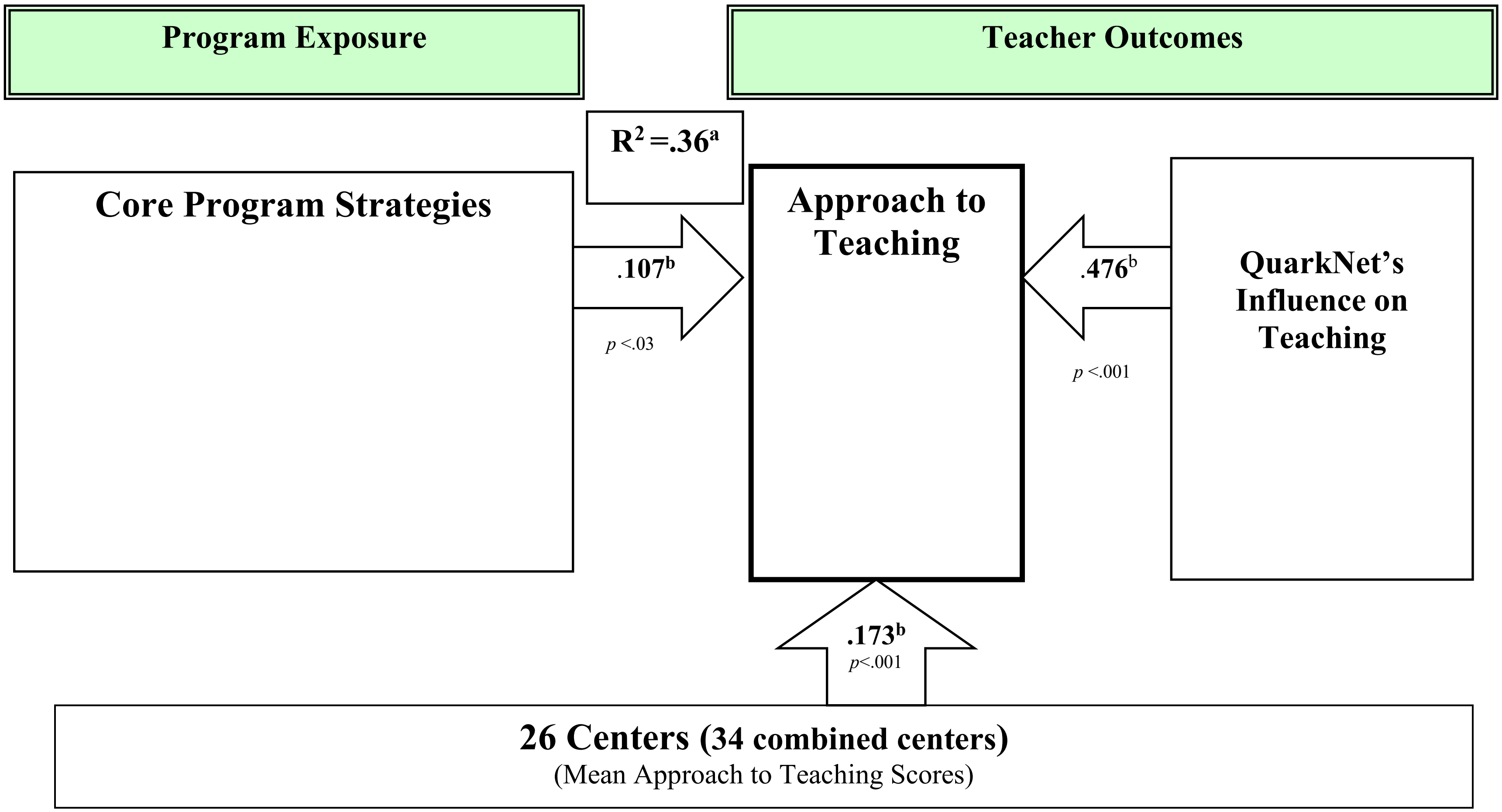


Figure 9. The relationship between engagement in QuarkNet program components and the measure of Core Strategies.



Reliability Coefficients:

Core Program Strategies	0.85
Approach to Teaching	0.87
QN's Influence on Teaching	0.93

$F_{(3, 388)} = 73.85$, $p < .001$

[a]Percent variance explained

[b]Standardized beta weights

Figure 10. The statistically positive relationship between exposure to Core Program Strategies, QuarkNet's Influence on Teacher, and Approach to Teaching as assessed using a hierarchical linear model.

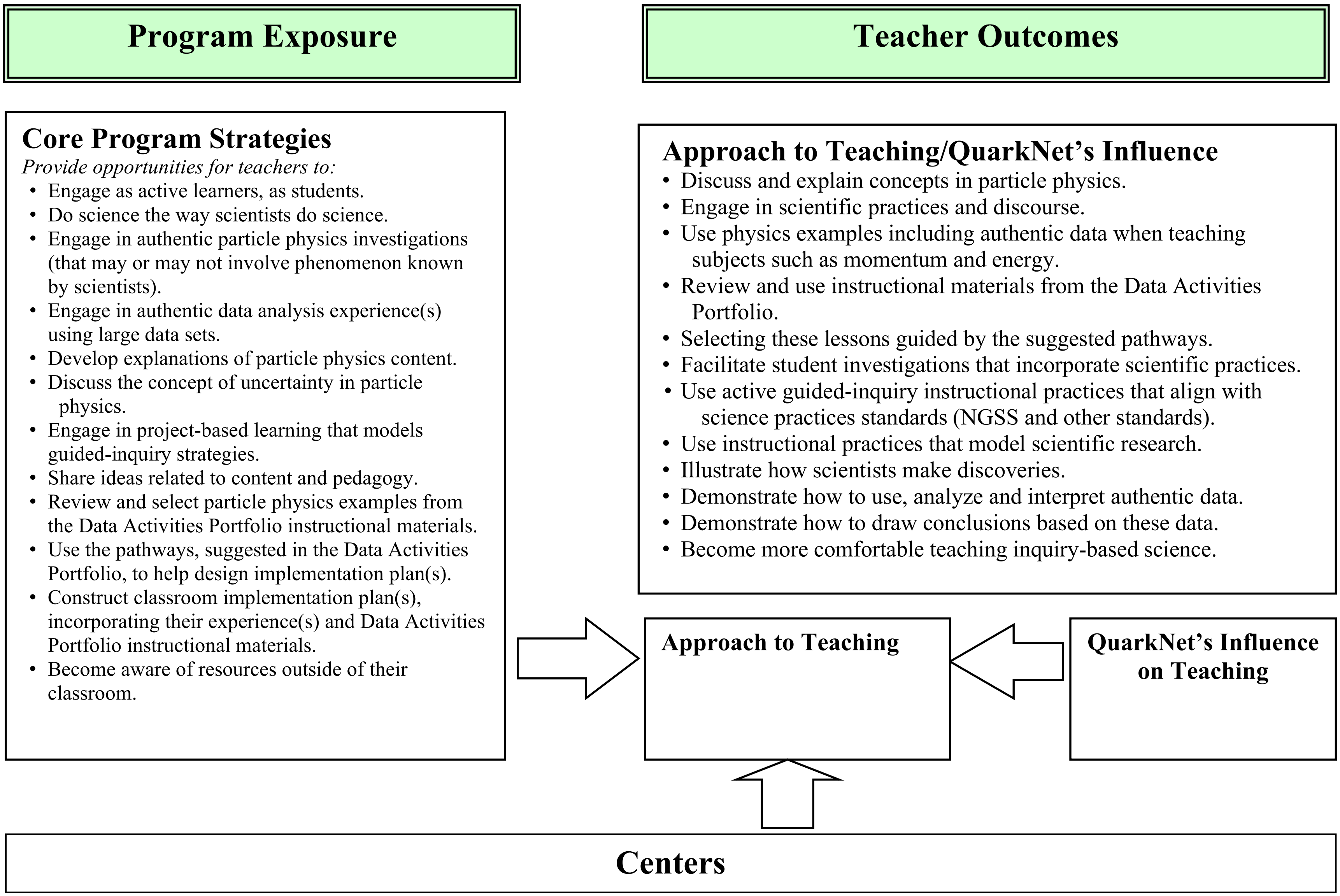


Figure 11. Survey items included in the measurement of Core Program Strategies scores, and Approach Teaching scores and perceived QuarkNet's Influence on Teaching scores.

To summarize, the weight of the evidence suggests that each QuarkNet component (i.e., Data Camp, Workshops and Masterclasses) contributes uniquely to one or more of the following: exposure to core strategies (program engagement), teacher outcomes, student outcomes, and long-term outcomes, where on average the more engagement by teachers (within each component) the higher the score of the outcome measure.

In turn, and of importance, exposure to core program strategies, which serves as a surrogate to program engagement, and the perceived influence QuarkNet have on teaching are positively and statistically related to teacher outcomes (Approach to Teaching scores). Accounting for the nesting of teachers by QuarkNet centers, these relationships are *systematically tied* to the Center in which the QuarkNet teachers engage in the program.

It is important to note that the results of the hierarchical analysis on QuarkNet's engagement and Approach to Teaching have been relatively stable over these analyses that have been repeated over time (that is, as each program year provides additional data to include in these efforts). This consistency continues to build our confidence in using and interpreting these results to support the assessment of QuarkNet's outcomes.

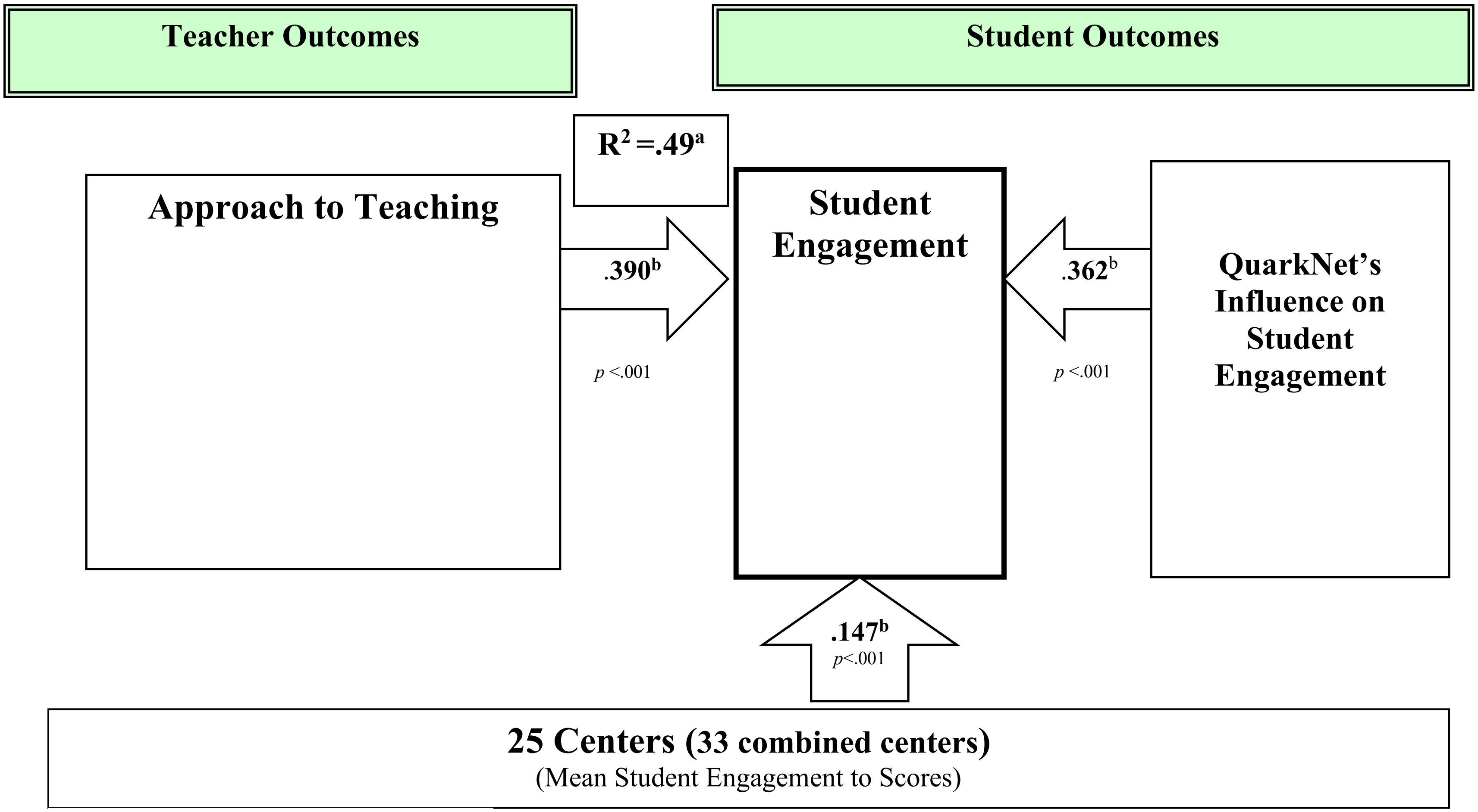
Student Engagement

How is QuarkNet related to Perceived Student Engagement?

In a similar vein, we look at the relationship between the teachers' perceptions of student engagement in the context of exposure to the program (Core Strategies), classroom implementation (Approach to Teaching scores) and the perceived influence of QuarkNet on Student Engagement. And again, we have used a hierarchical linear regression model to account for the nesting of teachers within QuarkNet Centers.

Similarly, this hierarchical linear regression analysis was based on 25 center (33 centers) as done in the previous analysis (one center was dropped because of insufficient data related to student engagement questions). The results of this analyses are modeled in Figure 12 where QuarkNet's Influence on Student Engagement, Approach to Teaching and Centers (as measured by mean Student Engagement scores) have on this Student Engagement. As indicated, these results are statistically significant [$F_{(3, 329)} = 106.53$, $p < .001$]. Figure 13 shows this relationship detailing the survey items that comprise each of these scale scores.

It should be noted that efforts to model QuarkNet's impact on student engagement continues to produce results that vary considerably. Thus, a consistent and stable model to model QuarkNet's effect on student engagement remains elusive even with new data added into the mix. This is not to say that these relationships are not important but to suggest that these results have fluctuated over time; results that are difficult to explain.



Reliability Coefficients:	
Approach to Teaching	0.87
Student Engagement (SE)	0.83
QN's Influence on SE	0.94

$F_{(3, 329)} = 106.53$, $p < .001$
[a]Percent variance explained
[b]Standardized beta weights

Figure 12 The statistically positive relationship between Approach to Teaching, QuarkNet's Influence on Student Engagement and Student Engagement as assessed using a hierarchical linear model.

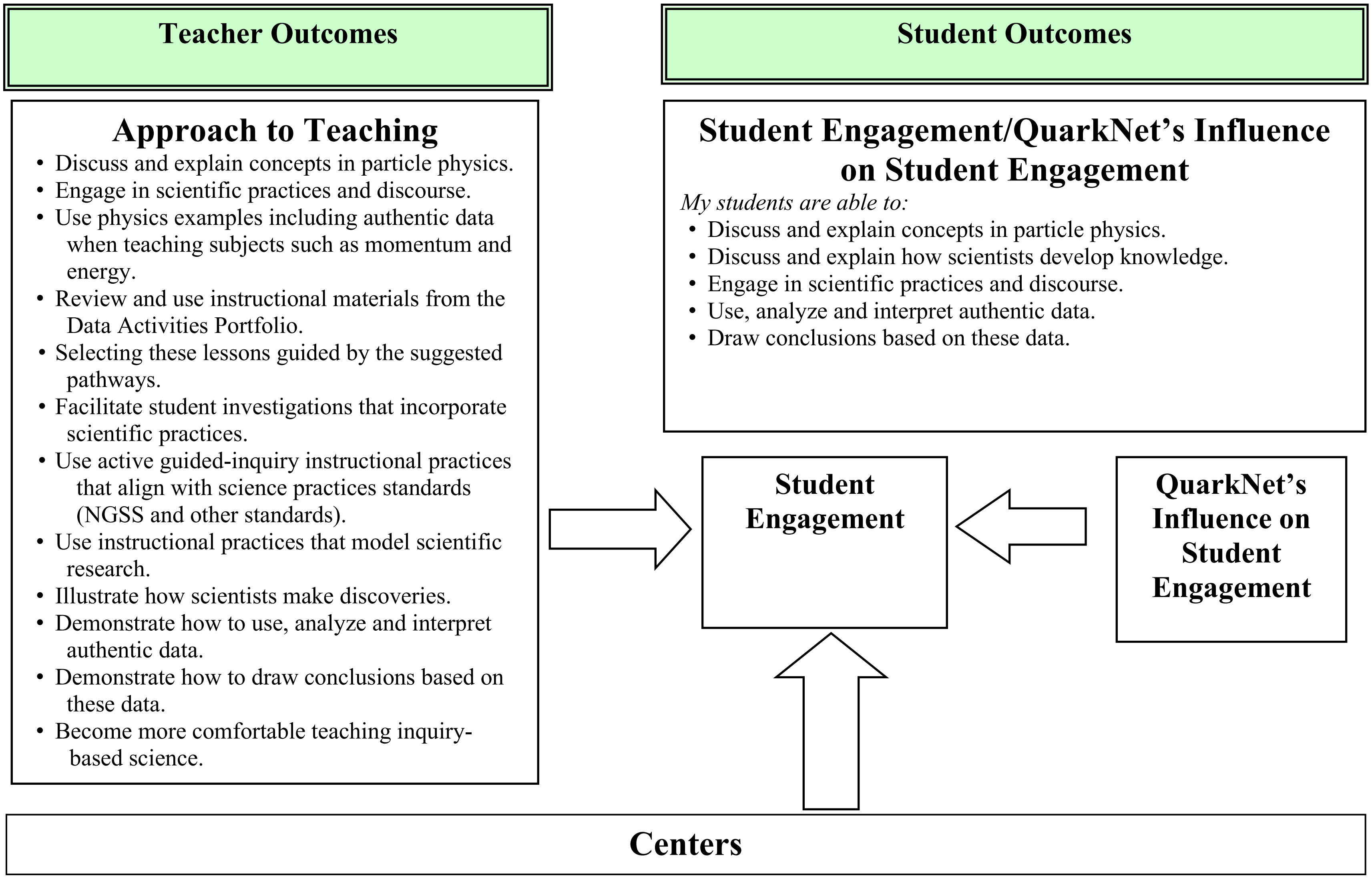


Figure 13. Survey items included in the measurement of Approach to Teaching scores, QuarkNet's Influence on Student Engagement scores and Student Engagement scores as assessed using a hierarchical linear model.

Long-term Outcomes: Teachers

Newer to these analyses is the measurement of long-term outcomes by participating QuarkNet teachers. The positive relationship between QuarkNet and long-term outcomes of teachers is shown in Figure 14. That is, perceived QuarkNet's Influence on Teaching, Student Engagement and Center-level mean scores are positively and statistically related to Long-term Outcomes: Teachers [$F_{(4, 306)} = 48.42$, $p < .001$].

Summarizing Results from Quantitative Analyses

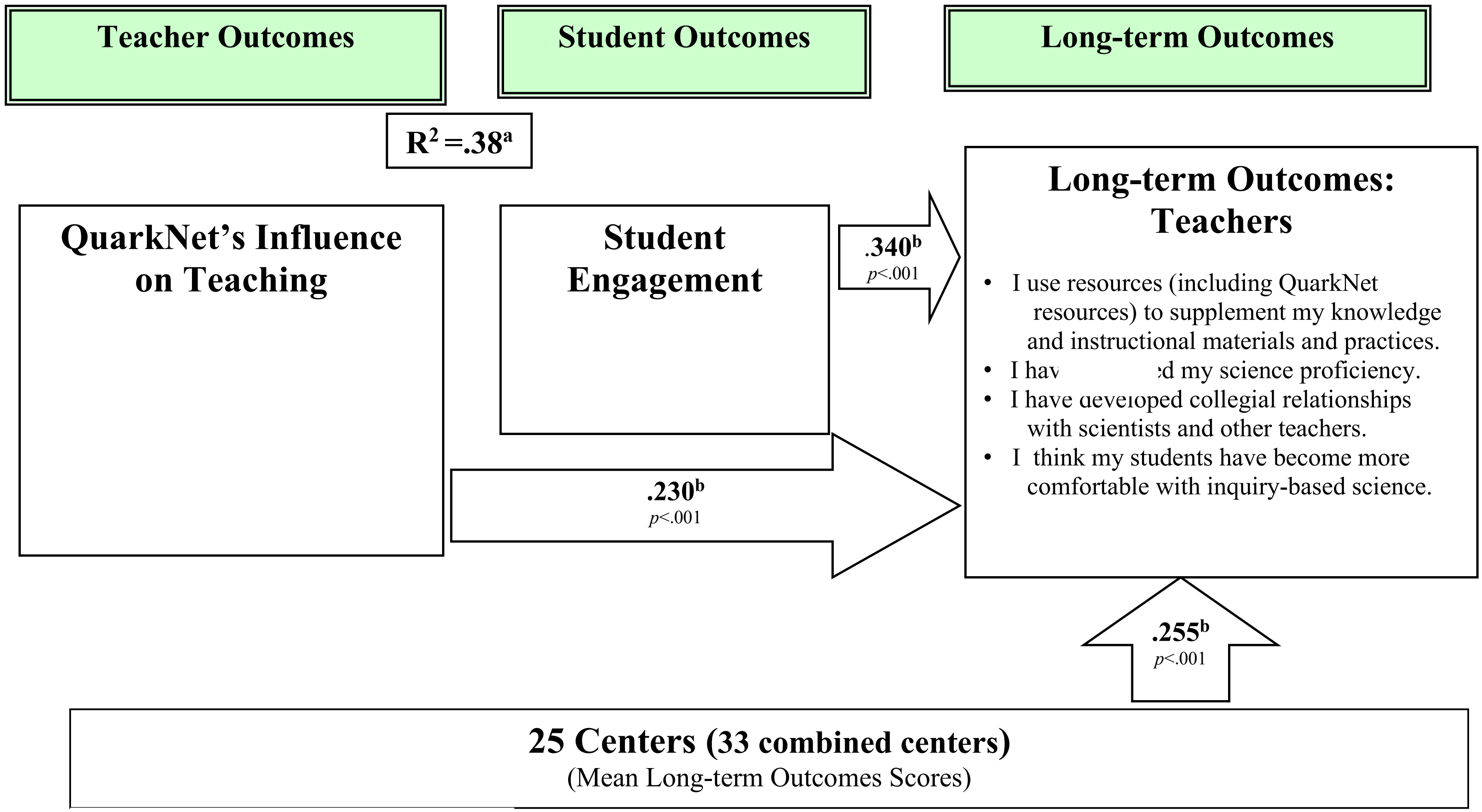
In quantitative analyses, we have used sets of survey item responses to form scale scores that measure exposure to QuarkNet, as well as teacher-, student- and long-term outcomes. Statistical analyses support the reliability (i.e., internal consistency) and use of these scales where the higher the score the more positive the assessment. These scales are: Core Strategies, Approach to Teaching, QuarkNet's Influence on Teaching, Student Engagement ment, QuarkNet's Influence on Student Engagement, and Long-term Outcomes: Teachers.

At the behest of NSF, we have conducted a series of simultaneous analyses (i.e., 2x3x2 ANOVA analyses) where the effects of engagement in Data Camp, (Variety of) Workshops and MasterClass are assessed by exposure to Core Strategies, Approach to Teaching, QuarkNet's Influence of Teaching, Student Engagement, QuarkNet's Influence on Student Engagement, and Long-term Outcomes: Teachers (each a dependent measure).

These analyses suggest that Data Camp and (Variety of) Workshops each contribute to teachers' reported engagement in Core Strategies while participating in QuarkNet, and that each major program component of QuarkNet contributes uniquely to at least one or more outcome measures: Approach to Teaching; QuarkNet's Influence on Teaching, Student Engagement (as reported by teachers), QuarkNet's Influence on Student Engagement; and Long-term Teacher Outcomes. Thus, these analyses suggest that each of the major components of QuarkNet contribute *uniquely* to outcomes as measured.

These analyses are limited, however, in that each *does not* take into consideration that teachers are nested within their individual QuarkNet center.

A series of hierarchical linear regression analyses were conducted to account for this nesting. Data from 26 (34 combined) centers were included in these analyses and program engagement was captured by using Core Strategies scores as a surrogate measure. Results suggest that exposure to core program strategies and the perceived influence of QuarkNet on teaching are positively and statistically related to teacher outcomes (Approach to Teaching scores). And these relationships are *systematically tied* to the Center in which the QuarkNet teachers engaged in the program. Student engagement was shown to be positively and statistically related to QuarkNet's Influence on Student Engagement, Approach to Teaching and Centers (as measured by mean Student Engagement scores) (with noted caveats). Long-term outcomes were positively and statistically related to perceived QuarkNet's Influence on Teaching, Student Engagement and Center-level means. Of importance, the Center in which the teachers engage in QuarkNet *matters.*



Reliability Coefficients:

QN's Influence on Teaching	0.87
Student Engagement (SE)	0.83
Long-term Outcomes	0.81

$F_{(4, 306)} = 48.42$, $p < .001$
[a]Percent variance explained
[b]Standardized beta weights

Figure 14. The statistically positive relationship between QuarkNet's Influence on Approach to Teaching, Student Engagement and Long-term Outcomes as assessed using a hierarchical linear model.

Classroom Implementation:
A Narrative Picture of QuarkNet's Influence

To support these quantitative analyses, we have conducted qualitative analyses highlighting information from these same 26 (34 combined centers). To this end, we have used three sources of information; these are:

- Reponses to open-ended questions from the update teacher survey (summarized in a table)
- Implementation plans posted by QuarkNet teachers (and examples of teacher work) (when available)
- Examples of student work including posters and presentations (when available)

Information from each of these sources are highlighted in what we refer to as center-level portfolios. This evaluation approach is consistent with the use of *authentic assessment* as a means to evaluate performance, "teaching for understanding and application rather than for rote recall" (Darling-Hammond & Snyder, 2000, p. 523).

Each center-level portfolio starts with a table that summarizes responses from teachers as to examples of ways in which QuarkNet content and materials have been (or planned to be) used in their classrooms. Each row in the table represents the responses to open-ended questions from the same teacher over time. Thus, we start with the original responses to the first time a teacher completes his/her full teacher and then track their responses from the update survey. We focus on answers to the three open-ended questions in the update survey; these questions are:

- *Briefly describe how you intend to incorporate (or have incorporated) your QuarkNet experiences into your classroom (e.g., Cosmic Ray, LHC, neutrinos, e-labs; masterclass) when teaching, for example, conservation laws, uncertainty, the standard model or something else.*
- *Which activities from the Data Activities Portfolio have you used (or will use) in your classroom? (Please list up to three activities. If you don't plan or haven't used these activities, please provide a short explanation as to why not.)*
- *What else would you like to tell us about your QuarkNet experience as you reflect on applications in your classroom?*

Because these are responses to open-ended questions, teachers are free (and encouraged) to provide information that he or she thinks most relevant.

In keeping with Darling-Hammond, Hyler and Gardner (2017), a characteristic of effective professional development is a program of sustained duration, providing "multiple opportunities for teachers to engage in learning around a single set of concepts or practices; that is rigorous and cumulative" (Darling-Hammond, et al., 2017, p. 15). As such, the table summarizes responses by teachers over the course of several program years and likely several QuarkNet programs and/or events in support professional development of a sustained duration.

In the table, if a particular box is blank, it likely means that a teacher did not participate in an event for that program year or skipped the question (or the center may not have had a major event that year). The table provides the essence of these responses; a given response, as presented, may be a direct quote, a paraphrase, or lightly edited; the intent is to convey the overall idea or its essence from that particular teacher.

The remainder of a center-based portfolio highlights examples of teacher implementation plans that are shared and posted on the QuarkNet website and examples of student work (examples within the classroom and beyond) when this information is available.

Although we have generated a portfolio for 26 (34 combined) centers we highlight examples for just three of these centers in the narrative of this report. We are in discussion with QuarkNet staff to determine how and in what ways we may share these portfolios with participating centers (e.g., posting on center-specific webpages).

Johns Hopkins University. Table 26 is an excerpt from the full summary table on responses from teachers who participate in QuarkNet at the Johns Hopskins Center. In review of these responses, teacher have reported a variety of ways in which QuarkNet content and materials have been used in their classrooms (or planned to be). Sometimes these responses indicate a progression of use from little to specific implementation. For example, in the second row, a teacher in 2019 indicated *I have not had the opportunity* .... in contrast to responses proffered in later years, where specific examples are given such as *plan on using spectral analysis activities*, *Mass of Pennies, What Heisenberg Knew* (reported in 2021), and a *Millikan experiment using histograms* (reported in 2022 and 2023).

Table 27 provides an example of one of the coding/implementation plans proffered by one QuarkNet teacher at the Johns Hopkins Center.

The complete table and several examples of posted implementation plans by teachers from the Johns Hopkins QuarkNet Center compiled in a center-level portfolio are shown in Appendix L.

Table 26
Self-reported Use of Data Activities Portfolio Activities: Based on Responses from the Full Survey and then Responses from the Update Survey in Subsequent Years **Johns Hopkins University**

Center	Program Year (Year of Full Survey)	Subsequent Program Year	Subsequent Program Year	Subsequent Program Year	Subsequent Program Year
Johns Hopkins University	2019	2020	2021	2022	2023
	Rolling with Rutherford. It's the most approachable, with a small amount of prep for students.	I am going to consider new physics principles, such as pulsars and microwave telescopes. Example: Rolling with Rutherford	I will use some of the new cosmology lessons with my Astronomy class. I teach them about the Big Bang, black body radiation and the HR diagram. I will use DAP activities as well as conservation tools. Examples: Signal and noise 1, signal and noise 2, and histograms. Rolling with Rutherford		Rolling with Rutherford is great - we gather data together as a class and analyze the results. QuarkNet has been a wonderful experience and a source of many high-quality lessons and activities. They have benefited my students greatly over the years.
	I have not had the opportunity to really share with other teachers and, unfortunately, in today's test happy society, it is difficult to fit these topics into class and to convince others to fit them into class.		I plan on using the spectral analysis activities we were working on this past week into my ninth-grade physics course. Examples: Mass of the pennies; What Heisenberg knew; CMS masterclass.	When teaching forces, I have a unit on the fundamental forces of nature where I present and the students explore the standard model and the reason why we have Fermilab and the LHC. The first lab is based on the Millikan experiment using histograms and searching for patterns.	Millikan experiment developing histograms. The projects based leaning with an inquiry approach drives my classroom instruction.
	Top Quark mass	I plan to teach a unit on particle physics using activities from the data portfolio and the cosmic ray detector in my classroom. Examples: Top quark mass, mean lifetime, shuffling the particle deck	I teach particle physics and astrophysics/ cosmology in my Physics course. I will use many of the activities we worked on this week including from the Data Portfolio and new activities developed at JHU. Examples: Top Quark Mass, Hidden Neutrino, Particle Transformations	I teach a unit on quantum physics including particle physics. This includes the standard model and activities from the data activities portfolio. Examples: Top quark mass, Hidden Neutrino, Quark workbench.	Top quark mass, Rolling with Rutherford, Histograms These activities allow students to explore particle physics concepts using physics they are learning in introductory courses.
	The I2U2 site examples, specifically modern physics puzzle	1. Use of the materials in classroom is great: The subparticle puzzle to start modern physics 2. Masterclass involvement and implementation 3. Standard model discussions, etc. Examples: 1. Quark puzzle/map involving learning color charge, bosons, etc. 2. Penny/coin activity	I have used a significant number of resources involving the QuarkNet workbench, some investigations and more. Overall, my last 10+ years at QuarkNet have really increased my knowledge of certain areas. Examples: The quark workbench, masterclass, J psi (occasionally)	I intend to use my QuarkNet experiences in my own modern physics unit with all physics classes as well as having my Science National Honor Society students to listen to some of the speakers who come to our high school. Examples: The Quark Puzzle, Z mass activities, missing momentum, etc.	Quark puzzle workbench and the mass of the top quark

Table 27

Johns Hopkins University Summer Workshop July 23-28 Implementation Plans/Coding Projects

<table>
<tr><th>Plan #</th><th>Title</th><th>Brief Description</th><th>Implementation Plan</th></tr>
<tr>
<td>1</td>
<td>Spring Mass</td>
<td>Understand how masses behave on (vertical) springs as well as how to create and apply code to express this behavior.

Brief Summary: This is a modified Mass on a Spring JupyterLite notebook. The use of the Lite notebook is for educators whose students are not able to access normal Jupyter notebooks due to security/IT issues.

The Mass on a Spring has been modified for use in an AP Physics 1 and AP Physics C mechanics class. This will serve not as an introduction to the topic but instead is more of a culminating set of activities to incorporate coding with physics.</td>
<td>Mass On A Spring with JupyterLite

<table>
<tr><th>Topic</th><th>Comments</th></tr>
<tr><td>Intro to Physics, Kinematics and Projectile Motion</td><td>Possible use of the Graphing notebooks and/or the Falcon9 notebook to introduce coding with physics</td></tr>
<tr><td>All Basic Forces, Pulleys, Ramps</td><td>Possible use of Pulley notebook adjusted with ramp activities</td></tr>
<tr><td>Energy</td><td></td></tr>
<tr><td>Momentum</td><td>Use of QuarkNet workbench activities (Top Quark)</td></tr>
<tr><td>Rotation and Angular</td><td></td></tr>
<tr><td>Simple Harmonic Motion</td><td>Use of Spring code notebook as presented here</td></tr>
</table>

Spring Notebook Background:
This collaboration Spring notebook is serving as a summary experience for students that takes place near the end of the Simple Harmonic Motion topic. It is taking place as a mini coding activity for students to demonstrate competence of spring motion and the relationships governing the position of a spring mass. Furthermore, the coding aspects of the activity serve to help the student navigate the difficult parts of spring motion analysis.

The students will have access to a separate document they will use to answer the questions and paste their code analysis and results. I leave it to the reader to decide whether to have this as an individual project or a pair collaboration project.

Students are expected to be able to determine the spring constant of a basic vertical spring with mass on it through the analysis of a graph based on student created data. In addition, students will be able to graph the position of a mass on a spring as a function of several different variables, and be able to justify how changing a variable affects the positions outcome over time.

Spring Notebook Application:
Students will be introduced to the Spring notebook with at least 45 minutes in the period. A class wide conversation will introduce this notebook and the goals behind it, along with the importance of being able to represent the physics ideas involved through a coding approach. From there, students will be introduced to the actual task. From there, students have a number of built-in checks for students to come to the instructor that will serve as a way to judge student progress.</td>
</tr>
</table>

The Catholic University of America QuarkNet Center. Table 28 represents a page from the summary table of responses from participating teachers at Catholic University.

Tracking one teacher:

- *I have used the Mass of Pennies lab in chemistry previously for average mass determination. I have worked with something similar to the Mapping Magnetic Fields lab, but with electric fields and carbon paper*. (Reported in 2019)

- *Virtual Coding: From this activity, I want to pull in the coding-specific lesson design to my physics classes. I'd like to target on-level physics students with coding-based activities. Excited to use many of the histogram-related activities. I am also EXTREMELY excited to incorporate the STEP UP activities in my classroom and evangelize them to my department*. (Reported in 2022)

- *Coding will come up in a big way in my AP Physics C classes this year. I intend to implement them as a standard way to do data analysis throughout the school yar. I hope to incorporate QuarkNet particle physics activities near the end of the year in my Honors Physics class. I also hope to incorporate some cross-curricular with our art department or marker space to bring particle physics forward in our community. I hope to use the Energy, Momentum and Mass activity (hopefully the quantitative version) with my AP students in this year. As time allows, I intend to use one or more of it Making It Round the Bend both in AP Physics but also honors physics at the end of the year when we reach magnetism.* (Reported in 2023)

Examples of three implementation plans proposed by participating teachers is shown on the following pages (pp. 84-85 in Exhibit G) (Posted on the QuarkNet center's website in 2023). The full table and set of implementation plans from this QuarkNet center summarized in a center-level portfolio are shown in Appendix M.

University of Oklahoma/Oklahoma State QuarkNet Center. Similarly, Table 29 represents a page from the summary table of responses from participating teachers at Oklahoma State/University of Oklahoma QuarkNet Center. The full table and set of implementation plans from this QuarkNet center complied in a center-level portfolio are shown in Appendix N.

Table 28
Self-reported Use of Data Activities Portfolio Activities: Based on Responses from the Full Survey and then Responses from the Update Survey in Subsequent Years **Catholic University**

Center	Program Year (Year of Full Survey)	Subsequent Program Year	Subsequent Program Year	Subsequent Program Year	Subsequent Program Year
Catholic University	2019	2020	2021	2022	2023
	I have used the Mass of Pennies lab in chemistry previously for average mass determination. I have worked with something similar to the Mapping Magnetic Fields lab, but with electric fields and carbon paper.		Virtual Coding: From this activity, I want to pull in the coding-specific lesson design to my physics classes. I'd like to target on-level physics students with coding-based activities. Excited to use many of the histogram-related activities. I am also EXTREMELY excited to incorporate the STEP UP activities in my classroom and evangelize them to my department	Coding will come up in a big way in my AP Physics C classes this year. I intend to implement them as a standard way to do data analysis throughout the school yar. I hope to incorporate QuarkNet particle physics activities near the end of the year in my Honors Physics class. I also hope to incorporate some cross-curricular with our art department or marker space to bring particle physics forward in our community. I hope to use the Energy, Momentum and Mass activity (hopefully the quantitative version) with my AP students in this year. As time allows, I intend to use one or more of it Making It Round the Bend both in AP Physics but also honors physics at the end of the year when we reach magnetism.	Most recently the STEP UP Women in Physics activities were adapted for use in my physics classes. I have also used the Coding in Jupyter Notebooks to frame lesson design around coding implementation in Colab notebooks.

Center	Program Year (Year of Full Survey)	Subsequent Program Year	Subsequent Program Year 2023
	2021	2022	
	Classes have not yet begun, e-Labs and the data provided will be of great use; understanding detector construction will allow a more thorough explanation of function of iPad cosmic collection apps.	In discussion of em radiations during space unit (grade 6) and energy unit (grade 7). These factors play a role in the units previously discussed.	
	Mass of a penny; shuffling the particle deck; rolling with Rutherford.		
	None at present as this is my first year.		
	Data is continually updated and data from new experiments is uploaded regularly		Data bases for use in creating analytical graphs and histograms// select e-labs adapted to grade // Quark Net presentations on cosmic rays and cosmic ray detectors

CUA Lesson Implementation July 2023

Teacher #3

Standard Learning Goals	Assessments	Lesson/unit ideas
• Understand energy on Macroscopic as well as Atomic scale • Analyze momentum conservation • Data analysis by collecting data and graphing it • Make real world connections with particle physics	• Students will do some sort of data analysis from CERN data (I have heard it's available) • Perform muon detector lab (Cosmic watch lab, demonstrated by Ken) • Have students explore the activities from the QuarkNet website. (showed by Ken)	These activities will be incorporated in units of energy, energy and momentum conservation, graphing and data analysis!! Show videos on Standard Model in particle physics Share the QuarkNet experience, Jefferson lab presentation
If there's time … I would like to talk about the Mayan pyramids and how the secret chambers are detected via cosmic ray detectors to address CROSS-DISCIPLINARY SKILLS		Show videos, share presentations

Teacher #4

12th grade - Research Practicum - Physical Sciences
Student learning Goals:

- Develop an understanding of the Standard Model in general, Muons in the context of cosmic rays in particular (using video(s)) and of muon tomography (using pyramid example → annotated bibliography)
- Be able to present data graphically (scatter plots, histograms) and interpret graph
- Be able to describe and calculate the mean of a set of data
- Be able to describe and calculate the measures of the spread of data (variance, standard deviation)
- Be able to conduct and interpret hypothesis tests for two population means.

Assessment:
- Application to data collected during a Physics lab in the previous year
- Ongoing

Exhibit G. Implementation plan examples from participating teachers at The Catholic University of America QuarkNet Center.

Teacher #5

Level	Unit	Goal	QuarkNet-related Activity
sc6	Astronomy Meteorology Geologic Time	1) identify evidence the existence of extraterrestrial sources of energy 1) Explain why the thermosphere affects the ability of life to live on earth's surface !) Use a model of radioactive decay to date samples	• Use om Apple app- muon detector to demonstrate existence of cosmic rays • "cosmic compass" would be more accurate: experiment to determine angle of particle source • Use of cloud chamber to illustrate paths of charge particles • Use of QuarkNet resource:**https://www.i2u2.org/elab/cosmic/content/CosmicExtremes.pdf** • **Adaptation of QuarkNet lab https://www.i2u2.org/elab/cosmic/home/project.jsp** •
sc7	Energy Atoms Analysis of Data	1) Describe the effects of magnetic fields on matter 2) identify the properties of an atom's particles 3) using histograms to analyze data	• Introduction to particle detectors https://particleadventure.org/modern_detect.html • Demo- glass/plastic ornament with mystery objects inside-in zip lock baggie smashed against surface • Use of magnetic fields to control motion ○ Demo- static charges' effect on flowing water ○ Video: cathode-ray tubes (as in old TV) • Quark Net database for histograms:
sc8	Genetics	1)Explain the effects of radiation on the structure of DNA	•

Exhibit G. Implementation plan examples from participating teachers at The Catholic University of America QuarkNet Center. (con.t)

Table 29
Self-reported Use of Data Activities Portfolio Activities: Based on Responses from the Full Survey and then Responses from the Update Survey in Subsequent Years **Oklahoma State University/University of Oklahoma**

Center	Program Year (Year of Full Survey)	Subsequent Program Year	Subsequent Program Year	Subsequent Program Year
Oklahoma State University/ University of Oklahoma	2019	2020	2021	2022
	I have not used the Data Activities yet, but would like to learn more about how to integrate them into my classroom.			
				I will definitely bring students to the Masterclass. I like the Polar Bear activity and the Rolling with Rutherford activity.
	None	I use many QuarkNet activities already in my classroom. I will certainly use the Step Up activities this coming year. Examples: Card Game, Rolling with Rutherford, Calculating z particles		
	Dice, Histograms, and Probability Mass of US Pennies			
	I have taken students to a master class at Oklahoma state university	I plan on using Step Up plans as a new item to work with as we move forward. I have used other lessons for years from the QuarkNet program.		
	Quark workbench, Rolling with Rutherford, Isotopes of Pentium, various games with dice	Use cosmic ray detector as example of real time data gathering and large data sets. Used top quark mass to introduce particle accelerator and reinforce vectors as an analysis tool. Use quark work. Examples: Quark workbench Penny mass Top Quark mass		
	Quark workbench, particle deck, calculating top quark mass, particle adventure website, z-path, phyching out the system			
	I have used these for chemistry not physics class. I think that QuarkNet needs to expand their thinking about just wanting physics teachers. It has helped me go deeper into my lessons with chemistry students when talking about the atom. Before, it was so superficial. I have a better understanding and therefore I think my kids will too. This can be the first step toward a better physics class that students take the following year. I have used the marbles and dice, mass of pennies, and particle deck.			

Group 1

For Biology and ACT using histograms to graph and synthesize data.

AP Physics - use the Case of the Missing Neutrino event data as an addendum to a two-dimensional collisions lab.

AP Research - utilizing the History of Science Collection at OU to investigate the history of research in science.

Science club - utilization of masterclass

Physical Science-exposure to scientific thinking and graphing, Dice, histograms

Group 2

- Physics
  - Muon Particle Detector will come back into use.
  - Probability of radioactivity decay.
- Chemistry
  - Examination of the Standard Model looking at the exotic particles.
  - Modeling quantum numbers
- All labs
  - Include error on predictions and measurements using bar graphs and bell curves
  - Virtual labs: Cosmic Ray Studies, Phydemo, Falstad, PhET
  - Use eV/c^2 as a dimensional analysis exercise

Group 4

Physics/ Chemistry/ Physical Science

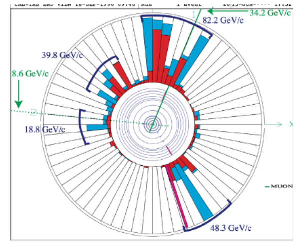
- The "Dice, Histograms, and Probability" activity supports student data collection, graphing, and analysis skills. This can also be applied for radioactive decay.
- After introducing subatomic particles and quarks, the "Shuffling the Particle Deck" data activity is a great way to introduce the standard model.
- As a possible extension activity, students could be placed into groups and have them research different neutrino experiments such as ATLAS, NOvA, DUNE, MINERva, LHC, etc. being conducted around the world.
- For high school physics students, the "Case of the Missing Neutrino" activity is a great application of conservation laws to a more interesting situation than two carts on a track.

Group 5

Teacher #1 - I plan on using the muon detector to collect data and show to my astronomy students. For my Physical Science students, I will use the data collected from the detector for basic graphing of information. It was also very helpful to get the latest information on Neutrino experiments as well as updates on Dark Matter research. I learned a lot about Dark Photons this meeting.

Teacher #2 - I am going to start making use of the stuff in the quarknet data activities portfolio. The dice and histograms and probability activity will be really useful for helping physics students understand how averages work out over time.

Teacher #3 - The physics students will use a dice roller to show the distribution of data. I also liked the use Replit in place of some of the software that is available to me at my school. This was shown to me by Jessica.



Group 3

What are you looking to do?

Data collection and analysis through Histograms (FWHM for uncertainty)

Dice Probability tied into Coin Probability. Exploring misconceptions of Probability between single and compound events

Using Fermilab data to measure momenta via vector addition in 2D to discover evidence of particles(momentum)

Introduction to Standard Model/Particle Physics (Shuffle the Deck Activity)

What class?

Physical Science, Chemistry, Physics

What unit?

Lab/Data Skills, Conservation of Momentum/Energy Units, Waves and Radioactive Decay

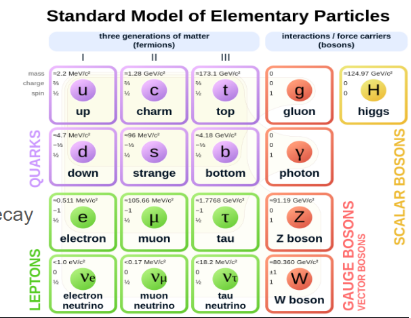


Exhibit H. Implementation plan examples from participating teachers at the Oklahoma State University/University of Oklahoma QuarkNet Center.

Examples of Teacher/Student Work

Over the course of the next several pages, we provide examples of QuarkNet teacher work as well as examples of work by their students. We start with teachers. Each example is taken from one of the 26 (34 combined) QuarkNet centers that were included in the quantitative analyses previously highlighted. In each case, the example was gleaned from information posted on the individual center webpages of the QuarkNet website. Please keep in mind that each example is an excerpt from the center-level portfolios that we have were created for these centers.

The first example (Exhibit I) is a screenshot of program for presentations given at a regional section of American Association of Physics Teachers (AAPT) by QuarkNet teachers from the Colorado State University center and QuarkNet staff. This event occurred on November 4, 2023.

Exhibit J presents the results of an experiment conducted by teachers from the Kansas State University center and their students conducted at a rural high school in Kansas.

And Exhibit K shows teachers from the Syracuse University QuarkNet center actively engaged in activity where Feynman diagrams are drawn.

American Association of Physics Teachers Colorado/Wyoming Section Meeting
Colorado State University, Natural and Environmental Sciences Building
November 4, 2023

Time	Event	Presenter	Room
8:30-9:00 a.m.	Registration and Coffee		A-302/304
9:00-9:45 a.m.	*What is Mass – Really? From Democritus to Higgs*	Bob Wilson, Colorado State University	B-302
9:45-10:15 a.m.	*Cosmology and High Energy Physics*	Joshua Berger, Colorado State University	B-302
10:15-10:30 a.m.	Break		
10:30-11:00 a.m.	*Neutrinos*	Julia Gehrlein, Colorado State University	B-302
11:00-11:30 a.m.	*Iron Chef Physics*	Cecilia Dauer, Little Shop of Physics	B-322
11:30-12:00 a.m.	Business meeting and drawing for NSTA prize	Cherie Bornhorst, Section President	
12:00-1:00 p.m.	Lunch and explore Little Shop of Physics Engagement Spaces		A-302/304, B-323/325/329
1:00-1:45 p.m.	Denver Area Physics Teachers Circular Motion Workshop	Cherie Bornhorst and Matt Leach, DAPT	B-322
1:45-2:30 p.m.	*QuarkNet: Bringing 21st Century Physics Into the Classroom*	Shane Wood, QuarkNet	B-302
2:30-2:45 p.m.	Break		
2:45-3:15 p.m.	*Harry Potter Physics*	Carolyn Crapo, Grandview High School	B-302
3:15-4:00 p.m.	*Building Bridges to Interdisciplinary Collaboration*	Nadene Klein and Joe Schneiderwind, DC Oakes High School	B-302
4:00 p.m.	Adjourn; social gathering at Black Bottle Brewery		

Exhibit I. Presentations by QuarkNet teachers and staff at regional AAPT meeting. Colorado State University QuarkNet Center.

Kansas State University QuarkNet Center, 2022-2023 Annual Report (excerpt):

"Coordinated a research project with QuarkNet Fellow Jim Deane that involved our dozen CRMD teachers working with their students to correlate muon rates with atmospheric temperature and pressure changes (available from NASA) as weather fronts move through Kansas and Arkansas."

Example from Washburn Rural High School

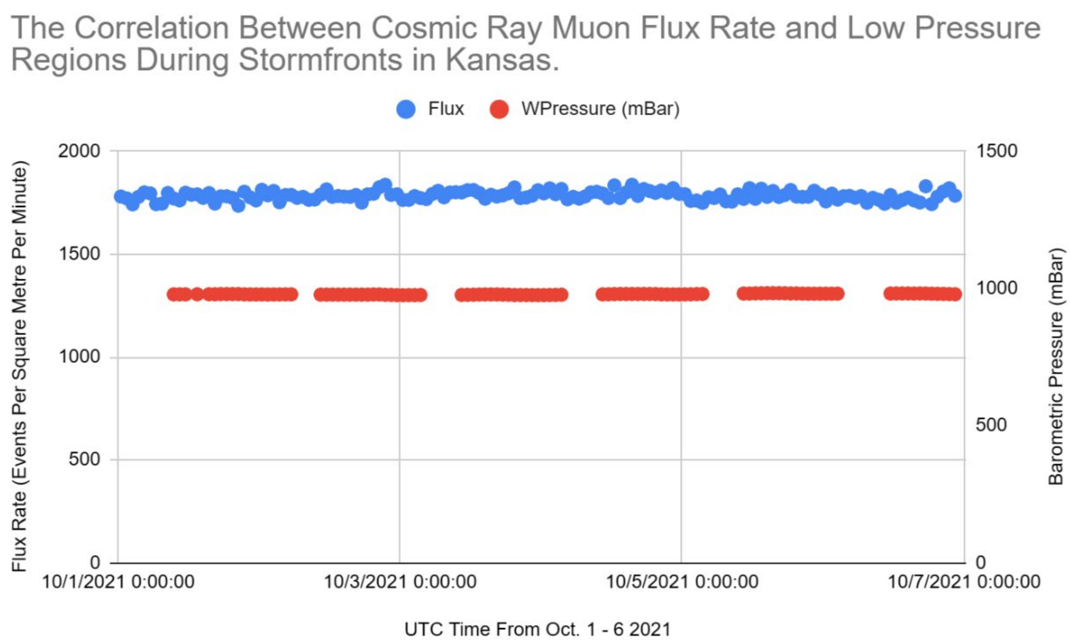
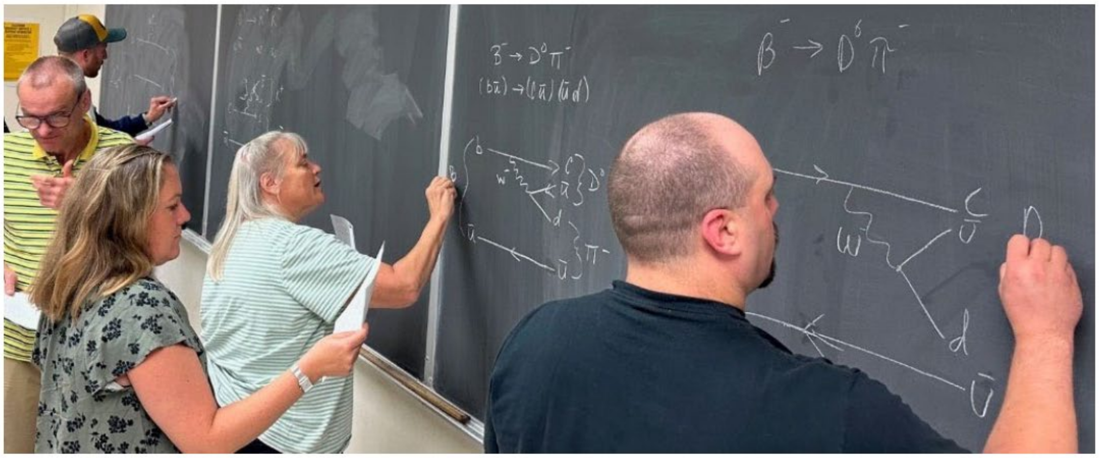


Exhibit J. Experiment conducted by teachers and students at Washburn Rural High School, Topeka KS; Kansas State University QuarkNet Center.



Prof. Blusk gave a second talk on Weak Decays," followed by an activity that had teachers drawing Feynman diagrams for weak decays of heavy quarks. (See photo.)

Photo and description extracted from the Syracuse University Center's Annual Report
Microsoft Word - Summer2023WorkshopReport (quarknet.org)
Summer 2023 QuarkNet Workshop hosted by Syracuse University group from Aug 14-16, 2023.

Exhibit K. QuarkNet teachers from the Syracuse University QuarkNet Center actively engaged in drawing Feynman diagrams.

Student Work Examples

Classroom Work. We begin with providing examples of student work from students whose teachers engaged in QuarkNet through one of the 26 (34 combined) centers that are included in the quantitative analyses. The first example is student work from a classroom visit by a QuarkNet staff teacher where students engaged in two QuarkNet DAP activities, *Shuffling the Particle Deck*, and *Rolling with Rutherford*. This visit was at a public elementary school where the teacher is a participant in QuarkNet at the University of New Mexico Center.

Teacher Instructions for *Shuffling the Particle Dec*k read:

Each card depicts one of the fundamental particles and its characteristics: mass, date of discovery, electric charge, etc. Students use these cards to become familiar with the Standard Model as an organized system of a limited number of fundamental particles with distinct characteristics and as constituents of more complex particles. In this activity, students, working in groups, organize the cards based on the characteristics of the particles. They decide how to do this and discover additional correlations based on their results. This activity is a foundation for learning about the Standard Model and for more complex particle physics activities. This activity parallels the methods used by scientists to organize the elements into the period table.
particle_cards_tchr_05jul2019.pdf (quarknet.org)

Thus accordingly, groups of students from this public school were asked to sort these particle cards. As noted per an email from S. Wood (December 15, 2023), after the group completed their work, the whole class engaged in a "field trip" around the classroom to learn the justification for each group's work. (See Exhibit L.) (Note. Pictures of students actually engagement were not taken to protect their anonymity.)

<u>Student Presentation during QuarkNet Workshop.</u> The next example depicts a slide from a presentation given by a student during a virtual QuarkNet workshop conducted by the Lawrence Berkeley National Laboratory center. The student is exploring the consistency of Boson decay theory and experimental data. (See Exhibit M.)

<u>Masterclass Student Work.</u> Exhibit N presents data collected from 31 high schools and five teachers who were engaged in the Boston Area QuarkNet Center Masterclass held on March 31, 2023.

<u>Science Fair Student Work</u>. During a presentation at the Idaho State University QuarkNet workshop (July 26, 2023) a teacher gave a presentation on *A Year of Modern Physics* conducted during their 2022-2023 school year [A Year of Contemporary Physics at West High School (quarknet.org)]. Exhibit O presents an excerpt from her presentation of a poster presented by students during a science fair event at a public high school in Salt Lake City, UT.

<u>Student Presentations at AAPT</u>. Exhibit P are screenshots of posters and talks given by students whose teachers engaged in QuarkNet through the University of Illinois/Chicago State University center.

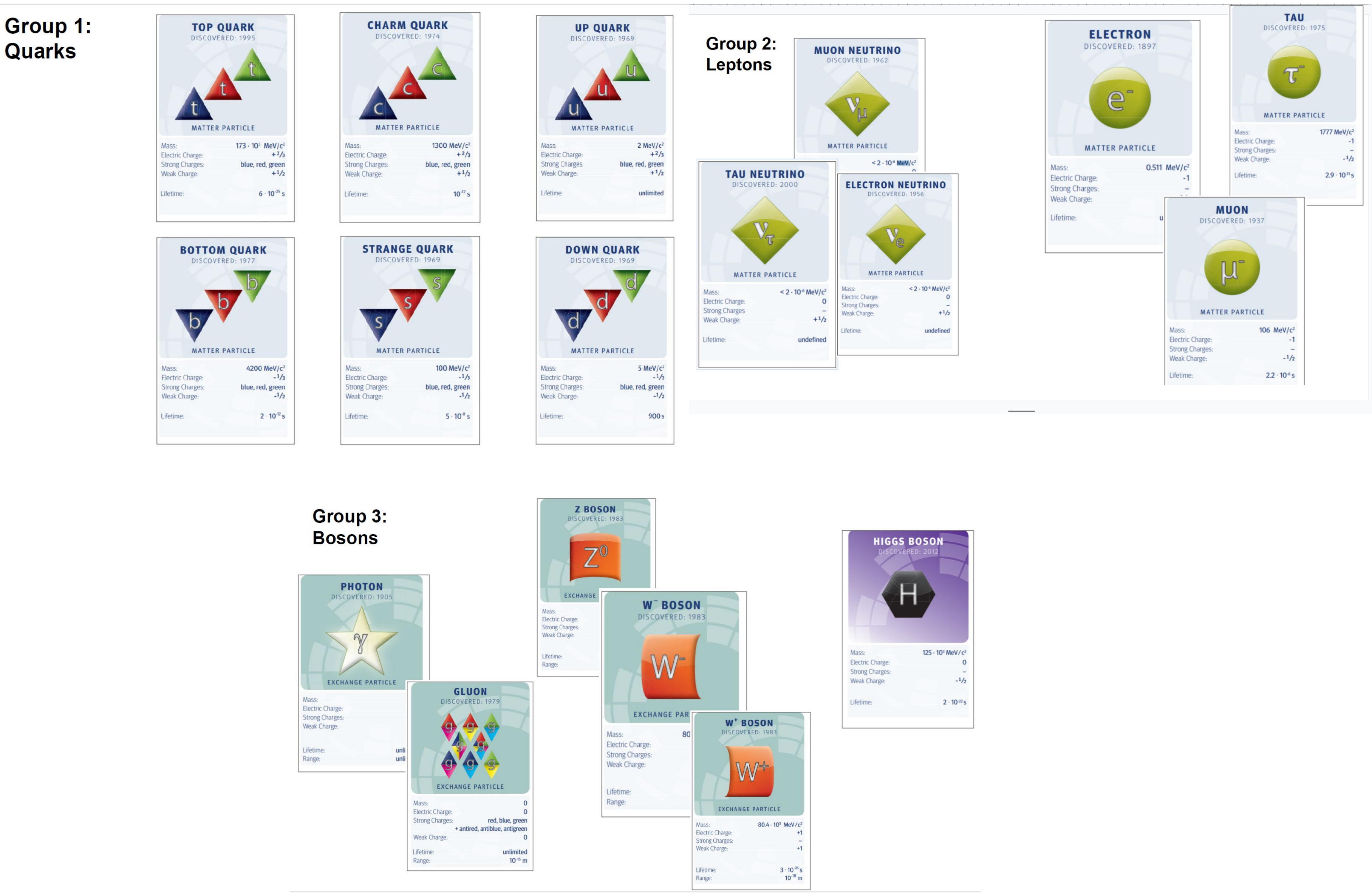
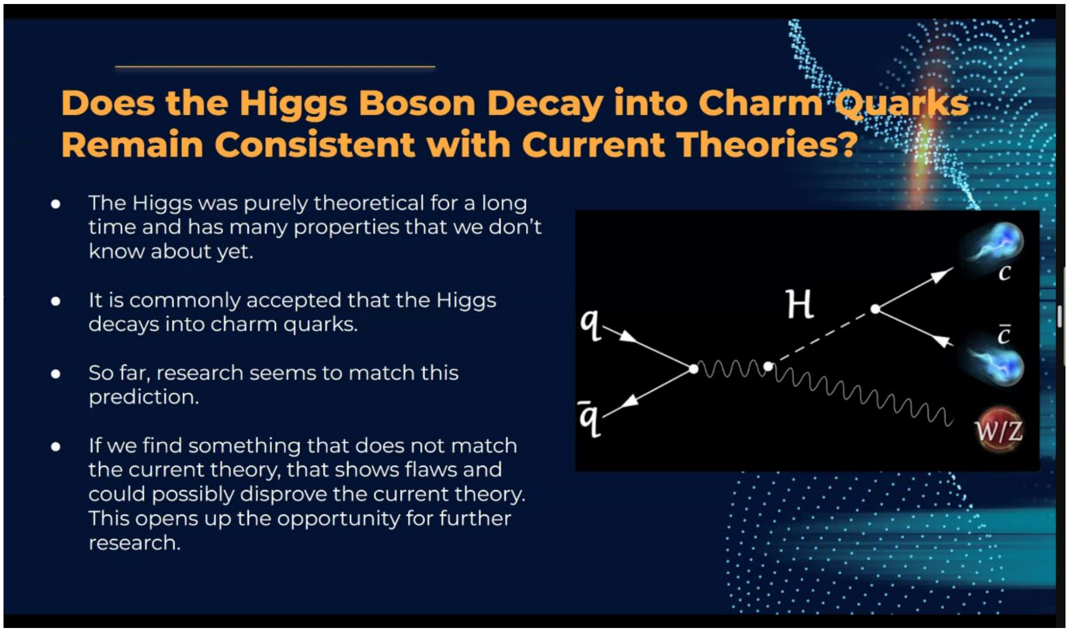


Exhibit L. Students sorted particle cards as part of a classroom implementation of *Shuffling the Particle Deck*



Excerpt from Lawrence Berkeley National Laboratory Annual Report July 20, 2023
Screen shot from a student presentation.

Exhibit M. Screenshot from a student presentation given during an on-line virtual workshop; held each weekday for 2 weeks for 3 hours from July 20 to July 3)) at the Lawrence Berkeley National Laboratory QuarkNet center.
(Source: Annual Report July 20, 2023)

Below is an example of a histograms created by data collected and analyzed during a Particle Physics Masterclass held on March 11, 2023 at Northeastern University. A total of 31 high school students and five QuarkNet teachers from Massachusetts, Rhode Island, and Vermont participated. (As described in the Boston QuarkNet Center 2022-2023 Annual Report.) Students worked in groups of two to collect the data graphed below.

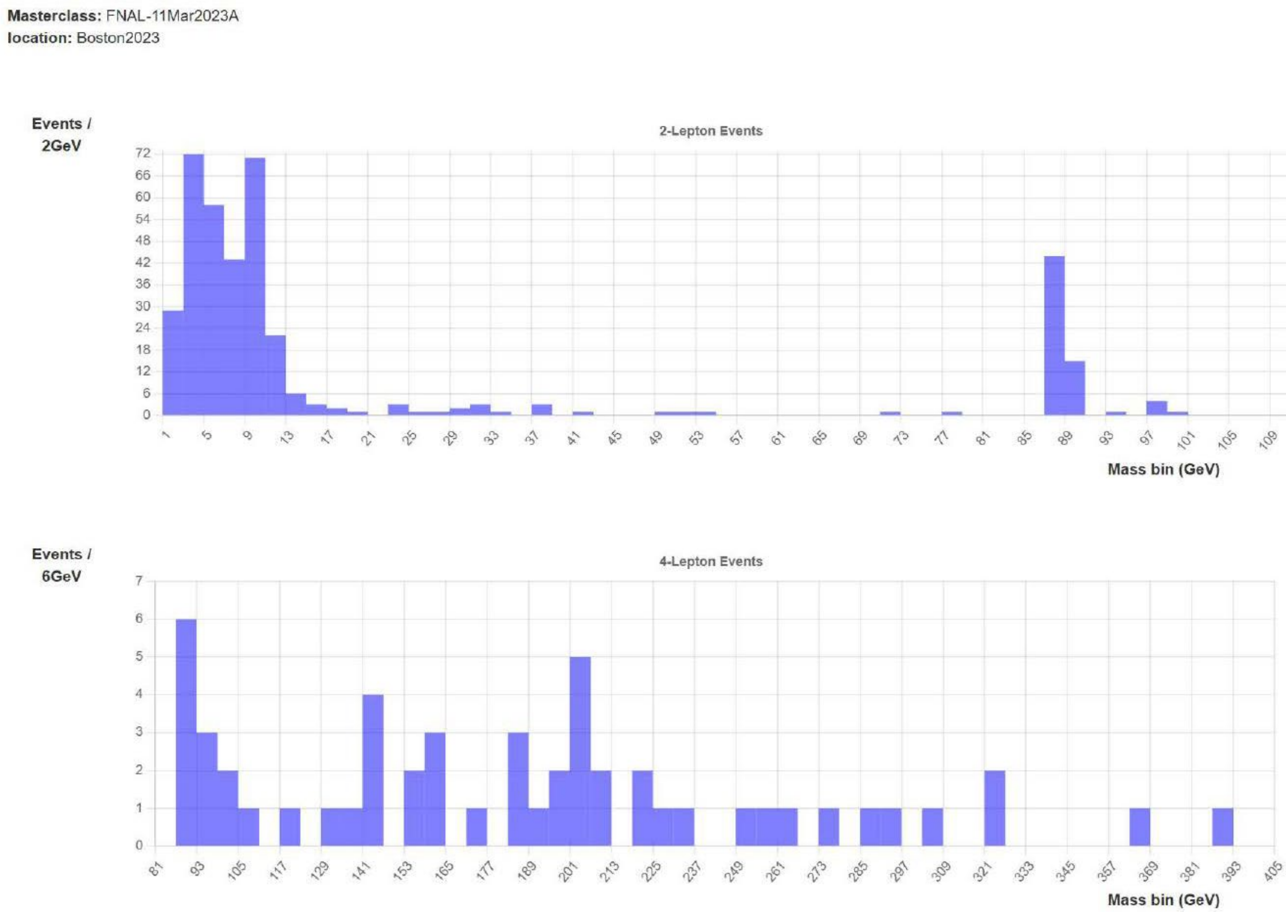


Exhibit N. Student work during CMS Masterclass conducted by Boston Area QuarkNet Center March 11, 2023.

Utilizing Proton-Sensitive Film to Visualize Bragg Peaks

Cole Chu, Natalie Germanov, Thatcher Goff, Marriane Liu, Sanskriti Negi,
Christopher Pankow, Hanxiao Shi, Fiona Zara, Tony Zhang

2023 April 12

1 Motivation

On a visit to the Huntsman Cancer Institute Proton Therapy Department, we became intrigued about how high energy hadrons deposit ionizing energy as they travel through matter: Bragg peaks. Approximately one third of the world's population will be diagnosed with cancer in their lifetime — many of whom will choose to use proton therapy as a form of treatment. Bragg peaks can precisely target tumors and minimize collateral tissue damage, making this form of therapy especially preferable for more prevalent cases. However, the invisible, high-energy beam can be extremely disconcerting to the patient due to a lack of understanding of the technology. By harnessing proton-sensitive materials to create visualizations of a particle beam exhibiting Bragg peak behavior, we can not only assuage cancer patients' worries, but also combine art with science to provide valuable insight into the behavior of particle beams through different materials. While this behavior can theoretically be predicted with equations, a physical visualization can help expand our understanding.

2 Experimental Setup

Our experimental setup contains two phases: the first is to gather quantitative information to support theor

In our first phase

rule[7,9]. We first plac

and radiochromic film

correspondent uses E

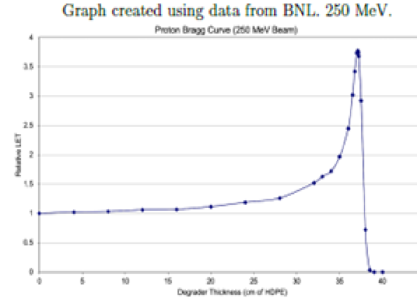
quantitative and visu

amount of uncertainty

Win or not, every year the students and I find value in the endeavor of producing a proposal. We learn physics content, practice technical writing, make connections with the physics community, and work collaboratively.

Win or not, every year I am proud of the students' final product.

Figure 4:
Graph created using data from BNL. 250 MeV.



We found a close correlation between the measured Bragg peak depth (26.1 cm at 205 MeV and 37.1 cm at 250 MeV) and our calculated values (26.33 cm and 34.67 cm, respectively).

In these graphs, the peak of the curve represents the Bragg peak. The inverse Bragg-Kleeman rule equation graphs a vertical asymptote, representing the mean position of the highest energy loss. However, the Bragg-Kleeman rule is an approximation because it does not account for all relativistic effects and other complex physics [7, 9]. For an in-depth explanation of our understanding of the more precise formulae, see: https://docs.google.com/document/d/1bxGBXjTn7FdMJ15IeN$_\chi nA3MsyxLYD_QJBWJ274Pz10/edit?usp = sharing$.

Once we confirm our understanding of the Bragg-Kleeman rule, we can use it to predict the position of our experiment's Bragg peaks. For example calculations, we will use stainless steel and lead at 1 GeV. Values for α and p of stainless steel and lead were found in Table 2 of "The Physics of Proton Therapy[7]." Example calculations:

eel:

$$\alpha = 5.659 \times 10^{-4}, p = 1.706$$
$$R_0 = 5.659 \times 10^{-4}(1000)^{1.706} \approx 74.257\text{cm}$$

$$\alpha = 6.505 \times 10^{-4}, p = 1.676$$
$$\alpha = 6.505 \times 10^{-4}(1000)^{1.676} \approx 69.382\text{cm}$$

at a proton beam at 1 GeV will respectively have an approximate Bragg inless steel and lead of 74 cm and 69 cm, respectively

4

Exhibit O. Example of student work presented during a science fair event at West High School, Salt Lake City UT.

SPS Poster Session (6–7 p.m.) Saturday

SAT-SPS-101 | Poster Presentation Traditional | Baseline: Looking For the Cosmic Ray Moonshadow

Presenting Author: Aitak Mosen Harzandi, New Trier High School
Co-presenting Author | Garrett Chong, New Trier High School
Co-presenting Author | Benjamin Baronofsky, Ida Crown Jewish Academy
Co-presenting Author | Jedidiah Marcus, Ida Crown Jewish Academy
Additional Author | Nathan A. Unterman, New Trier High School

Using multiple detectors set at different angles of elevation, the schools in the collaboration observed a large portion of the sky, collecting muon data to look for the moon's cosmic ray shadow. Each school used one of four angles of elevation, each producing their own sets of data and graphs for each day. These graphs were combined into monthly, then yearly averages. These four graphs were then analyzed and compared to find a consistent dip in muon count, which would hint at the presence of a cosmic ray shadow. The data are consistent with no signal, so an upper limit was determined to guide future experiments.

SAT-SPS-105 | Poster | Method for Measuring Low-Energy Cosmic Rays Using Time

Presenting Author: Ash Eliaser, Rochelle Zell Jewish High School
Co-presenting Author | Miriam Bush, Rochelle Zell Jewish High School
Co-presenting Author | Dalya Frank, Rochelle Zell Jewish High School
Co-presenting Author | Dory Marshall, Ida Crown Jewish Academy
Additional Author | Nathan A. Unterman, New Trier High School
Additional Author | Allen Sears, Ida Crown Jewish Academy

A collaboration of high school students set up cosmic ray detectors to measure low-energy cosmic rays using time with the goal of locating the moon's cosmic ray shadow. The detectors were arranged at different elevation angles aiming south to capture the moon's passage each day. As Earth rotates, the detectors swept the sky daily. Lower energy primary cosmic rays bend more due to magnetic fields and should be found as a shadow well before the moon crosses the meridian. The shadow was not expected after the moon passed the meridian since there are almost no anti-protons in the primary rays. Experiment methods are discussed in this poster.

SAT-SPS-107 | Poster | How Spatial Disorder Affects Quantum Eigenvalue Statistics

Presenting Author: Noah Koch, Berry College
Additional Author | Todd K Timberlake, Berry College

The objective of this project is to illustrate the role of spatial disorder in determining statistical properties of the energy spectrum for a quantum system. We investigate the distribution of energy level spacings in a simple quantum system consisting of several Dirac delta barriers placed

18 2024 AAPT Winter Meeting

Session SUN-DA: Cosmic Ray Studies in the Classroom Sunday, Jan. 7, 3–4 p.m.
Commerce - 3rd Floor Moderator: Shane Wood Sponsor: Committee on Contemporary Physics

SUN-DA-01 (3:00 to 3:12 PM) | Contributed Talk | Use of Time to Measure Momentum/Energy of Cosmic Rays

Presenting Author: Miriam Bush, Rochelle Zell Jewish High School
Co-presenting Author | Dalya Frank, Rochelle Zell Jewish High School
Co-presenting Author | Ash Eliaser, Rochelle Zell Jewish High School
Co-presenting Author | Dory Marshall, Ida Crown Jewish Academy
Additional Author | Nathan A. Unterman, New Trier High School
Additional Author | Allen Sears, Ida Crown Jewish Academy

During the total eclipse of 2017, students reported that the anticipated cosmic ray shadow was not in line with the moon (and sun)1. It was suggested that the lunar shadow may be elsewhere in the sky. An experiment was designed to look for the cosmic ray lunar shadow to the west and east of the Moon to account for effects from the Earth's magnetic field. Low energy primary cosmic rays would be bent more than those of higher energy. This allowed the experiment to use time ahead of lunar meridian passage to measure a range of cosmic ray energies—a novel approach. The design of such an experiment will be discussed.

(1) Dallal, Tamar A., et al.; Solar Eclipse and Cosmic Ray Flux, The Physics Teacher, volume 60, pp 100-104. February 2022

SUN-DA-02 (3:12 to 3:24 PM) | Contributed Talk | The Cosmic Watch in the Classroom

Presenting Author: Kenneth Cecire, University of Notre Dame

January 6–9, 2024 33

Exhibit P. Two poster presentations and a contribute talk at the Winter Meeting of AAPT January 2024. (Source: Screenshots of AAPT program descriptions). University of Illinois at Chicago QuarkNet Center.

Center-level Outcomes: Informing These and Other Analyses

During the previous grant period, the involvement of center-level engagement in QuarkNet was measured through the Center Feedback Template; this was added to the mix of the individual-teacher analyses to provide the context in which teachers participate in QuarkNet at the center level. This information had been used to corroborate (or not) teacher-level responses and to gauge center-level outcomes in their own right. Further, results of quantitative analyses have suggested the importance role that centers play in QuarkNet implementation and engagement by teachers.

The timetable of this evaluation effort and brief description of the method used are shown in Appendix J.

Engagement by QuarkNet Teachers as Active Learners/Opportunities to Building Relationships/Networking

In this report we show a summary table of selected results where individual-teacher and center-level responses are compared (see Table 30). This summary table is followed by a series of tables (Tables 31-33) that provided the details behind this summary. On this basis, we conclude:

- There is good agreement between individual teacher responses and center-level reports of opportunities for teacher to engage as active learners as students during their engagement in QuarkNet programs and events. The perceived influence QuarkNet has on this behavior (at the center level) is reported as *Very High/High.*

- Similarly, individual teachers and centers tend to agree on opportunities to engage with mentors and other teachers during QuarkNet program engagement. QuarkNet's influence again is reported as *Very High/High* (at the center level).

- And both individual teachers and centers tend to report that QuarkNet program engagement facilitates forming lasting collegial relationships with QuarkNet's influence on relationship building as *Very High/High*.

Alignment of the Implemented QuarkNet Program with NGSS Science Practices

As previously discussed, QuarkNet predates the articulation of Next Generation Science Standards (NGSS). From the start, QuarkNet fundamentally embraced a claims/evidence/reasoning approach (McNeill & Krajcik, 2008) to professional development which lent well to its embrace of NGSS science and engineering practices. These practices as well as inquiry (which was operationally defined in the PTM) and characteristics of professional development ala Darling Hammond (et. al., 2017) are anchors of QuarkNet's PTM.

Table 30
Comparison of Center-level[a] and Individual Teacher[b] Responses

Program Engagement Opportunities	Center: Engage Teachers as Active Learners, as Students[a]	Teachers: QuarkNet provides opportunities for teacher to engage as an active learner, as a student[b]	Center: QuarkNet's Influence on Teachers (on this behavior)[a]
Teachers engage as active learners, as students	*Almost all* Teachers 20/25 centers	81% of teachers reported opportunities as *Excellent*	Rated as 14/25 centers *High* 11/25 *Very High*
Teachers interact with Mentor(s) and/or	*Almost all* Teachers 18/25 centers	~85% of teachers reported opportunities as *Excellent*	Rated as 16/25 centers *Very High* 6/25 centers *High* 22/25 *Very High/High*
Other teachers	22/25 centers		12/25 centers *Very High* 9/25 centers *High* 21/25 center *Very High/High*
Form lasting collegial relationships	*Almost all* Teachers 12/25 centers *Most* Teachers 7/25 centers *Almost all/Most* Teachers 19/25	63% of teachers reported opportunities to form collegial relationships with scientists/teachers as *Excellent* 72% of teachers reported opportunities to building a local learning environment as *Excellent*	Rated as 12/24 centers *Very High* 9/24 centers *High* 19/24 centers *Very High/High*

[a]Based on 25 (33 combined) centers.
[b]Based on teacher survey data from three program years (2019-2023).

Table 31
Summary of Center-level Assessment and Individual Teacher-levels Responses to:
Opportunities for Teachers to Engage as Active Learners, as Students

Center	Center-level Assessment: Engage Teachers as Active Learners, as Students			Individual Teacher-level Responses: QN provides opportunities for teacher to engage as an active learner, as a student					Center-level Assessment: QN's Influence on Teachers (on this behavior)	
	Almost All	Most	Some	Excellent	Good	Average	N/A	Total	Very High	High
Black Hills State University	✔			12	2	0	0	14	✔	
Boston Area/Brown University[a]		✔		14	3	0	0	17		✔
Brookhaven National Laboratory/Stony Brook[a]	✔			13	5	0	0	18	✔	
Catholic University of America	✔			12	4	0	0	16	✔	
Colorado State University	✔			13	1	0	0	14	✔	
Fermilab/University of Chicago[a]	✔			39	4	0	1	44		✔
Florida State University	✔			15	2	0	0	17		✔
Johns Hopkins University[a]	✔			15	3	0	0	18	✔	
Kansas State University	✔			13	2	0	1	16		✔
Oklahoma State/University of Oklahoma[a]	✔			29	3	0	0	32	✔	
Purdue Northwest	✔			4	1	0	0	5	✔	
Rice University/University of Houston[a]	✔			23	0	0	0	23		✔
Southern Methodist University	✔			18	4	0	0	23		✔
Syracuse University		✔		13	6	1	1	21		✔
Texas Tech University	✔			1	1	1	0	3		✔
University at Buffalo			✔	5	1	0	0	6		✔
University of Cincinnati			✔	17	5	1	0	23		✔
University of Illinois at Chicago[a]	✔			7	2	0	0	9		✔
University of Iowa/Iowa State University[a]	✔			13	7	0	0	20	✔	
University of Kansas	✔			4	1	0	0	5		✔
University of Minnesota	✔			14	2	0	0	16	✔	
University of Notre Dame	✔			16	3	0	0	19	✔	
University of Puerto Rico – Mayaguez		✔		21	2	0	0	23	✔	
Vanderbilt University	✔			9	2	2	0	13		✔
Virginia Center	✔			10	8	0	0	18		✔
Virtual Center	✔			11	2	0	0	13		✔
Total	20	3	2	361 (81.1%)	76 (17.1%)	5 (1.1%)	3 (0.7%)	445 (100%)	11	14

Note. Percents are used only for the grand total across centers because the responses within an individual center are too small to justify percentages. [a]Combined centers (34 total centers).

Table 32
Summary of Center-level Assessment and Teacher-levels Responses to:
Opportunities for Teachers to Engage with Mentors and Other Scientists and Other Teachers

Center	**Center-level**			**Center-level**			**Individual Teacher-level Responses**					**Center-level Assessment**			**Center-level Assessment**		
	Teachers engage interact with Mentors and other scientists			Teachers engage/interact with other teachers			Opportunities for Teachers to interact with other scientists and collaborate with each other					QN's influence on Teacher interaction with Mentor/other scientists			QN's influence on teacher engagement/ interaction with other teachers		
	Almost All	Most	Some	Almost All	Most	Some	Excellent	Good	Average	N/A Mis.	Total	Very High	High	Mod-erate	Very High	High	Mod-erate
Black Hills State University		✓			✓		12	1	0	0	13			✓			✓
Boston Area/Brown University[a]			✓	✓			11	3	0	0	14		✓		✓		
Brookhaven National Laboratory/ Stony Brook University	✓			✓			15	1	1	1[b]	18	✓			✓		
Catholic University of America	✓			✓			14	1	0	0	15	✓			✓		
Colorado State University		✓		✓			13	1	0	0	14	✓			✓		
Fermilab/U of Chicago[a]		✓		✓			38	4	0	0	42		✓			✓	
Florida State University	✓			✓			16	1	0	0	17						
Johns Hopkins University	✓			✓			15	2	1	0	18	✓			✓		
Kansas State University		✓		✓			12	3	0	0	15		✓			✓	
Oklahoma State/University of OK	✓			✓			21	3	0	0	24	✓			✓		
Purdue Northwest	✓			✓			4	1	0	0	5	✓			✓		
Rice University/ University of Houston	✓			✓			22	1	0	0	23		✓			✓	
Southern Methodist University	✓			✓			17	7	0	0	24	✓				✓	
Syracuse University[c]							10	3	1	0	14						✓
Texas Tech University	✓			✓			3	0	1[d]	0	4			✓			✓[e]
University at Buffalo	✓			✓			5	1	0	0	6	✓			✓		
University of Cincinnati			✓			✓	19	2	1	0	22		✓				✓
University of Illinois at Chicago[a]	✓			✓			8	1	0	0	9	✓				✓	
University of Iowa/Iowa State University[a]	✓			✓			15	5	0	0	20	✓			✓		
University of Kansas	✓			✓			4	1	0	0	5		✓			✓	
University of Minnesota	✓			✓			17	0	0	0	17	✓			✓		
University of Notre Dame	✓			✓			14	5	0	0	19	✓				✓	
University of Puerto Rico – Mayaguez	✓			✓			20	0	0	0	20	✓			✓		
Vanderbilt University		✓				✓	11	1	1[d]	0	13	✓				✓	
Virginia Center	✓			✓			8	6	0	0	14	✓				✓	
Virtual Center	✓			✓			10	3	0	0	13	✓			✓		
Total	18	5	2	22	1	2	365 84.7%	59 13.7%	6 1.4%	1 0.2%	431 100%	16	6	1	12	9	4

[a]Combined center (34 total). [b]Rated as "poor." [d]Not able to reach consensus on these ratings. [d]Rated as "fair." [e]Rated as "A Few." Note. Percents are used only for the grand total across centers because the responses within an individual center are too small to justify percentages.

Table 33

Summary of Center-level Assessment and Teacher-levels Responses to:

Opportunities for Teachers and Mentors to **Form Lasting Collegial Relationships**

	Center-level Assessment				**Teacher-level Responses**					**Center-level Assessment**		
	Form lasting collegial relationships locally and nationally				Provide opportunities for teachers and mentors to build a local (or regional) learning community					QN's Influence on forming these relationships		
Center	Almost All	Most	Some	A Few	Excellent	Good	Average	Fair/NA	Total	Very High	High	Moderate
Black Hills State University				✓[b]	13	0	0	0	13			✓[c]
Boston Area/Brown University		✓			10	3	2	0	15		✓	
Brookhaven National Laboratory/Stony Brook University			✓		12	3	0	1	16			✓
Catholic University of America		✓			13	1	1	0	15	✓		
Colorado State University		✓			14	0	0	0	14	✓		
Fermilab/University of Chicago		✓			30	11	1	0	42		✓	
Florida State University			✓		16	0	0	1[c]	17			✓
Johns Hopkins University	✓				15	1	0	2	18	✓		
Kansas State University	✓				10	4	1	0	15			✓
Oklahoma State/University of Oklahoma		✓			17	5	2	0	24	✓		
Purdue Northwest	✓				4	0	1	0	5			✓[d]
Rice University/University of Houston	✓				21	2	0	0	23	✓		
Southern Methodist University			✓		14	9	0	1[e]	24			✓
Syracuse University				✓	10	5	0	0	15			✓
Texas Tech University	✓				2	0	1	0	3		✓	
University at Buffalo		✓			5	1	0	0	6	[e]		
University of Cincinnati			✓		18	3	1	0	22		✓	
University of Illinois at Chicago	✓				6	3	0	0	9			
University of Iowa/Iowa State	✓				16	3	1	0	20	✓		
University of Kansas		✓			4	1	0	0	5		✓	
University of Minnesota	✓				16	1	0	0	17	✓		
University of Notre Dame	✓				13	4	1	1[e]	19	✓		
University of Puerto Rico – Mayaguez			✓		16	3	0	1[e]	20		✓	
Vanderbilt University	✓				10	2	1	0	13	✓		
Virginia Center	✓				7	7	0	0	14	✓		
Virtual Center	✓				6	3	1	1[e]	11	✓		
Total	12	7	6	2	318 76.7%	74 17.8%	15 3.6%	8 1.9%	415 100%	11	6	7

[a]Combined centers (34 total centers). [b]Rated as "Rarely." [c]Rated as "Low." [d]Rated as "Very Low." [e]Did not answer.

Note. Percents are used only for the grand total across centers because the responses within an individual center are too small to justify percentages.

We have reviewed the alignment of the *implemented* QuarkNet program with NGSS Science Practices across centers (rather than by individual center). In Figure Set 15, the graph in the upper left-hand corner reflects the potential exposure to NGSS practices based on all DAP activities *as designed* and is repeated here (previously Figure 5) for ease of comparison to QuarkNet DAP activities as *implemented*.

The graph in the upper right-hand corner shows the exposure to NGSS practices based on *implemented* QuarkNet workshops held during the 2019 through 2023 program years (based on review of workshop agendas for each of these program years) where DAP activities embedded in the workshop were counted, and then aligned with NGSS practices.

Taken together data in these two graphs suggest the alignment of NGSS science practices evident in DAP activities at the program level as *designed;* and as *implemented* --- via workshops held across the program years during this (and previous) grant periods.

(Also evident, the graph in the upper right-hand corner suggests that the implementation level of embedded DAP activities returned to pre-COVID levels, comparing data from 2019, 2022 and 2023 program years.)

The next graph in the lower left-hand corner presents the perceived engagement in NGSS practices by teachers based on center-level assessment of their *implemented* program. This reflects an assessment of engagement at the individual teacher level. (Based on responses from Center Feedback Templates.) As shown, data in this graph suggest that the individual-teacher engagement at the center aligned with these NGSS practices, as "*Most*" or "*Almost All*" teachers engaged in endeavors that align with each of these science practices during their participation in QuarkNet.

The graph in the lower right-hand corner presents the centers' assessment of QuarkNet perceived influence of this alignment. (Again, based on responses from Center Feedback Templates.) This graph suggests that these centers judged QuarkNet's influence on participating teachers relative to these practices as "*High*" or "*Very High*."

Together these graphs suggest that, at the overall program level, participating QuarkNet teachers are engaged in scientific endeavors during the *implemented* program that align with NGSS science practices; and this engagement mirrors the pattern of alignment with the DAP activities as *designed.* Of importance, this engagement occurred at a high and frequent level as measured by the count of DAP activities embedded in workshops during multiple program years (at the overall program level) and as measured by center-level assessments based on center that participated in the Center Feedback Template process (at the individual teacher level).

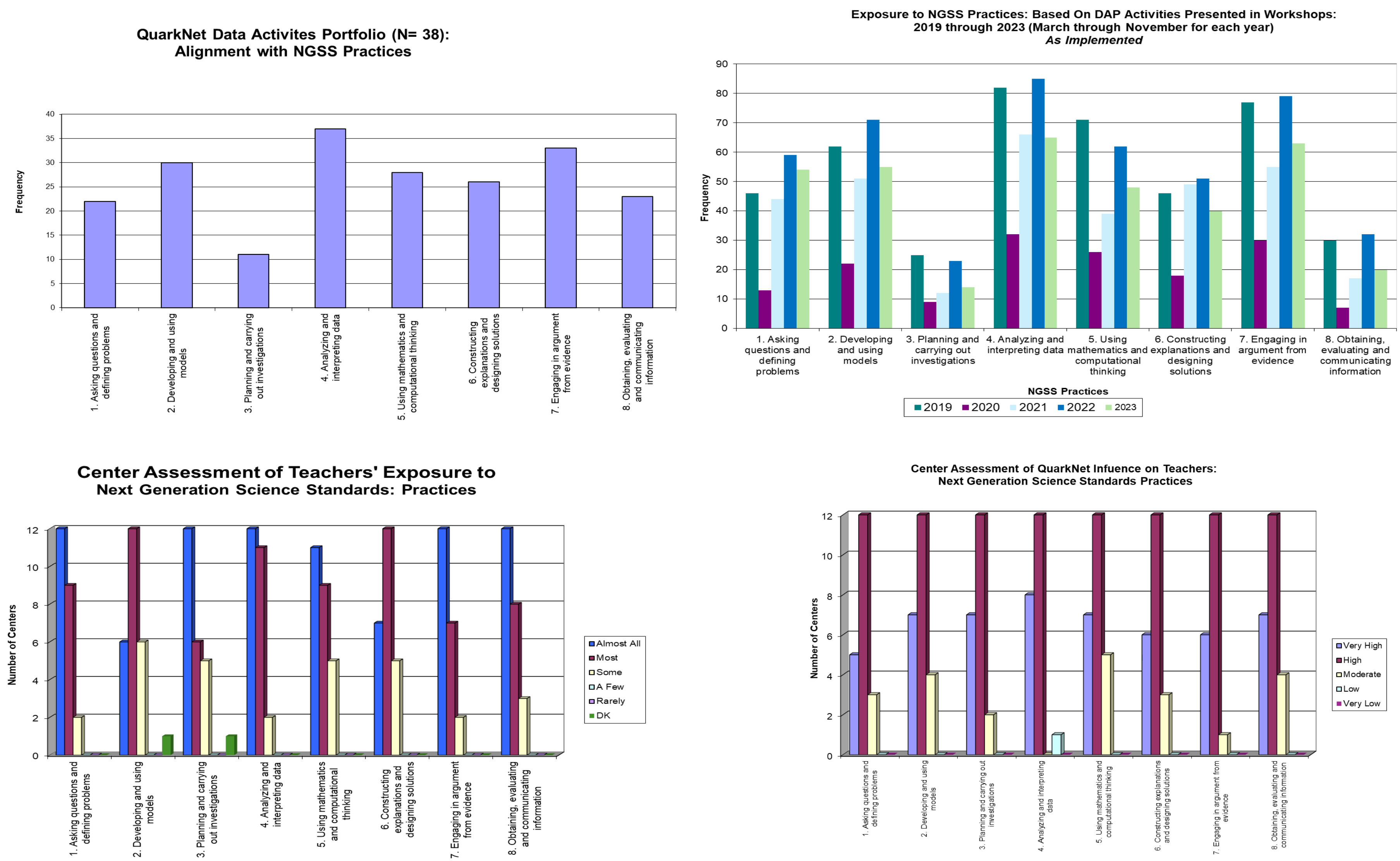


Figure Set 15. Alignment of Next Generation Science Standards (NSS) science practices and activities from the Data Activities Portfolio as designed (upper left-hand corner). Then, the exposure to NGSS practices based on *implemented* QuarkNet workshops held during the 2019 through 2022 program years (upper right-hand corner); and finally based on QuarkNet program content and DAP activities as assessed by

Effective Practices: QuarkNet Centers

The importance of the partnership between QuarkNet and participating centers have already been noted. To help review these centers through the lens of effective practices, Young and Associates (2017) created a matrix of interrelated factors and in turn, we embedded the assessment of these factors by centers within the Center Feedback Template. A summary of these center-level assessments is shown in Table 34 (for centers that completed their template). Because of the individual characteristics of each center, we would expect some variability across these assessments and indeed variability is evident. The more telling profile, however, is that individually and collectively these centers tend to report that they have met the standards proposed by these factors.

That said, there were two areas where centers most often cited a challenge. We begin with Factor 3. *Participants meet regularly.* (QuarkNet model is for a summer session with follow-up during the academic year or sessions during the academic year. Follow up includes working with the national staff and collaboration within and across centers. Mentors and teachers have flexibility to set the annual program locally.)

For example, these challenges/comments were noted:

- (Yes, but) Strong seasonal involvement; could increase overall frequency and depth.
- (Yes, but) We often fail to follow up during the school year; probably need to try harder to make this happen.
- (Yes, but) We usually only meet as a QuarkNet group during the summer. An in-person meeting during the academic year is not feasible and there are no follow up sessions during the year.
- (Yes, but) No group meetings generally during the academic year – think that would be helpful even if informal. Mentor does visit schools and teachers, often working with small student groups.
- (Yes, but) Currently we meet about twice a year. 3-4 days in the summer, 1 day in Jan/Feb for Masterclass orientation, and 1 day in March/April for Masterclass. it

Perhaps the most frequently mentioned challenge for these centers is reflected in responses to Factor 7. *Money for additional activities or additional grants.* (Seeking additional funding to fulfill the mission/objective of the center; providing supplemental or complementary support for QuarkNet e.g., providing transportation, lodging, buying equipment, providing food.)

- (Yes, but) Money for stipends to attend meetings has been generally available. Also, QuarkNet has provided four teachers with cosmic ray detectors. We have not asked for more.
- (Yes) Preparing a NSF proposal.
- (Yes) QuarkNet helped with paying mileage to teachers who have to travel quite far for our summer workshop and also paid for a shared set of equipment for a specific lab experiment.
- (Yes, but) Lately funding has shrunk, so teacher stipends shrunk or we capped the participant number.

Table 34

Summary of Center-Level Success Factors: A Self-assessment by QuarkNet Centers

Effective Practices/Success Factors[a]	QuarkNet Centers											
	A	B	C	D	E	F	G	H	I	J	K	L
1. *Program provides opportunities for a* ***strong teacher leader***. (Teacher provides leadership in areas of content and/or is a technical expert; models exemplary pedagogical skills; able to provide organizational skills. These characteristics may be present in one or a team of teacher leaders.)	Yes	Yes	Yes	Yes, but[1]	Yes	Yes	Yes	Yes	Yes	Yes, but[1]	Yes, but[1] /No	Yes
2. *Program provides opportunities for a* ***strong mentor***. (Mentor provides leadership skills mainly of content and/or technical expertise; understands education and professional development -- working with teacher leaders as needed; models research.)	Yes, but[1]	Yes	Yes, but[1]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes/ Unsure	Yes, but[1]
3. *Participants meet regularly*. (QuarkNet model is for a summer session with follow-up during the academic year or sessions during the academic year. Follow up includes working with the national staff and collaboration within and across centers. Mentors and teachers have flexibility to set the annual program locally.)	Yes	Yes, but[1]	Yes, but[1]	Yes, but[1]	Yes, but[1]	Yes	Yes, but[1] /Yes	Yes, but[1]	Yes, but[1]	No	Yes, but[1]	Yes, but[1]
4. *Meaningful activities* (The standard for meaningful activities is focusing topics in modern physics, discussing how to implement this content in classrooms, conducting research and discussing scientific inquiry methods; using Data Activities Portfolio instructional materials.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes/ Yes, but[1]	Yes	Yes	Yes	Yes	Yes
5. *Directly addresses classroom implementation of instructional materials for all teachers.* (Time for teachers to discuss Data Activities Portfolio instructional materials and pathways; to consider NGSS, AP, IB or other science standards; presentation(s) from veteran teachers on classroom implementation experiences or similar engagement.)	Yes	Yes	Yes	Yes, but[1]	Yes	Yes	Yes/ Yes, but[1]	Yes	Yes	Yes	Yes, but[1] /Yes	Yes, but[1]
6. Program is able to provide regular contact and support with teachers. (Specific support and or follow up from staff; staff teachers are available and/or volunteers who support teachers, especially related to classroom implementation.)	Yes	Yes, but[1]	Yes, but[1]	Yes	Yes, but[1]	Yes	Yes	Yes	Yes, but[1]	Unsure	Yes, but[1] /Yes	Yes
7. Money for additional activities or additional grants. (Seeking additional funding to fulfill the mission/objectives of the center; providing supplemental or complementary support for QuarkNet e.g., providing transportation, lodging, buying equipment; providing food.)	Yes, but[1]	Yes	Yes	Yes	Yes, but[1]	No	Yes, but[1]	Yes, but[1]	No	No	No	Yes, but[1]
8. Stable participant base.(A stable participant base can provide an expert group that can help other teachers, support outreach, and provide organizational leadership.)	Yes	Yes	Yes	Yes, but[1]	Yes, but[1]	Yes	Yes/ Yes, but[1]	Yes	Yes	Yes	Yes	Yes, but[1]
9. Addresses teacher professionalism. (The standard is to provide opportunities for at least a few teachers to attend professional meetings; support teachers taking leadership roles in their school, school districts, outreach, and highlight PD opportunities for continuing development.)	Yes	Yes	Yes	No	Un-sure	Yes	Yes/ Yes, but[1]	Yes	Yes, but[1]	Yes	No/ Yes	Yes
10. Establish a learning community. (The standard is forming a cohesive group where teachers learn from one another; engage with mentors and other scientists; provide outreach to other teachers.)	Yes	Yes	Yes	Yes, but[1]	Yes, but[1]	Yes	Yes/ Yes, but[1]	Yes	Yes	Yes, but[1]	Yes, but[1] /No	Yes, but[1]

[a]This section of the protocol has been adapted from M.J. Young & Associates (2017, September). *QuarkNet: Matrix of Effective Practices.* [1]Needs work or fine tuning; or there are notable caveats.
A= Boston Area/ University of Boston. B= Catholic University of America. C= Colorado State University. D = Fermilab/University of Chicago. E = Florida State University/University of Florida. F = Johns Hopkins University. G = Kansas State University. H = Oklahoma State/University of Oklahoma. I= Rice University/ University of Houston. J=Southern Methodist University. K= Syracuse University. L = University of Cincinnati.
Note. Not all centers reached consensus in their ratings; this is reflected by multiple responses for these centers.

Table 34 (con't.)
Summary of Center-Level Success Factors: A Self-assessment by QuarkNet Centers

Effective Practices/Success Factors[a]	**QuarkNet Centers**												
	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1. *Program provides opportunities for a* ***strong teacher leader***. (Teacher provides leadership in areas of content and/or is a technical expert; models exemplary pedagogical skills; able to provide organizational skills. These characteristics may be present in one or a team of teacher leaders.)	Yes	Yes, but[1]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2. *Program provides opportunities for a* ***strong mentor***. (Mentor provides leadership skills mainly of content and/or technical expertise; understands education and professional development -- working with teacher leaders as needed; models research.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes, but[1]	Yes	Yes	Yes	Yes	Yes
3. *Participants meet regularly*. (QuarkNet model is for a summer session with follow-up during the academic year or sessions during the academic year. Follow up includes working with the national staff and collaboration within and across centers. Mentors and teachers have flexibility to set the annual program locally.)	Yes	Yes, but[1]	Yes	Yes	Yes, but[1]	Yes	Yes	Yes	Yes	Yes, but[1]	Yes, but[1]	Yes	Yes, but[1]
4. *Meaningful activities* (The standard for meaningful activities is focusing topics in modern physics, discussing how to implement this content in classrooms, conducting research and discussing scientific inquiry methods; using Data Activities Portfolio instructional materials.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No/ Not sure	Yes
5. *Directly addresses classroom implementation of instructional materials for all teachers.* (Time for teachers to discuss Data Activities Portfolio instructional materials and pathways; to consider NGSS, AP, IB or other science standards; presentation(s) from veteran teachers on classroom implementation experiences or similar engagement.)	Yes	Yes	Yes	Yes	Yes	Yes, but[1]	Yes	Yes, but[1]	Yes	Yes, but[1]	Yes, but[1]	Yes	Yes, but[1]
6. Program is able to provide regular contact and support with teachers. (Specific support and or follow up from staff; staff teachers are available and/or volunteers who support teachers, especially related to classroom implementation.)	Yes	Yes, but[1]	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes, but[1]	Yes	Yes, but[1]
7. Money for additional activities or additional grants. (Seeking additional funding to fulfill the mission/objectives of the center; providing supplemental or complementary support for QuarkNet e.g., providing transportation, lodging, buying equipment; providing food.)	No	Yes, but[1]	Yes	Yes	No	Yes, but[1]	No	Yes	Yes	No/ Not sure	Yes, but[1]	Yes, but[1]	No/ Not sure
8. Stable participant base.(A stable participant base can provide an expert group that can help other teachers, support outreach, and provide organizational leadership.)	Yes, but[1]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes, but[1]	Yes, but[1]	Yes, but[1]
9. Addresses teacher professionalism. (The standard is to provide opportunities for at least a few teachers to attend professional meetings; support teachers taking leadership roles in their school, school districts, outreach, and highlight PD opportunities for continuing development.)	Yes	Yes, but[1]	Yes	Yes	Yes	Yes	Yes	Yes, but[1]	Yes	No/ Not Sure	Yes	Yes	Yes
10. Establish a learning community. (The standard is forming a cohesive group where teachers learn from one another; engage with mentors and other scientists; provide outreach to other teachers.)	Yes	Yes	Yes	Yes	Yes, but[1]	Yes	Yes	Yes	Yes	Yes	Yes	Yes, but[1]	Yes

[a]This section of the protocol has been adapted from M.J. Young & Associates (2017, September). *QuarkNet: Matrix of Effective Practices.* M = University of Iowa/Iowa State University. N = University of Minnesota. O = University of Norte Dame. P = University of Puerto Rico, Mayaguez. Q = Vanderbilt University. R = Virginia Center. S = Virtual Center. T = Brookhaven National Laboratory/Stony Brook University. U= University of Illinois at Chicago. V = Black Hills State University. W = Texas Tech University. X = University at Buffalo. Y = University of Kansas.
Note Not all centers reached consensus in their ratings; this is reflected by multiple responses for these centers. [1]Yes but defined as *Needs work or fine tuning; or there are notable caveats.*

Table 35
Presentations and Posters Presented in 2023 by QuarkNet Staff and Teachers

Author (Last, First)	**Role (staff, fellow, etc.)**	**Center (if applicable)**	**Date**	**Title**	**Format (Publication, Presentation or Poster)**	**Name of conference, publication, etc.**
Cecire, Kenneth, et al[c]	Staff	Notre Dame	08/09/2023	Adapting the Cosmic Watch for the Classroom	Poster and Proceedings Paper	International Cosmic Ray Conference 2023
Assamagan, Ketevi, et al[b]	Staff		07/2023	The African School of Physics Reaches a New Level	Article	African Physics Newsletter
Wood, Shane, et al[a]	Staff		04/22/2023	QuarkNet: Sustained Professional Development for High School Teachers	Presentation	MN Section AAPT Meeting 2023
Wood, Shane	Staff		04/16/2023	Particle Physics Masterclasses	Presentation	APS April Meeting 2023
Wood, Shane	Staff		01/16/2023	Neutrino Physics Masterclasses	Presentation	AAPT Winter Meeting 2023

[a]With Jon Anderson, Minnesota lead teacher. [b]Cecire contributed
[c]With Jeffrey Chorny, Daniel Kallenberg, Maggie Karban, Rowan McNeely, and Jeremy Wagner
Excerpt from information compiled by K. Cecire and S. Wood.

- (No) We can do more with funding. We have had a very successful center but have had budget cut after budget cut.
- (Yes) Extra food and opportunities to discuss in an informal setting are really appreciated

Funding is of course fundamental to the sustainability of any program but through the assessment of these factors we have hoped to address the question, *What is sustained via this implemented program?* (relative to program fidelity and measured benefits).

Getting the Word Out

Finally, during this current grant period QuarkNet staff and teachers have combined for a total of 72 presentations, posters, or keynote talks at professional conferences such as the American Association of Physics Teachers (AAPT) from 2019-2023 (as of 6/29/24) (information compiled by K. Cecire and S. Wood) http/: quarknet.org/ content/ publications-presentations-and-posters-sept-2018-sept-2013. An excerpt of the list of presentations posters conducted in 2023 included on this website is shown is Table 35.

PROCEEDINGS OF SCIENCE

High School Students' Muon Underground Shielding Experiment

Nathan A. Unterman[1]
New Trier High School
7 North Happ Road, Northfield, IL 60093 USA
E-mail: nunterman@gmail.com

Mark Adams
University of Illinois at Chicago
Physics Department, 845 W. Taylor Street, Chicago, IL 60607, USA
E-mail: adams@uic.edu

Tom Blackmore, Emmanuelle Copeland, Marybeth Senser
Downers Grove South High School
Science Department, 1436 Norfolk Street, Downers Grove, IL 60516, USA
E-mail: msenser@csd099.org

Henry Seiden, Anthony Valsamis
Glenbrook North High School
Science Department, 2300 Shermer Road, Northbrook, IL 60062, USA
E-mail: avalsamis@glenbrook225.org

Benjamin Grey, Jacob Miller, Max Miller, Allen Sears
Ida Crown Jewish Academy
Science Department, 8233 North Central Park Avenue, Skokie, IL 60076, USA
E-mail: asears@icja.org

Paul Graham, Ellie Winkler
New Trier High School
Science Department, 7 North Happ Road, Northfield, IL 60093, USA
E-mail: nunterman@gmail.com

Alex Bernat, Shoshana Frank, Joshua Simon, Shira Eliaser
Rochelle Zell Jewish High School
Science Department, 1095 Lake Cook Road, Deerfield, IL 60015, USA
E-mail: seliaser@rzjhs.org

PoS(ICRC2019)170

PROCEEDINGS OF SCIENCE

QuarkNet Coordination of a Cosmic Ray Experiment Outreach Project During a Total Solar Eclipse

Mark Adams[1]
University of Illinois at Chicago
Physics Department, 845 W. Taylor Street, Chicago, IL 60607, USA
E-mail: adams@uic.edu

Nathan Unterman, Clarissa Carr, Jacob Rosenberg, Anthony Valsamis
Glenbrook North High School

Tamar Dallal, Michelle Matten, Jacob Miller, Ezra Schur, Allen Sears
Ida Crown Jewish Academy

Abstract:

The QuarkNet program has distributed hundreds of cosmic ray detectors for use in high schools and research facilities throughout the world over the last two decades. To test the hypothesis that the rate of cosmic rays may change during a solar eclipse, a collaboration of high school students and teachers came together to build cosmic ray telescopes that were reproduced by thirty groups across the USA. Groups from a wide geographic region collected data and measured rates of muons during the solar eclipse on August 21, 2017. The process of outreach and execution will be discussed. No variation in the muon flux during the eclipse was observed.

36th International Cosmic Ray Conference -ICRC2019-
July 24th - August 1st, 2019
Madison, WI, U.S.A.

PoS(ICRC2019)1045

Exhibit Q. Presentations given by QuarkNet staff, teachers and their students at the 36th International Cosmic Ray Conference, July 24-August 1, 2019 in Madison, WI.

Exhibit Q (previous page) provides a screenshot of the Proceedings of Science presentation given by QuarkNet staff, teachers and students at the 36th International Cosmic Ray Conference July 24-August 1, 2019, in Madison, Wisconsin.

QuarkNet Evaluation Summary

Since the start of the 2019 QuarkNet program Year, the evaluation themes are: (1) (Develop and) Use a Program Theory Model (PTM); (2) Measure Outcomes (teacher, student and long-term); and (3) Measure Center-level Program Outcomes. During the previous grant period, new evaluation measures based on the PTM were created; these were combined with selected previous evaluation measures. We seek to link program engagement, as articulated through program strategies, to measurable program outcomes (see Figure 1 repeated here).

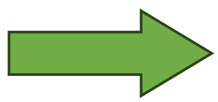
Program Strategies  **Measurable Program Outcomes**

Figure 1. Throughout the evaluation program engagement (i.e., specifically exposure to core program strategies) provides the context in which assessment has occurred.

Program Theory Model (PTM): What's New and What's Kept

QuarkNet's PTM was reviewed and revised (in small but important ways) to coincide with the current renewal grant. To this end, we had added: a new partner (i.e., the Institute for Research and Innovation in Software for High Energy Physics, IRIS-HEP); added new program components; and, reviewed, updated and revised descriptions of other programs, as needed. The programmatic anchors of the PTM focus on: characteristics of effective professional development (Darling-Hammond, Hyler and Gardner, 2017); NGSS Science and Engineering Practices (NGSS, April 2013); and an operational definition of inquiry (Herron, 1971 as modified by Jan-Marie Kellow, 2007). And the details of the PTM describe the major partners, program goals, program components of QuarkNet, articulating program strategies and their linkage to expected outcomes.

Evaluation Measures and Sources of Information

The evaluation measures and sources of information that have been used to inform the evaluation is shown in Exhibit F (also repeated). These measures align with the PTM.

Sources of Outcomes Data

Teacher Full Survey
Primary Focus: Quantitative analyses of teacher, student, and long-term outcomes
Update Survey
Primary Focus: Qualitative analyses of QN content and material use in classrooms
Center Feedback Process and Template
Primary Focus: Comparing center-level and teacher-level responses
Virtual Workshop Visits by Evaluator
Primary Focus: Implementation plan discussions

Multiple Sources of Information: Evidence of Program Engagement/ Alignment with PTM

Workshop Summary Table compiled from:
Workshop Agendas
Annual Reports from Centers
Data Activities Portfolio alignment with:
NGSS Science Practices
Workshop Engagement
Enduring Understandings
Acknowledge and Review other Information
(e.g., cosmic ray studies, use of comic watches, professional presentations; masterclasses; student-collected data)

Exhibit F. Summary and Overview of Evaluation Measures and Program Engagement

Summary of Evaluation Results

The summary of evaluation results is highlighted in Table 36, using the outline highlighted below to achieve this purpose. The narrative of the evaluation report has detailed support for the conclusions presented for each of the following:

1. Survey Implementation and Response Rates
2. Program Fidelity: *Designed* vs. *Implemented* Program
3. Summary of QuarkNet Teachers: Demographics
4. School Characteristics and Student Demographics
5. Unique Contribution of Major QN Program Components
6. Quantitative Analyses: Teacher, Student and Long-term Outcomes
7. Qualitative Analyses: Center-level Portfolio
8. Center-level Outcomes and Effective Practices
9. Getting the Word Out

Table 36
QuarkNet Evaluation: Summary of Major Efforts and Results

Evaluation Effort	Source of Information(s)	Highlighted Major Results
1. Survey Implementation and Response Rates	• Full Teacher Survey • Update Teacher Survey (English and Spanish versions)	• Survey implemented during workshop participation with follow-up email as necessary. • Survey response rate range (2019-2023) from 78% to 80%.
2. Program Fidelity: *Designed* vs. *Implemented* Program Measured through the alignment of NGSS Science Practices	• Data Activities Portfolio (DAP) • Workshop Agendas • Center Annual Reports • Completed Center Feeback Templates	• DAP activities as *designed* shown to align well with NGSS Science Practices. • Workshop agendas incorporate DAP activities; these *implemented* activities align well with NGSS Science Practices. • Center-level responses from Center Feedback Templates indicate that QuarkNet teachers engaged in NGSS Science Practices as part of their workshop engagement; and this experience has a noted influence on teachers related to these practices.
3. Summary of QuarkNet Teachers: Demographics		
a. Teacher Gender (not statistically related to outcomes)	• Full Teacher Survey	• Program engagement close to parity (~ 55% men; ~45% women)
b. Years in QuarkNet (balancing professional development that is sustained as well as attracting new teachers)	• Full Teacher Survey	• Approximately 33-36% of teachers are new/1-year engagement in QuarkNet. • Mean number of years ~5 years • Median number of years 2.0 years
c. School Location	• Full Teacher Survey	• ~ 48% of teachers represent schools in urban locations
d. Teacher Physics	• Full Teacher Survey	• ~ 80% of teachers teach Physics • Other fields mentioned include Chemistry, Physical Science, Earth Sciences, Statistics, Math
e. Program Year Participation	• Full Teacher Survey	• Outcomes do not vary by which year a teacher participates in QuarkNet.

Table 36 (con't.)
QuarkNet Evaluation: Summary of Major Efforts and Results

Evaluation Effort	Source of Information(s)	Highlighted Results
4. School Characteristics and Student Demographics (based on publicly available school-level information) **a. Location** **b. Enrollment size** **c. Student: Gender (%), Ethnicity/ Race (%); Free or Reduced Lunch (%)**	• Large scale case study • Either www.publicschoolreview.com or www.privateschoolreview.com • Information accepted at face value. • Based on teachers enrolled in QuarkNet during 2022 program year. • ~ 250 teachers from ~120 schools.	• Organized by center. • Schools represented by QuarkNet teachers are varied; representing mostly public schools both large and small; and, to a lesser extent, private schools. Some centers show evidence that students represented by schools are diverse in ethnicity and represent notable percents of low-income students (e.g., free or reduced lunch eligibility). Other centers less so.
5. Unique Contribution of Major QuarkNet's Program Components **a. Data Camp** **b. (Variety of) Workshops** **c. Masterclasses**	• Full Teacher Survey (Program Exposure and Outcome Scale Scores: Core Strategies, Approach to Teaching, QuarkNet's Influence on Teaching, Student Engagement, QuarkNet's Influence on Student Engagement, and Long-term Outcomes: Teachers. • Series of simultaneous Analysis of Variance (ANOVA) analyses • Because of sample limitations these analyses do not consider the important role played by Centers.	• Statistical analyses support the use of scale scores as program exposure/outcome measures. • These analyses suggest that Data Camp and Variety of Workshops each contribute to teachers' reported exposure and engagement in Core Strategies. • Each major program component of QuarkNet contributes uniquely to at least one or more outcome measures: Approach to Teaching; QuarkNet's Influence on Teaching, Student Engagement (as reported by teachers), QuarkNet's Influence on Student Engagement; and Long-term Teacher Outcomes. • Thus, these analyses suggest that each of the major components of QuarkNet contribute *uniquely* to outcomes as measured.

Table 36 (con't.)
QuarkNet Evaluation: Summary of Major Efforts and Results

Evaluation Efforts	Source of Information(s)	Highlighted Results
6. Quantitative Analyses: Teacher, Student and Long-Term Outcomes	• Full Teacher Survey • Hierarchical linear regression analyses that account for teachers nested in QuarkNet Centers. • Using scale scores to measure outcomes.	• QuarkNet Centers *matter* when assessing teacher, student, and long-term outcomes. (See below for short summary of each.)
a. Approach to Teaching	• Scale Scores: Core Strategies, Approach to Teaching, QuarkNet's Influence on Teaching and Center-level Mean Scores (Approach to Teaching)	• A hierarchical linear regression analysis based on these 26 centers (34 combined) explored the relationship between QuarkNet program engagement and Approach to Teaching. The results of this analyses suggest that QuarkNet's Influence on Teaching, Core Strategies and Centers (as measured by mean Approach to Teaching Scores) are shown to be positively related to teachers' use of content and instructional practices in their classrooms (i.e., Approach to Teaching). These results are statistically significant [$F_{(3, 388)} = 73.85$, $p < .001$].
b. Student Engagement	• Scale Scores: Student Engagement, QuarkNet's Influence on Student Engagement, Approach to Teaching and Center-level Student Engagement Mean.	• This hierarchical linear regression analysis was based on 25 (33 combined) centers. The results of this analyses suggest QuarkNet's Influence on Student Engagement, Approach to Teaching and Centers (as measured by mean Student Engagement scores) have a positive relationship on this Student Engagement. These results are statistically significant [$F_{(3, 329)} = 106.53$, $p < .001$].
c. Long-Term Outcomes	• Scale Scores: QuarkNet's Influence on Teaching, Student Engagement and Long-term Outcomes	• Again, using a hierarchical linear regression analysis, perceived QuarkNet's Influence on Teaching, Student Engagement and Center-level Means (Long-term Outcomes) are positively and statistically related to Long-term Outcomes: Teachers [$F_{(4, 306)} = 48.42$, $p < .001$].

Table 36 (con't.)
QuarkNet Evaluation: Summary of Major Efforts and Results

Evaluation Efforts	Source of Information(s)	Highlighted Results
7. Qualitative Analyses: Center-level Portfolios (compiled for centers included in the quantitative analyses)	• Full Teacher Survey (open-ended questions) • Update Survey (open-ended questions) • Virtual workshop site visits by evaluator • Teacher Implementations Plans (workshop agendas/center annual report) • Examples of teachers' work • Examples of student work	Organized by center, portfolios are comprised of: • Teachers reported planned or actual use of QuarkNet content and materials in their classroom over time (based on survey responses). When available: • Implementation plans prepared by teachers or groups of teachers and posted on QuarkNet website are included. • Examples of teacher work (during workshop, science fairs, presentations at workshops/ professional conferences) are included. • Examples of student work are included.
8. Center-level Outcomes and Effective Practices	• Center Feedback Template • Effective Practices (M.J. Young & Associates (2017, September). *QuarkNet: Matrix of Effective Practices*	• Comparisons suggest good agreement on select responses by individual QuarkNet teachers and QuarkNet centers [25 (34 combined) centers]. • Results suggest good alignment of centers to meet the criterion of each of 10 effective practices. • Offers a suggestion of program sustainability (i.e., what is being sustained).
9. Getting the Word Out	• https://quarknet.org/content/publications-presentations-and-posters-sept-2018-sept-2023 Compiled by K. Cecire and S. Wood	• As of the 2023 program year, QuarkNet has posted a total of 72 presentations, posters, and publications by staff, teachers and/or students. • In 2024, include success stories from former students, QuarkNet teachers, fellows, and staff.

Program Summary and Recommendations

The following program summary and recommendations are proffered:

P1.The program has had a long-standing practice of holding regularly-scheduled staff meetings. One is staff-wide; one is specific to IT concerns; and one is specific to program content and development. The evaluator has regularly attended the staff-wide meeting. These weekly staff-wide meetings provide a convenient and frequent means for staff and the evaluator to exchange ideas, such as opportunities to highlight evaluation results and for the evaluator to learn and respond to program needs when possible. This meeting structure was essential during COVID for the evaluator (and likely QuarkNet staff as well). Going forward the evaluator has attended weekly staff-wide meetings as her schedule has permitted; this open invitation is greatly appreciated.

Recommendation P1: The frequent opportunity to exchange ideas among staff members as well as the evaluator is important and should be continued.

P2. Over the course of the grant period, the collection of program operations data has improved substantially including for example, simple counts, e.g., number of participating teachers during a given program year. QuarkNet staff have the responsibility of managing workshop RFP's and the award of monies to conduct these efforts as well as tracking teachers to award stipends. These efforts are managed well as are attempts to gather a complete list of registered teachers, although these responsibilities are shared across QuarkNet staff rather than the responsibility of one individual.

Recommendation P2: Continue to improve the collection of program operations to help facilitate both program and evaluation efforts. In keeping with these efforts, improved program operations data has helped with a running count of *new* teachers in QuarkNet each year across participating centers. It also may help to provide insight into the outreach to additional teachers who are not as directly engaged in QuarkNet who nevertheless benefit from the program in other ways.

P3. Starting in the 2019, and continuing during the 2020 through 2023 program years, there has been a concerted effort by QuarkNet staff to help nationally- and center-led workshops document the content of their workshops through the development and use of agenda templates. These agenda examples are readily available and offer a simple and pragmatic step that is very valuable; these agendas can and have been modified and used by QuarkNet centers. In many cases, agendas are modified during the event which memorializes the program in a just-in-time fashion. These documented agendas can help centers prepare their annual reports, which each participating center is asked to do.

Recommendation P3: Continue to support these efforts.

P4. Documenting workshop agendas and center annual reports – and posting these online -- have been extremely helpful in gathering information useful to the evaluation. Specifically, the workshop agendas improved the ability to identify which (and how) activities from the Data Activities Portfolio (DAP) have been incorporated into workshops, especially nationally-led workshops and a growing number of center-led workshops. Other information gathered from these sources helps to summarize program year QuarkNet engagement by centers in general, and specifically in helping centers to complete the Center Feedback Template. We have also used this information for comparisons of the *designed* and *implemented* program; and in comparing individual teacher- and center-level response similarities/ differences.

Recommendation P4: For these reasons (plus benefits noted in 3) continue to encourage centers to use the agenda template options to create their own and to post these on the QuarkNet website.

P5. As evident in the narrative of this report, the Data Activities Portfolio has grown substantially during this past grant period and into this new period. Of importance DAP activities, collectively, have been shown to align well with Next Generation Science Standards Science and Engineering Practices. To this end, QuarkNet staff have provided operational definitions to support how this alignment is determined. The DAP activities have also been aligned with the Enduring Understandings of Particle Physics. Noteworthy, these activities are a bridge for teachers to implement QuarkNet content and materials into their classrooms. Many of these activities were modified for online uses expanding implementation options for teachers (with COVID the impetus for this effort). These options can now be used to support in-person instruction. Early efforts have translated several of these activities (and supportive resources) into Spanish. Teacher and student resources have been added; and older activities have been updated, modified, or even removed as scientific knowledge has advanced.

Recommendation P5: The dynamic effort that underlies the DAP is acknowledged and program support to maintain this effort is encouraged.

P6. The number (and the quality) of activities in the DAP has increased dramatically from 2017. This has included applying the review and restructuring of previously developed activities, offering activities by graduated student skill sets, and separating activities by data strand and curriculum topics. As the number of these activities has grown so has the workload for their development and eventual use.

Recommendation P6: Consider adding a select group of lead teachers or fellows to help in this process in the future. These individuals could help the education specialist with DAP activity development as well as have other responsibilities related to updating and augmenting resource information related to these activities.

P7. During the past and present grant period, QuarkNet staff have demonstrated to teachers how to access DAP activities on the website; demonstrated search options and the availability of supportive resources such as teacher notes and student notes. Participating teachers often have had the opportunity to engage in these activities as active learners (as students) and to reflect on their possible use during implementation plan development and discussion that is part of the agendas of the workshops.

Recommendation P7: Continue program efforts to maximize the use of Data Portfolio Activities by teachers at center-led and nationally-led QuarkNet workshops and meetings; and to encourage teachers' classroom implementation of these activities.

P.8 Starting with the 2020-2021 program year, staff created an implementation plan template to help teachers reflect on and develop implementation plans that can be incorporated into teachers' classrooms using QuarkNet content and instructional materials. Staff members have mandated this discussion in nationally-led workshops and they have strongly encouraged this inclusion in center-run workshops. Many of these implementation plans are posted on the QuarkNet website. Early results suggest that this structured approach, that is, time for planning and discussion as well as the implementation templates over a variation of it, -- has helped teacher frame their classroom plans in meaningful ways. It is likely that these program efforts have made it easier for teachers to respond to implementation questions asked in the Update Survey(s). These efforts are valuable for the teachers and are very valuable for the evaluation. Because of these efforts, many implementation plans created by teachers have been incorporated into center-level portfolios that include other qualitative data as well.

Recommendation P8: Continue to incorporate the use of these templates (or a variation of it) and encourage teachers to post these on the QuarkNet website. Documenting these implementation plans will substantially help in providing the narrative as to the *how/what/why* QuarkNet content and materials are used in their classroom. In keeping with this, "coding camps" and workshops use a protocol of "share-out spreadsheets" where implementation plan coding projects are regularly posted by participating teachers. Adopting something similar to this protocol may aid in the consistent documentation of these proposed efforts across all QuarkNet workshops and programs. Regularly posting implementation plans may encourage teachers to post other examples of how QuarkNet content and materials are incorporated into their classrooms.

P9. Sustained duration is among the characteristics of effective professional development identified by Darling-Hammond et al (2017).

Recommendation P9: QuarkNet has been a long-standing program. To support the sustained duration of the program for participating teachers throughout the year, encourage centers to meet during the school year in support of and to augment summer-led events. Although there are other issues such as time commitments and scheduling within a school year, the familiarity and necessity of online remote meetings during the 2020-2023 program years may help centers move in this direction.

P.10. The Program Theory Model offers an approximate fit of QuarkNet as designed and provides a road map as to how change is expected to occur.

Recommendation P10: Reflect on ways in which the Program Theory Model may be used to inform others in the program, those participating in the program (including centers), and those external to the program.

Although not recommendations per se a few additional thoughts are warranted.

Credit goes to QuarkNet staff for a roll-out of a series of mini-workshops for lead teachers at QuarkNet centers (started in the 2021 program year and again in the 2023 program year). Given that nearly all QuarkNet centers are mature (except for a few new centers), staff have taken this opportunity to clarify and expand the roles and responsibilities of lead teachers and to give these teachers a platform to exchange ideas on these possibilities.

QuarkNet staff have proposed during this grant period to hold a series of focus groups across several participating centers (one such meeting was held on December 16, 2023, at the Rice University/University of Houston QuarkNet Center) to help broaden participation to reach more teachers and students who are underrepresented in STEM. This and planned focus groups are intended to augment the in-roads made during this past grant period, through such outreach efforts as the development of STEP-UP classroom materials; or STEAM workshops intended to incorporate art with science concepts and Native American culture as well as increasing the number of schools that serve underrepresented students through representation by QuarkNet teachers.

Finally, QuarkNet staff has done outstanding work to support evaluation efforts and to help embed evaluation efforts and requirements within the structure and delivery of the program. This is reflected in a standing invitation for the evaluator to attend staff-wide weekly meetings, setting aside time during the workshop for the completion of Teacher Surveys (either the full or shorter update versions), as well as coordinating with centers for the Center Feedback process and the virtual workshop site visits by the evaluator during teachers' discussions of implementation plans. The success of the evaluation's implementation is due to this cooperation by QuarkNet staff and is greatly appreciated. As is the participating teachers' willingness to complete the survey (both full and update versions) in a timely and frank manner.

Evaluation Recommendations

The following evaluation summary and recommendations are proffered:

E1. The response rates for the Full Teacher Survey and the Update Survey remain high over the 2019 through 2023 program years (ranging between 78% to 80%). Survey links have been embedded in the agendas of workshops to help facilitate a high response rate. This success is due to the commitment of QuarkNet staff teachers, fellows, and center mentors in allocating time during their workshops and meetings for this purpose. We acknowledge and are grateful for this commitment; and to participating teachers who complete it.

Recommendation E1: Continue to work with QuarkNet staff in their support of evaluation efforts.

E2. The Update Teacher Survey dovetails well with the in-workshop discussions by teachers about implementation plans. These discussions have served the evaluation well (and likely the program) as it provides teachers with a quick means to capture their thoughts in describing how and in what ways teachers plan to or have used QuarkNet program content and materials in their classrooms when completing the Update Survey. During the 2023 program year, there has been an important uptick of teachers posting implementation plans which is very important to help qualitatively describe implementation in-roads of QuarkNet content and materials in the classroom.

Recommendation E2: With QuarkNet staff help, increase the number of teachers who post their implementation plans or ideas on the QuarkNet website.

E3. The use of the Update Teacher Survey has allowed a more in-depth descriptive analysis of the *how/what/why* of the use of QuarkNet content and materials by teachers in the classroom (and reduces the ask of teachers to supply evaluation information) over time. The linking of these surveys (both full and updates) by individual teachers has provided a valuable picture of how these plans and QuarkNet content/material use may have changed over time as participation in QuarkNet continues. Both the review of posted implementation plans and responses from the Update Teacher Survey have helped to provide the story or narrative behind the results of the quantitative analyses; this information is now captured in center-level portfolios along with examples of teacher/student work. (These portfolios are consistent with the use of *authentic assessment* as a means to evaluate performance, “teaching for understanding and application rather than for rote recall.” Darling-Hammond & Snyder, 2000, p. 523.)

Recommendation E3: These qualitative analyses have been expanded during this grant period to provide a more in-depth descriptive look at classroom implementation of QuarkNet content and materials across centers and the program overall. This effort should be continued as these qualitative analyses help to provide a narrative of what classroom implementation of QuarkNet content and materials looks like. Add examples of teacher work, student work, and presentations/posters given at professional conferences when available.

E4. The Center Feedback Template process continues to provide valuable information to compare individual teacher- and center-level views on teacher engagement and on center-level outcomes. For the near future this effort may be put on the back burner and revisions to this process may be explored. This is the case, in part, because the most active centers and those most likely to align their center-level efforts with the national program as well as the Program Theory Model have completed the process.

Recommendation E4. Going forward, we will explore two ends; first, a quick and easy method to assess centers so that individual and center level responses can be compared. Second, it is expected that this revised process will be designed to help jump start or re-ignite centers to help increase their engagement in QuarkNet.

E5. Per recommendation by NSF, we revamped the preliminary quantitative analyses to investigation the unique contribution major QuarkNet components play in the measurement of program engagement and outcomes. These analyses suggest that Data Camp and Variety of Workshops each contribute to teachers' reported engagement in Core Strategies, and that each major program component of QuarkNet contributes uniquely to at least one or more outcome measures: Approach to Teaching; QuarkNet's Influence on Teaching, Student Engagement (as reported by teachers), QuarkNet's Influence on Student Engagement; and Long-term Teacher Outcomes. Thus, these analyses suggest that each of the major components of QuarkNet contribute uniquely to outcomes as measured.

Recommendation E5: Continue to explore the unique contribution of major QuarkNet program components with the caveat that these analyses do not take into consideration the center in which teachers engage in the program (because of sample size limitations).

E6. *Centers Matter.* Teachers principally participate in QuarkNet through centers suggesting the statistical need to account for this nesting of teachers within these centers. Thus, a hierarchical linear regression analysis based on 26 centers (34 combined) explored the relationship between core program strategies, perceived influence QuarkNet has had on classroom teaching practices and implemented instructional practices (Approach to Teaching). The results of this analysis show that QuarkNet's Influence on Teaching, Core Strategies and Centers (as measured by mean Approach to Teaching Scores) are shown to be positively related to teacher use of content and instructional practices in their classrooms (i.e., Approach to Teaching). These results are statistically significant [$F_{(3, 388)} = 73.85$, $p < .001$].

Recommendation E6: Continue to analyze teacher-level outcomes based on nested centers and increase the inclusion of as many teachers and centers in these analyses as is feasible and that meets analysis criteria.

E7. Similarly for Student Engagement, the center in which the teacher participates in QuarkNet *matters*. Thus, a hierarchical linear regression analysis [(based on 25 center (33 centers)] was conducted where QuarkNet's Influence on Student Engagement, Approach to Teaching and Centers (as measured by mean Student Engagement scores) were shown to be positively related Student Engagement [$F_{(3, 329)} = 106.53$, $p < .001$].

Recommendation E7: Modelling student-level outcomes through analyses continue to be challenged where a wide variety of possible relationships may exist suggesting that a stable, reliable model has remained elusive. That said, continue to explore student-level outcomes analyses based on nested centers with the hope that additional data will help to stabilize these results.

E8. Long-term outcomes by participating QuarkNet teachers were measured in a similar fashion. That is, perceived QuarkNet's Influence on Teaching, Student Engagement and Center-level means scores are positively and statistically related to Long-term Outcomes: Teachers [$F_{(4, 306)} = 48.42$, $p < .001$].

Recommendation E8: Since this is the first iteration of these analyses (Long-term Outcomes: Teachers), seek to replicate these findings with additional data collected during subsequent program years.

E9. Qualitative analyses have supported the results of these quantitative analyses by providing descriptive details including examples of classroom implementation plans of QuarkNet content and materials by participating teachers. This information has been compiled in center-level portfolios (as already mentioned) which have included: teacher responses to open-ended survey questions over time as to the *what/how/why* of classroom implementation; examples of implementation plans created by teachers, as well as examples of teacher work, and student work. Examples of presentations at professional conferences are included as well, when available.

Recommendation E9: Continue to explore the development and use of these center-level portfolios.

E10. Continue to work with program staff to help articulate ways in which the PTM can be used and how to facilitate this use. This includes seeing the PTM as representative of the program (as an "approximate fit") and the value of its Theory of Change.

Recommendation E10: It is important that the evaluator remains mindful of the many responsibilities of QuarkNet program staff, mentors and teachers. Work to ensure that evaluation requests are reasonable and doable in a timely manner. And to the extent possible, embed evaluation requests and efforts within the structure and delivery of the program as has been done during this grant period. In addition, work to ensure that evaluation efforts and results are of value (or of potential value) to all those involved in the process. This includes QuarkNet staff and network of partners, advisory board members, participating teachers, NSF and others who may be interested in QuarkNet.

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Brief History of Program

After the cancellation of the Superconducting Super Collider, which occurred in 1993, a concerted effort by a group of physicists was undertaken to help avert what might have resulted in an "impending demise of particle physics research in the U.S." (https://www.nd.edu/stories/causality-principle). This included physicists Randy Ruchti, from Norte Dame; Oliver Baker, from Hampton University; and Michael Barnett, from the Lawrence Berkeley National Laboratory); and, Marge Bardeen an educator (Fermilab educator now emeritus) as well as a commitment from the National Science Foundation and the Department of Energy to support the Large Hadron Collider (LHC) and LHC experiments (QuarkNet proposal, 2018).

In 1999, the National Science Foundation (NSF) affirmed its interest in developing an education and outreach national program across the physics centers in the United States in anticipation of the development of the LHC and to coincide with its support of the LHC and LHC experiments. [The LHC has become the world's largest and most powerful particle collider as part of CERN's (Conseil Européen pour la Recherche Nucléaire) accelerator complex at the European Center for Nuclear Research, with its first started up in September 2008.] In broad terms, the vision for this proposed education and outreach program was to mirror the experience and success of the MarsQuest program (Dusenberry & Lee, 1998), a program started to coincide with an up and coming decade of the exploration of the planet Mars, co-funded by NSF and NASA.

To begin, QuarkNet program stakeholders surveyed as many as 60 research centers to learn what educational and outreach efforts were implemented at these centers, at that time. Results indicated that efforts varied considerably across these centers further underscoring the need for a concerted national effort. From its beginning, QuarkNet focused on bringing teachers into the particle physics research community providing program continuity to participating centers by offering a national network of structured workshops and programs grounded in core program strategies (personal communication, M. Baredeen, September 18, 2018).

Development of the QuarkNet Program Theory Model (PTM)

In sync with the start of the award period (2019-2022), the evaluation began with the development of a Program Theory Model (PTM). The complexity of the program and its network of partners as well as its longevity suggested that the development of such a model was warranted. The creation of a program theory model largely involved making key program components and strategies -- that have evolved and been implemented over time -- explicit and served to help link these to an outcomes-based evaluation.

We used a variety of information sources in its development, including relevant literature on effective professional development; the Next Generation Science Standards (and other relevant standards); and, structured interviews with key program stakeholders. We included a framework that adds program sustainability strategies and outcomes into the mix.

Why a Program Theory Model was Developed

Often the term “logic models” and “program theory models” are used interchangeably. We intentionally use the later term for a variety of reasons. Although logic models often distinctly focus on describing the program as *it is in operation* -- offering an advantage if this is desired -- these models often blur the lines between the designed and implemented program. By developing and using a PTM, we intended to offer a representative picture of how *change* is expected to happen -- at least in theory -- by describing in detail the program *as designed.* PTM models differentiate between the program *as designed* from the program *as implemented* helping to underscore the importance of measuring program fidelity, program “dosage” or participation levels, as well as other operational variables and suggesting at least what, if not how these, might be measured. It also underscores that variations between the *designed* and *implemented* program are expected and that these variations are worth knowing and noting.

Of importance, PTM’s often underscore that the *context* in which the program is implemented *matters*, including program partnerships and supporting institutions. This context can be particularly helpful in suggesting, perhaps the type and continuum of engagement, whether or not to scale-up the program, and, whether replicating or generalizing of the program will work in other settings or situations. And in the case of QuarkNet, the PTM has underscored factors related to the sustainability of the program.

We see the following benefits and uses derived by creating a PTM:

- The program is articulated in a representative way reflecting its integrated components.
- Program strategies and measurable program outcomes logically link together.
- Identified indicators and proposed measures align with priority outcomes.
- Future program modifications, if any, adhere to strategies identified as core to the program.
- Program staff, key stakeholders and the evaluator have a common understanding of the program. (Donaldson, 2007)
- The potential to facilitate the generalization of program and evaluation efforts to other programs with similar goals and outcomes, including participating QuarkNet centers.

These evaluation efforts are consistent with program models or theory of change models that are often developed by evaluators and stakeholders to articulate how program outcomes link to specific program strategies and activities (Brett & Race, 2004; Rogers, Petrosino, Huebner & Hasci, 2000; Race & Brett, 2004; Renger, 2006). As already stated, such models facilitate the achievement of a common understanding of the program by stakeholders and the evaluator (Donaldson, 2007), and serve to conceptualize a program relative to its operation, the logic that connects its activities to the intended outcomes, and the rationale for why the program does what it does (Rossi, Lipsey & Freeman, 2004).

Thus, QuarkNet's PTM:

1. Offers "an approximate fit" of the theory of the QuarkNet program as *designed.*
2. Allows for a comparison between the program as *designed* and as *implemented.*
3. Links core program strategies to program outcomes.
4. Directs evaluation efforts.

It is important to note that although the PTM is intended to be inclusive, both from the standpoint of providing a consensus as to the model's representativeness of the program among key stakeholders and a comprehensive picture of program outcomes, evaluation efforts will focus on key program outcomes and program sustainability efforts. Thus, not all articulated program outcomes are assessed.

Theory of Change

To a large extent the Program Theory Model (described shortly) elaborates on how change is expected to occur, based on following QuarkNet Theory of Change:

By immersing teachers in doing authentic particle physics research and by engaging them in professional development that supports guided-inquiry and standards-aligned instructional practices and materials designed for the classroom, teachers become empowered to teach particle physics to their students in ways that model the actual practices of scientists and support instructional best practices suggested by the educational research literature. (Modified from Beal & Young, QuarkNet Summative Evaluation Report 2012-2017).

The development of a PTM and a Theory of Change is consistent with common guidelines proffered by the Institute of Education Sciences, U.S. Department of Education and the National Science Foundation (2013). Weiss (1995) noted that grounding evaluation in theories of change means integrating theory with practice. She postulated further that making assumptions explicit and reaching consensus with stakeholders about what they are trying to do, and why, and how, may ultimately be more valuable than eventual findings (Weiss, 1995), having more influence on policy and popular opinion (Rallis, 2013).

Model Development

Key steps in the development of the PTM were a series of interviews with key program staff and a meeting with past evaluators.

Initial Interviews with Key Program Stakeholders

An important part of the information-gathering step in creating the PTM was the conduct of structured interviews with key program stakeholders, including the Principal Investigators and staff, and the two past evaluators. To guide these interviews, a written protocol was developed; then, reviewed and revised based on suggestions from the Principal Investigators (PIs). The protocol used for these interviews is presented at the end of this appendix. Each interview was conducted over the phone and most lasted between 1 to 1 ½ hours. As necessary, a second interview was scheduled to complete the information covered in the protocol. All interviews were conducted from September 18, 2018, through October 11, 2018.

There were five general themes discussed during these interviews, to obtain: 1. A general picture of the individual's role and responsibilities in the program; 2. Individual perceptions about program development and implementation; 3. Program strategies that the individual thought essential; 4. Program outcomes for teachers, their students, centers, and others; and, 5. Sustainability issues and concerns for the centers and the national program.

Each interview was digitally recorded, consent of this was verbally obtained, and each individual was given the option of stopping the recording at any time during the interview. These interviews were transcribed, with information extracted with an eye toward informing the PTM and did not necessarily represent a verbatim account of these discussions.

Meeting with Past Evaluators

In addition to these interviews, a face-to-face meeting was conducted with M. Jean Young and Ginny Beal, the two past evaluators, on October 2, 2018, in Tucson, AZ. along with the current evaluator. This was a day-long meeting where past evaluation efforts were discussed as well as plans for future evaluation efforts. Previous evaluation measures were reviewed and discussed as relevant. Although the purpose of this meeting was not solely focused on the development of the PTM, this discussion did inform the model relevant to QuarkNet's program evolution, its structure and core strategies as well as program outcomes related to teachers, centers, and sustainability efforts.

Information from these sources were culled into drafts of the PTM; and, shared and revised during iterative meetings with the PIs and key stakeholders until agreement was reached on the content of its component parts. Once the narrative of the PTM was agreed upon, a graphic presentation of it was created.

QuarkNet: Initial Interview Protocol

After a brief background question, I would like to discuss five main themes with you. These are: 1) your role in this project; 2) your perceptions about program development and implementation; 3) program strategies that you think essential; 4) program outcomes for teachers, students, centers and others; and, 5) sustainability issues and concerns for the centers and the national program. My purpose in our conversation is to use this information, along with other relevant resources, to build a program theory model of QuarkNet and to focus evaluation efforts around core program strategies and program outcomes including long-term sustainability of the program.

It is expected that our conversation will take about 1 to 1 ½ hours and unless you object I will digitally record our conversation for note taking purposes only. At any time, you may ask that I stop recording and I will comply with your request. I will extract information for this and other interviews to form the basis of a program theory model to identify program strategies and suggest logical links to program and long-term outcomes. No responses by individuals will be identified by name unless specific permission to do so is obtained.

I have sought to ask a standard set of questions to get a sense of the varying degrees of stakeholder knowledge about the program. Thus at times, I may ask a question that you may have some or little background information about; at other times a particular question likely will generate a great deal of discussion. Please feel free to proffer ideas or recommendations not asked if you think these are germane or critical to QuarkNet.

Background

I want to start with a few quick background questions.

Please give a brief professional sketch of yourself (as this pertains to your involvement in *QuarkNet*).

Organizationally, how does *QuarkNet* relate to, interconnect or fit within your institution?

Your Role

What is your role in *QuarkNet*? What are your main responsibilities in this program?

Program

Development/Historical Perspective

What ideas, resources, and/or materials were initially used to develop this program? Who was involved in the initial planning of this program?

How or in what ways has *QuarkNet* changed or evolved over the past several years? If relevant please talk about the process as to how this change occurred.

Target Audience/Recruitment

Who do you see as the target audience(s) (in terms of teachers, students, centers, others) of *QuarkNet*?

How are new centers added to *QuarkNet*? What process is or has been used to recruit teachers for in this program? What criteria are used? Is the program reaching the "right" teachers; others?

Program Components

Briefly describe the program strategies or core activities that you think are essential to *QuarkNet*. (Reference either the national program or center-level program or both.) Which of these do you think are most important? Are there program strategies that are not used during the implementation of the program or that could/should be strengthened?

Program Outcomes

I'd like to talk about your perceptions regarding program outcomes for participating teachers, students and participating centers?

What program outcomes do you believe are the most important for teachers to gain from this program? What are the long-term outcomes you believe would result from program participation by teachers? How do identified program outcomes link to core program components?

What outcomes do you believe are the most important to gain for the national program? What outcomes do you believe are the most important for participating centers? How about students? Any others?

What level of evidence of program impact do you and/or your institution need to sustain your involvement in the program?

Partnership/Sustainability

What are the barriers or challenges to an institution's participation in *QuarkNet*? What program or infrastructure components do you think need to be put in place in order for an institution to sustain its participation in this program within the 5-year grant period or beyond?

What criteria or measures do you think we should used to gauge program sustainability among program centers? For the national program?

What do you think the program can do to help assist centers in their efforts to sustain *QuarkNet* through their own funding efforts?

Is there anything else that you want to share regarding the program or your involvement?

QuarkNet Partners

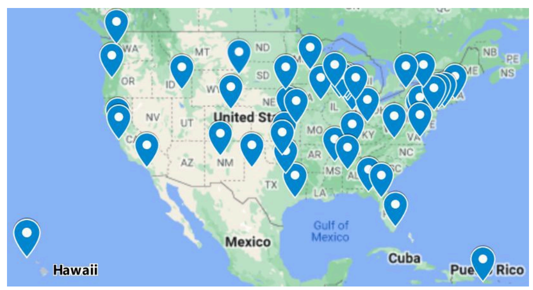
NSF: The National Science Foundation is an independent federal agency created by Congress in 1950 "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…" NSF supports basic research and people to create knowledge that transforms the future. QuarkNet is funded through NSF's Integrative Activities in Physics Program.

Fermilab: America's particle physics and accelerator laboratory whose vision is to solve the mysteries of matter, energy, space and time for the benefit of all. Fermilab, a co-sponsor of QuarkNet, hosts Data Camp held each summer and supports the cosmic ray studies program. Fermilab hosts DUNE and the Long-Baseline Neutrino Facility. DUNE brings together over 1,000 scientists from more than 175 institutions in over 30 countries.

Broadening Participation and Community Outreach: QuarkNet works on multiple fronts to help broaden participation beyond the existing community, including teachers and students who are underrepresented in physics. Examples include center needs assessment workshops that serve to identify ways to reach out to these communities. QuarkNet partners with other STEM organizations to reach more teachers and students. Recent partners are *STEP UP, STEMarts Lab, and i.am.Angel Foundation.* Many Data Activities Portfolio activities have been translated into Spanish. Often, participating teachers develop classroom implementation plans that integrate culturally sensitive content. Centers integrate QuarkNet in their community outreach efforts, partnering to reach beyond existing QuarkNet schools to students traditionally underrepresented in STEM.

Advisory Board: Typically, eight to ten individuals both familiar with and new to the program meet annually to review QuarkNet program achievements and make recommendations for future plans and objectives. Members represent a diverse mix of high school physics teachers, education administrators, research physicists and physics outreach leaders.

QuarkNet: The QuarkNet Collaboration is a long-term, national program that *partners high school science teachers with particle physicists* working in experiments at the scientific frontier. A professional development program, QuarkNet immerses teachers in authentic physics research and seeks to engage them in the development of instructional strategies and best practices that facilitate the implementation of these principles in their classrooms.



QuarkNet Centers: Centers both form the essential backbone of and are partners in QuarkNet. A center is housed at a university or laboratory, serving high school physics and physical science teachers; active local centers number 50+.

IRIS-HEP: A software institute funded by the National Science Foundation. It aims to develop the state-of-the-art software cyberinfrastructure required for the challenges of data intensive scientific research at the High Luminosity Large Hadron Collider (HL-LHC) at CERN, and other planned HEP experiments of the 2020's. In partnership with IRIS-HEP, QuarkNet offers professional development opportunities for teachers to improve coding skills to enhance classroom implementation of particle physics instructional materials.

U.S. ATLAS: A collaboration of scientists from 45 U.S. institutions. ATLAS is one of two general-purpose detectors at the Large Hadron Collider in Geneva, Switzerland. The ATLAS experiment investigates a wide range of physics, from the search for the Higgs boson to extra dimensions and particles that could make up dark matter. U.S. ATLAS is a co-sponsor of QuarkNet.

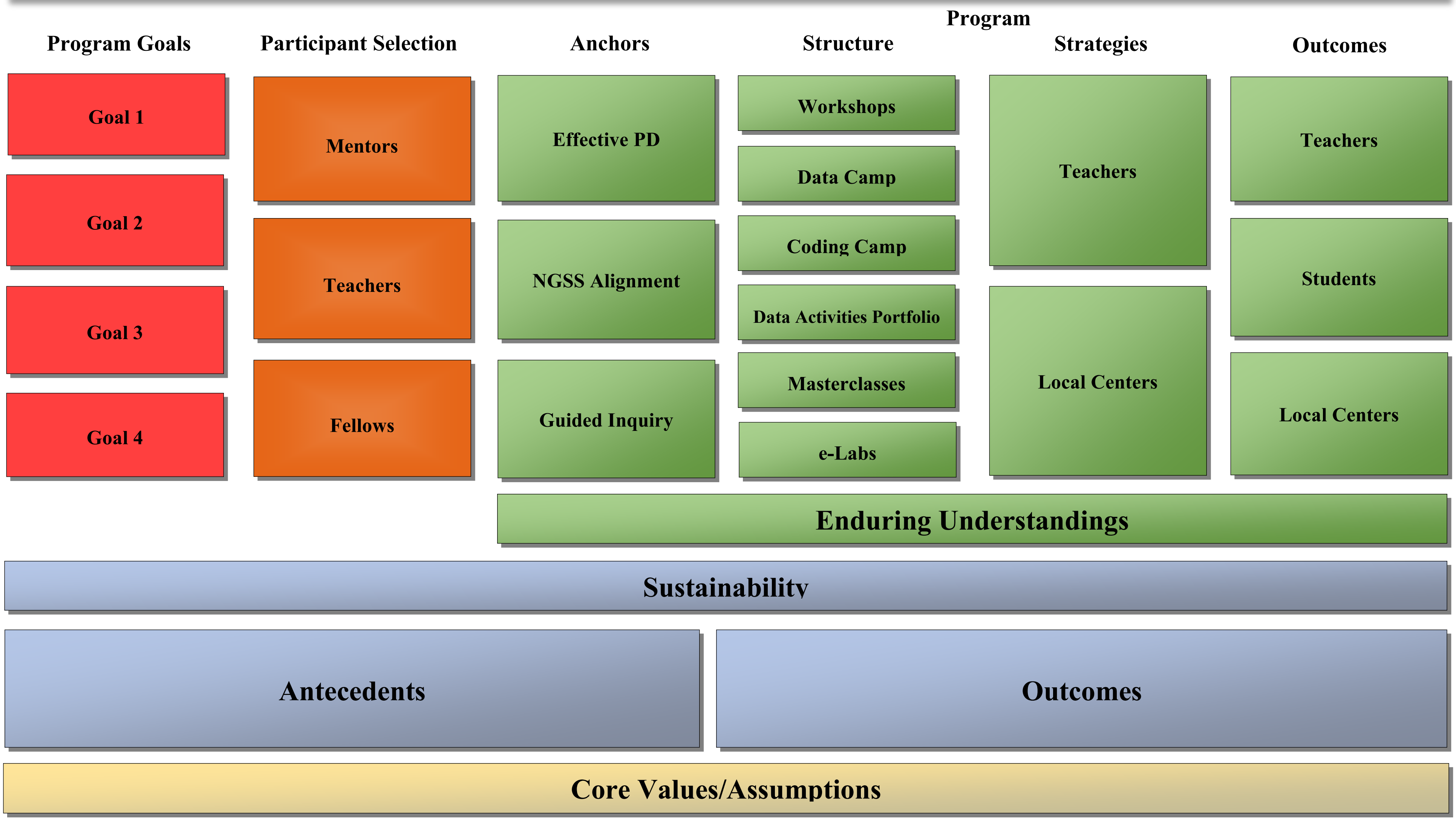
U.S. CMS: A collaboration of more than 900 scientists from 50 U.S. institutions who make significant contributions to the Compact Muon Solenoid (CMS) detector. Discoveries from the CMS experiment are revolutionizing our understanding of the universe. USCMS is a co-sponsor of QuarkNet.

Broader Impacts: QuarkNet has led in facilitating the public use of large particle physics datasets. Working within the International Particle Physics Outreach group (IPPOG), QuarkNet shares the overall central coordination of International Masterclasses (IMC). QuarkNet schedules and coordinates ATLAS, CMS, MINERvA and NOvA International Masterclasses with videoconferences based at Fermilab. Also, QuarkNet develops and coordinates World Wide Data Day, an IMC extension, and shares leadership in the global cosmic ray studies project. QuarkNet provides a wealth of information for IPPOG members to consider in their own education and outreach programs. QuarkNet staff and teachers attend and present at meetings of the American Association of Physics Teachers and the American Physical Society. These presentations have highlighted how QuarkNet works, e-Labs, the Data Activities Portfolio and scientific discovery for students.

QuarkNet Program Theory Model

Program Statement: The QuarkNet Collaboration is a long-term, national program that partners high school science teachers with particle physicists working in experiments at the scientific frontier. A professional development program, QuarkNet immerses teachers in authentic physics research and seeks to engage them in the development of instructional strategies and best practices that facilitate the implementation of these principles in their classrooms.

Centers: QuarkNet delivers its professional development program in partnership with local centers.



QuarkNet Program Theory Model

Program Statement: The QuarkNet Collaboration is a long-term, national program that partners high school science teachers with particle physicists working in experiments at the scientific frontier. A professional development program, QuarkNet immerses teachers in authentic physics research and seeks to engage them in the development of instructional strategies and best practices that facilitate the implementation of these principles in their classroom.

QuarkNet delivers its professional development program in partnership with local centers.
QuarkNet Centers: Centers both form the essential backbone of and are partners in QuarkNet. A center is housed at a university or laboratory, serving primarily teachers who live within reasonable commuting distances. An online center, the Virtual Center, provides a home for teachers who no longer live close to a particle physics research group. At the center, program leaders include one or two particle physicists who serve as mentor(s) and team up with one or two lead teacher(s). Each center seeks to foster lasting relationships through collaboration at the local level and through engagement with the national program.

Program Goals

Measurable professional development (PD) goals are:
Goal 1: To continue a PD program that prepares teachers to provide opportunities for students to engage in scientific practices and discourse and to show evidence that they understand how scientists develop knowledge. To help teachers translate their experiences into instructional strategies, which reflect guided inquiry and NGSS science and engineering practices.

Goal 2: To sustain a national network of independent centers working to achieve similar goals. To provide financial support, research internships, an instructional toolkit, student programs and professional development workshops. To investigate additional funding sources to strengthen the overall program.

Goal 3: To reenergize teachers and aid their contributions to the quality and practice of colleagues in the field of science education.

Goal 4: To provide particle physics research groups with an opportunity for a broader impact in their communities.

Participant Selection

Teachers: High school physics/physical science teachers who express interest in QuarkNet and/or who are invited to participate through staff, fellows, or mentors/ center teachers. Mentors may know high school teachers who would be good additions to their research team and/or who may become associate teachers at the center.

Mentors: Particle physics researchers working at a university or laboratory who have expressed interest in participating in QuarkNet. Mentors propose a research project, identify a mentor team, and describe previous outreach experience. Staff and PIs approve before adding the mentors/centers to the QuarkNet network.

Fellows: QuarkNet teachers who are invited by staff to become fellows based on participants' experiences working with a local center or on national programs such as Data Camp.

Program Anchors

Characteristics of Effective Professional Development[1]

- Is content focused
- Incorporates active learning utilizing adult learning theory
- Supports collaboration, typically in job-embedded contexts
- Uses models and modeling of effective practice
- Provides coaching and expert support
- Offers opportunities for feedback and reflection
- Is of sustained duration

[1]Darling-Hammond, L., Hyler, M.E., & Gardner, M. (2017, June). Effective teacher professional development. Palo Alto, CA: Learning Policy Institute.

Pedagogical and Instructional Best Practices
Aligns with the Science and Engineering Practices of the NGSS. APPENDIX F – Science and Engineering Practices in the NGSS (2013, April). As suggested, these practices are intended to better specify what is meant by inquiry in science. Science and Engineering Practices

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Content addresses **Disciplinary Core Ideas and Crosscutting Concepts** (NGSS):

1. Patterns
2. Cause and Effect
3. Scale, Proportion and Quantity
4. Systems and System Models
5. Energy and Matter in Systems
6. Structure and Function
7. Stability and Change of Systems

Guided Inquiry
Guided inquiry (teacher provides problem or question) and Structured inquiry (where teacher provides problem and procedure) [Herron, M.D. (1971). The nature of scientific enquiry. *School Review, 79*(2), 171- 212.] **Guided Inquiry** - The **solution is not already existing/known in advance** and could vary from student to student. **Students EITHER investigate a teacher-presented question** (usually open-ended) **using student designed/selected procedures OR investigate questions that are student formulated** (usually open-ended) **through a prescribed procedure** (some parts of the procedure may be student designed/selected). (2007 Jan-Marie Kellow)

Program Structure

Data Camp: Offered annually at Fermilab, this 1-week summer program is an introductory workshop for teachers of physics and physical science who either have had little-to-no experience with particle physics and/or who have had little experience with quantitative analysis of LHC data. The camp emphasizes an authentic data analysis experience in which teachers engage as active learners (as students) of a challenging topic they may have known very little about. In the beginning of the week, teachers receive an authentic CMS dataset and work in small groups to determine the mass of particles produced during LHC proton-proton collisions. Successful completion of this phase of the workshop culminates in each group presenting and explaining their analyses. In the second half of the week, teachers explore various instructional materials in the Data Activities Portfolio that help incorporate particle physics concepts into their everyday lessons and propose an implementation plan for their classrooms. Throughout the week, teachers take tours and participate in seminars from theoretical and experimental physicists.

Coding Camp: A virtual 1-week program offered annually in the summer for teachers of physics and physical science with little-to-no experience in computer programming and/or incorporating computer science into their courses. The camp emphasizes an authentic data analysis experience in which teachers engage as active learners (as students) using common scientific programming software (e.g., Jupyter, Python, & SciPy) to analyze and visualize large datasets from various scientific disciplines, including particle physics, astronomy, and geology. Like Data Camp, during the first half of the week, teachers are learners of challenging content, In the second half, they use reformed pedagogy in planning how to integrate coding into their courses. Throughout the week, teachers participate in virtual seminars with scientists and programmers working in various fields.

Data Activities Portfolio: An online compendium of particle physics classroom instructional materials organized by data strand, level of student engagement, curriculum topics and NGSS Standards. Instructional materials conform to a specific instructional design and are aligned with NGSS and AP science standards (Physics 1 and Physics 2) as relevant. Materials are based on authentic experimental data used by teachers to give students an opportunity to learn how scientists make discoveries. Strands include LHC, Cosmic Ray Studies, and Neutrino. Level descriptions, 0 to 4, explain the data analysis skills that students apply at each level: tasks in Level 0 are simpler than those in Levels 1 and 2. While each level can be explored individually, students who start in one level and progress to more complex levels experience increasingly engaging and challenging tasks.

Each curriculum topic provides connections between topics routinely covered in physics class and particle physics content and methods. The drop-down menus identify activities related to desired content and student skill sets. Teacher, student resources and data sets are available for each activity. In the Curriculum Topic drop-down menu, Spanish Language versions are available for some activities. Also, coding activities are available.

Masterclass, QuarkNet Model: A one-day event in which students become "particle physicists for a day." Teachers and mentors participate in an orientation, either remote or in person, by QuarkNet staff or fellows. Teachers implement up to three hours of classroom activities prior to a masterclass. Then, during the masterclass that usually takes place at a center, mentors introduce students to particle physics, and teachers explain the measurements they will make using authentic particle physics data. Working in pairs, students analyze data from visual event displays, characterize the events, pool their data with peers, and draw conclusions. Students are helped by and discuss interpretation of data with one or more particle physicists and their peers and teachers. At the end of the day, students may gather by videoconference with students at other sites to discuss results with moderators, who are particle physicists, at Fermilab, CERN, or another high energy physics facility. Some masterclasses take place at school with teachers providing the particle physics and measurement information. QuarkNet Masterclasses are part of a larger program, International Masterclasses.

Workshops: The primary vehicle through which participating QuarkNet teachers receive professional development. Teachers engage in QuarkNet workshops when new to the program and often over multiple years.

Workshops are in-person events held at a center. (A virtual center accommodates teachers from a dispersed area.) QuarkNet staff work with individual centers to build this experience with considerable flexibility to organize workshops that meet local needs and interests. Workshops vary in length, from 1-to-5 days, typically occur during the summer, but many centers may meet during the summer and school year. Workshops can be locally led or nationally led and are often a combination of the two, thus varying in content and structure. Nationally-led workshops, conducted by QuarkNet staff and/or fellows, cover content including, for example, cosmic ray studies, LHC or neutrino data, coding in support of particle physics, and related activities from the Data Activities Portfolio. Nationally-led workshops support opportunities for teachers to engage as active learners, as students, engage in activities from the Data Activities Portfolio, collect and analyze data, work in a learning-community environment, learn and share ideas related to content and pedagogy, and build collegial relationships with other teachers, fellows and mentors. Of importance, teachers have time to develop and discuss classroom implementation plans. Often locally- led workshops mirror these components and offer opportunities for teachers to tour local research labs, participate in unique events, and/or hear presentations by local physicists and students.

Staff encourage centers to post their agendas and annual reports on the QuarkNet website to share this engagement with other centers. Often, centers collaborate with other centers (e.g., rotating host responsibilities from one year to the next), join together through shared interests or content needs and other opportunities for multi-center engagement.

e-Lab: A browser-based online platform in which students can access and analyze data in a guided-inquiry scientific investigation. An e-Lab provides a framework and pathway as well as resources for students to conduct their own investigations. e-Lab users share results through online plots and posters. In the CMS e-Lab, data are available from the Compact Muon Solenoid (CMS) experiment at CERN[2]'s Large Hadron Collider (LHC). In the Cosmic Ray e-Lab, users upload data from QuarkNet cosmic ray detectors located at high schools, and once uploaded, the data are available to any and all users.

[2] Conseil Européen pour la Recherche Nucléaire

Cosmic Ray Studies: Across most centers, QuarkNet supports a high school long-term collaboration based on the High Energy Physics model using particle detectors provided in kit form. In this hands-on learning opportunity, students assemble the parts into a working scientific instrument based on the design used in the Collider Detector at Fermilab. Students and their teachers use the detectors for inquiry-based learning involving authentic research tasks and experiments such as muon flux, muon lifetime, and speed of muons, using data they collect themselves. Their data can be uploaded to the cosmic ray e-Lab for analysis, creating graphed plots to display results.

Cosmic Watches: Smaller more portable particle detectors, cosmic watches extend the reach of authentic research activity to all students, not just research groups, by moving cosmic ray studies into classrooms increasing the number of teachers using cosmic rays to teach about elementary particles and observing the invisible.

Program Strategies

QuarkNet is not static but evolves to reflect changes in particle physics and the education context in which it operates.

Teachers

Provide opportunities for teachers to be exposed to:

- Instructional strategies that model active, guided-inquiry learning (see NGSS science practices).
- Big Idea(s) in Science (cutting-edge research) and Enduring Understandings (in particle physics).

Provide opportunities for teachers to:

- Engage as active learners, as students.
- Do science the way scientists do science.
- Engage in authentic particle physics investigations (that may or may not involve phenomenon known by scientists).
- Engage in authentic data analysis experience(s) using large data sets.
- Develop explanations of particle physics content.
- Discuss the concept of uncertainty in particle physics.
- Engage in project-based learning that models guided-inquiry strategies.
- Share ideas related to content and pedagogy.
- Review and select particle physics examples from the Data Activities Portfolio instructional materials.
- Use the pathways, suggested in the Data Activities Portfolio, to help design implementation plan(s).
- Construct classroom implementation plan(s), incorporating their experience(s) and Data Activities Portfolio instructional materials.
- Become aware of resources outside of their classroom.

Local Centers

Each center seeks to foster lasting relationships through collaboration at the local level and through engagement with the national program.

In addition, through sustained engagement provide opportunities for teachers and mentors to:

- Interact with other scientists and collaborate with each other.
- Build a local (or regional) learning community.

Program Outcomes

Teachers

Translate their experiences into instructional strategies, which reflect guided inquiry and NGSS science and engineering practice and other science standards as applicable[3,4] Specifically:

- Discuss and explain concepts in particle physics.
- Engage in scientific practices and discourse.
- Use particle physics examples, including authentic data, when teaching subjects such as momentum and energy.
- Review and use instructional materials from the Data Activities Portfolio, selecting lessons guided by the suggested pathways.
- Facilitate student investigations that incorporate scientific practices.
- Use active, guided-inquiry instructional practices in their classrooms that align with NGSS and other science standards.
- Use instructional practices that model scientific research.
- Illustrate how scientists make discoveries.
- Use, analyze and interpret authentic data; draw conclusions based on these data.
- Become more comfortable teaching inquiry-based science.
- Use resources (including QuarkNet resources) to supplement their knowledge and instructional materials and practices.
- Increase their science proficiency.
- Develop collegial relationships with scientists and other teachers.
- Are lifelong learners.

4 College Board Advanced Placement science standards and practice; and AP Physics; International Baccalaureate Science standards and practices.

5 To the extent possible in their school setting.

(And their) Students will be able to:

- Discuss and explain particle physics content.
- Discuss and explain how scientists develop knowledge.
- Engage in scientific practices and discourse.
- Use, analyze and interpret authentic data; draw conclusions based on these data.
- Become more comfortable with inquiry-based science.

Local Centers

- Model active, guided-inquiry instructional practices that align with NGSS and other science standards that model scientific research.

Through engagement in local centers

Teachers as Leaders:

- Act in leadership roles in local centers and in their schools (and school districts) and within the science education community.
- Attend and/or participate in regional and national professional conferences sharing their ideas and experiences.

Mentors:

- Become the nexus of a community that can improve their teaching, enrich their research and provide broader impacts for their university.

Teachers and Mentors:

- Form lasting collegial relationships through interactions and collaborations at the local level and through engagement with the national program.

Enduring Understandings (See last page.)

Sustainability[a]

Antecedents

Characteristics of the Specific Program
1. Fidelity to PTM core strategies as implemented (national or center level)[b]
2. Evidence of flexibility/adaptability at the center level (if/as needed)
3. Evidence of effectiveness

Organizational Setting at the Center-level Program[c]
1. (Good) fit of program with host's organization and operations
2. Presence of an internal champion(s) to advocate for the program
3. Existing capacity and leadership of the organization to support program
4. Program's key staff or clients believe in the program (believe it to be beneficial)

Specific Factors Related to the Center-level Program
1. Existing supportive partnerships of local organizations (beyond internal staff)
2. Potentially available/existing funders or funding
3. Manageable costs (resources and personal; supported by volunteers)[d]

Outcomes

1. Program components or strategies are continued (sustained fidelity in full or in part).[e]
2. Benefits or outcomes for target audience(s) are continued.[e]
3. Local/center-level partnerships are maintained.[f]
4. Organizational practices, procedures and policies in support of program are maintained.
5. Commitment/attention to the center-level program and its purpose is sustained.[f]
6. Program diffusion, replication (in other sites) and/or classroom adaptation occur.[f]

Core Values/Assumptions

QuarkNet provides opportunities:
1. That seek to meet the needs and interests of participating teachers.
2. For participating teachers and mentors to form collegial relationships that are an integral part of the QuarkNet experience.
3. Where participating teachers are professionals.
4. For teachers to get together to discuss physics and to form learning communities.
5. Where QuarkNet centers are central to building a national program and are an effective way to do outreach.
6. Where QuarkNet fellows are integral in helping the program reach teachers.
7. To help keep high school physics teachers interested and motivated in teaching and to help teachers avoid burnout.
8. Where a diversity of ideas is brought into the program to help the long-term commitment by teachers/mentors to the program.
9. To help build and improve science literacy in teachers and their students.
10. To help teachers build confidence and comfort in teaching guided-inquiry physics.

The program is based on the premise that:

11. All students are capable of learning science.
12. Science is public, especially in physics where many researchers collaborate together on the same experiments.
13. The program should strive to achieve equity in language and behavior relative to race, ethnicity and gender.
14. Through the program, teachers are able to go back to their classroom with enthusiasm and with ideas that they can use to appeal to the imagination of their students.
15. Master teachers as staff are effective PD facilitators and center contacts.

---

[a]This framework is based on the work of Scheirer and Dearing (2011); adopting their definition of sustainability, as well: "Sustainability is the continued use of program components and activities for the continued achievement of desirable program and population outcomes" (p. 2060). The QuarkNet Sustainability framework has been modified to better reflect the QuarkNet program (as recommended by Scheirer, et al., 2017). (See notes below.)

[b]Program fidelity, as *implemented*, has been added as a program characteristic.

[c]The language used to describe these organizational characteristics has been modified slightly to better fit the *QuarkNet* program.

[d]This cost component was moved to environmental or contextual concerns of the specific program.

[e]The order of these two outcomes are reversed from the original.

[f]The language of this characteristic was modified to better fit the QuarkNet program.

Enduring Understandings of Particle Physics

1. Scientists make a claim based on data that comprise the evidence for the claim.
2. Scientists use models to make predictions about and explain natural phenomena.
3. Scientists can use data to develop models based on patterns in the data.
4. Particle physicists use data to determine conversation rules.
5. Indirect evidence provides data to study phenomena that cannot be directly observed.
6. Scientists can analyze data more effectively when they are properly organized; charts and histograms provide methods of finding patterns in large datasets.
7. Scientists form and refine research questions, experiments and models using observed patterns in large data sets.
8. The Standard Model[5] provides a framework for our understanding of matter at its most fundamental level.
9. The fundamental particles are organized according to their characteristics in the Standard Model.
10. Particle physicists use conservation of energy and momentum to measure the mass of fundamental particles.
11. Fundamental particles display both wave and particle properties, and both must be taken into account to fully understand them.
12. Particle physicists continuously check the performance of their instruments by performing calibration runs using particles with well-known characteristics.
13. Well-understood particle properties such as charge, mass, momentum and energy provide data to calibrate detectors.
14. Particles that decay do so in a predictable way, but the time for any single particle to decay, and the identity of its decay products, are both probabilistic in nature.
15. Particle physicists must identify and subtract background events in order to identify the signal of interest.
16. Scientists must account for uncertainty in measurements when reporting results.

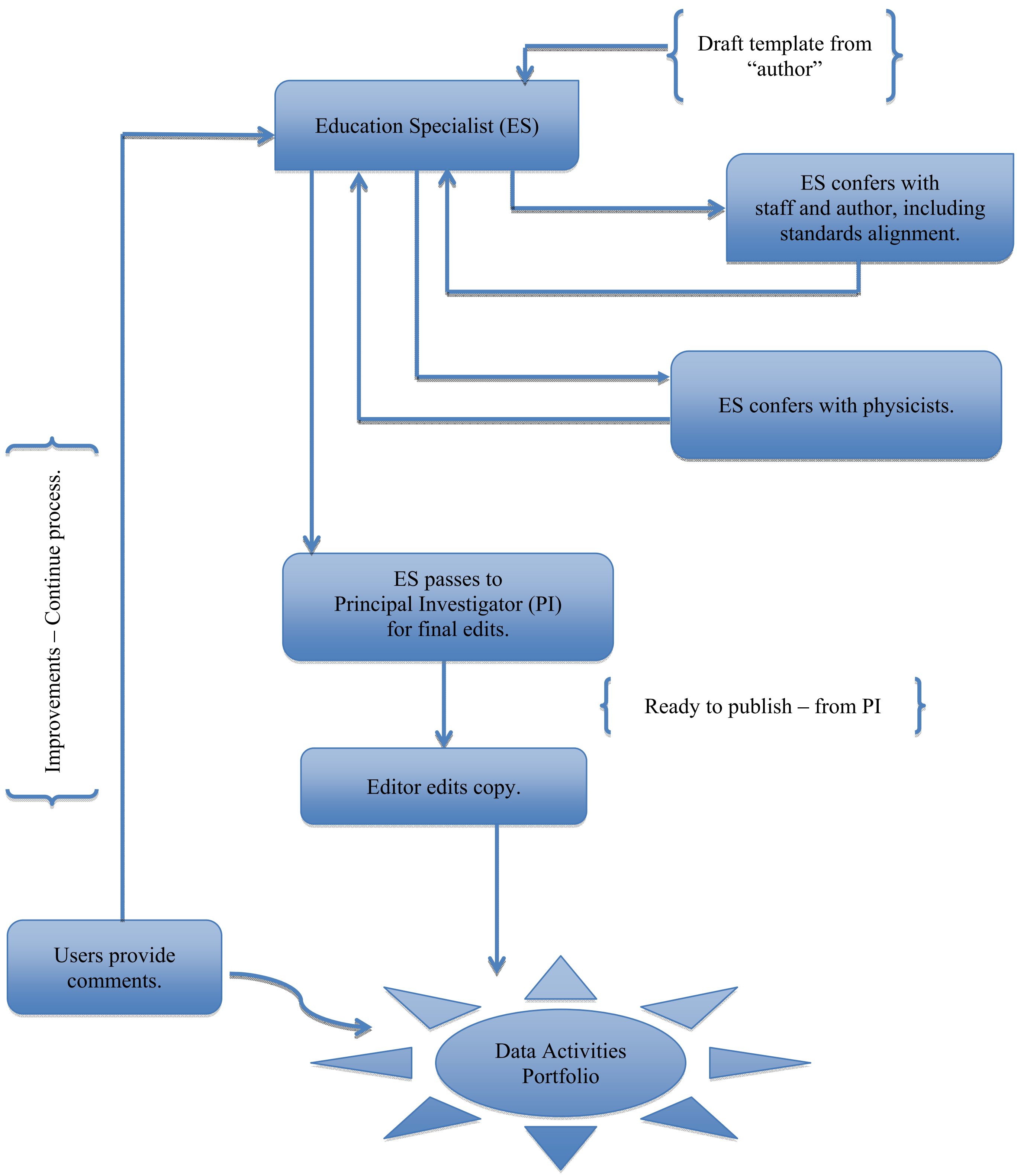
Based on the work of: Darling-Hammond, L., et al. (2017, June) and Wiggins, G. J. & McTighe, J. (2005). Developed for QuarkNet by Young, Roudebush, Smith & Wayne, 2019, revised 2021.

[5] The Standard Model of Particle Physics: the current theoretical framework that describes elementary particles and their forces (six leptons, six quarks and four force carriers). Physicists (and other scientists) can understand every phenomenon observed in nature by the interplay of the elementary particles and forces of the Standard Model. The search beyond the Standard Model of Particle Physics may lead to a larger, more elegant "theory of everything."

Graphics: L. Hudson 2023

Instructional Design Pathway and Templates for Data Activities Portfolio

PROCESS: To ensure what we publish is of highest quality.



<u>CRITERIA USED AT INSTRUCTIONAL DESIGN STAGE – ANNOTATED</u>

In line with the NGSS Framework*

Exemplars:

1. Includes a question to address and/or problem to solve; could be developing a model to explain a phenomenon or test a model. – Science Practices
2. Students gather data and/or test solutions; provide claims, evidence and reasoning. – Science Practices
3. Addresses crosscutting concept(s) and disciplinary core ideas

In line with the Common Core Literacy Standards**

Reading Exemplars:

1. 9-12.4 Determine the meaning of symbols, key terms . . .
2. 9-12.7 Translate quantitative or technical information . . .

In line with the Common Core Mathematics Standards**

Exemplars:

1. MP2. Reason abstractly and quantitatively.
2. MP5. Use appropriate tools strategically.
3. MP6. Attend to precision.

In line with AP Physics 1 Curriculum Framework Standards***

Exemplars:

1. EK 3.A.2: Forces are described by vectors.
2. EK 3.B.1: If an object of interest interacts with several other objects . . .
3. EK 3.C.3: A magnetic force results from the interaction of a moving . . .

In line with AP Physics 2 Curriculum Framework Standards****

Exemplars

1. EK 1.E.6.a: Magnetic dipole moment is a fundamental source . . .
2. EK 3.A.2: Forces are described by vectors.
3. EK 3.C.3: A magnetic force results from the interaction of a moving . . .

In line with IB Physics Standards*****

Standard 1: Measurement and Uncertainty
Standard 5: Electricity and Magnetism

**A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, National Research Council, 2012. https://www.nextgenscience.org/

**The Common Core State Standards for English Language Arts & Literacy in History/Social Studies, Science, and Technical Subjects, Council of Chief State School Officers (CCSSO) and the National Governors Association (NGA), 2019. http://www.corestandards.org/read-the-standards/

***AP Physics 1: Algebra-Based Course and Exam Description, College Board, 2017. https://secure-media.collegeboard.org/digitalServices/pdf/ap/ap-physics-1-course-and-exam-description.pdf

****AP Physics 2: Algebra-Based Course and Exam Description, College Board, 2017. https://secure-media.collegeboard.org/digitalServices/pdf/ap/ap-physics-2-course-and-exam-description.pdf

*****International Baccalaureate Physics (SL) Standards, IB Diploma Programme, 2016. https://www.ibo.org/globalassets/publications/recognition/physicssl2016englishw.pdf

International Baccalaureate Physics (HL) Standards, IB Diploma Programme, 2016. https://www.ibo.org/globalassets/publications/recognition/physicshl2016englishw.pdf

Macro Design

1. Activity addresses a 'big idea' (core idea); sub-ideas support the big idea (can be concepts and/or principles).

   Often, this is the same as or similar to the enduring understanding. A core idea can be as basic as "calibration," a classic physics concept such as "momentum," or a principle (law) such as $E = mc^2$. Research indicates that students come away from a well-structured lesson/activity with an understanding that they maintain even through life (it "endures"). Over time they lose the details but not the enduring understanding.

2. Students apply science process skills and/or design technology.

   There are a variety of skills that students learn in *doing* science. These include all the ways students use data as well as thinking/reasoning skills such as compare/contrast, infer/predict. Design technology means the process of design-develop-test-redesign-redevelop-retest . . . i.e., engineering.

3. Format is guided inquiry.

   Over the years, QuarkNet teachers have developed the understanding that in doing particle physics, students and teachers can learn best facilitated by guided, not open, inquiry. While leading/facilitating is important, such as asking clarifying questions, learning particle physics depends on difficult concepts, principles and procedures that need more guidance than some other science fields.

4. The conceptual framework is from simple to complex and supports activities that can include an "enrichment" or follow-on section.

   The conceptual framework is embodied in the Data Activities Portfolio (DAP). The DAP organizes activities by data strand, pathway and level of student engagement. Activities differ in complexity and sophistication—tasks in Level 0 are designed to build skills needed for higher levels. Level 1 activities are simpler than those in Levels 2 and 3. While each level can be explored individually, students who start in one level and progress to more complex levels experience increasingly challenging tasks. Pathways suggest activity sequences designed to develop understanding of a particular concept. Also, teachers can select activities to offer a learning experience of an appropriate length and level for their students.

Level Definitions

Level 0 Students builds background skill and knowledge needed to do a Level 1 activity. Students analyze one variable or they determine patterns, organize data into a table or graphical representation and perform simple calculations.

Level 1 Students use background skills developed in Level 0. They calculate descriptive statistics, seek patterns, identify outliers, confounding variables, and perform calculations to reach findings; they may also create graphical representations of the data. Datasets are small in size. The data models come from particle physics experimentation.

Level 2 Students use skills from Level 1. They perform many of the same analysis tasks but must apply a greater level of interpretation in order to distinguish between signal and background. Datasets are medium in size so that mathematical calculations are too large to be done using pencil and paper.

Level 3 Students use the skills from Level 2. They develop and implement a research plan utilizing large datasets. They make decisions in their analysis by taking into consideration complications such as background, signal to noise, and instrumentation effects.

Level 4 Students use the skills from Level 3. They identify datasets and develop analysis tools for the investigation of their own research plan.

Micro Design

1. There are behavioral objectives.

   The objectives start with a verb (what you want students to know and be able to do) and/or the action (behavior) is implicit in the objective. The objectives should ALL be measurable since they will drive what is in the assessment: Did students learn what you wanted them to know? Did they exhibit the skill you wanted them to learn?

2. There are connections to the real world such as awareness of scientific exploration, contemporary physics research, the skills that scientists use, and the importance of scientific literacy.

   Since one of the QuarkNet goals is for students to become more scientifically literate, it is important that the activities help them better understand what doing science actually involves and how scientists pursue science. This may include statements such as "This is what they do at CERN" or "This is how scientists do . . ." to ensure these data are useable/reliable/accurate."

3. Students analyze data to come up with a hypothesis/solution/explanation; they apply reasoning including critiquing their ideas; e.g., identify flaws in their argument.

   A main focus of the NGSS, Common Core, AP Physics 1, AP Physics 2, and IB is for students to be able to make a claim based on evidence and reasoning. Often, the final "reasoning" part is missing. They can describe the evidence, but they fail to make the logical reasoning to connect the data with the conclusion they draw. Students must be able to back up their conclusion with an evaluation of the extent to which their data is "good" evidence to support the conclusion.

4. Evaluation/assessment is based on whether or not the objectives are achieved; questions refer directly to the objectives. There are no distractions or extraneous ideas.

   Several activities will have a student report sheet. This could be used as the summative assessment if the objectives are aligned with the report sheet. Learning a skill, such as developing a histogram, can be a formative assessment that may or may not become part of the report sheet but is nonetheless assessed. Formative assessment may be just checking student work informally. If there is more that can be added to the activity, there might be an enrichment section. Adding extra ideas at the assessment stage, distractions and extraneous ideas, confuses the students about what you want them to know and be able to do.

   A sample template for an activity follows; this sample shows font size, type and other formatting that your activity must follow.

TITLE (*TIMES NEW ROMAN, 18*)

TEACHER NOTES (*TIMES NEW ROMAN, 16*)

(*TIMES NEW ROMAN, 12*)

DESCRIPTION (THIS TYPE OF STYLE CAN BE FOUND UNDER *FORMAT, FONT, SMALL CAPS*.)

Briefly provide an overview and purpose of the activity. *For example:* From where do cosmic rays come? Can they be from the sun? Or are they from elsewhere but blocked by the sun? Students search for a specific data file in the Cosmic Ray e-Lab and look for evidence of the passage of the sun in the flux measurements derived from this file. Many people new to studying cosmic rays initially *think* that cosmic rays originate in our sun. This activity allows students to investigate this idea and study evidence that can confirm or refute their original understanding. An e-Lab user collected data with the detector in a configuration that allowed the detector's axis to sweep across the sun at local solar noon including data before and after the sun's transit. Data collected at the beginning and end of the sweep provide the "control" or no effect from the sun, while solar noon provides data on effect of the sun. (*Layout, after, 5 pt* between paragraphs)

STANDARDS ADDRESSED (FILL IN AS APPROPRIATE. THIS LIST SHOWS FORMAT.)

Next Generation Science Standards

Science and Engineering Practices

4. Analyzing and interpreting data
5. Using mathematics and analytical thinking

Crosscutting Concepts

1. Observed patterns

Common Core Literacy Standards

Reading

9-12.4 Determine the meaning of symbols, key terms . . .

9-12.7 Translate quantitative or technical information . . .

Common Core Mathematics Standards

MP2. Reason abstractly and quantitatively.

AP Physics 1 Standards

Exemplars

AP Physics 2 Standards

Exemplars

IB Physics Standards

Exemplars

ENDURING UNDERSTANDINGS

- One EU per activity

Choose from one of the following:

1. Scientists make a claim based on data that comprise the evidence for the claim.
2. Scientists use models to make predictions about and explain natural phenomena.
3. Scientists can use data to develop models based on patterns in the data.
4. Indirect evidence provides data to study phenomena that cannot be directly observed.
5. Scientists can analyze data more effectively when they are properly organized; charts and histograms provide methods of finding patterns in large data sets.
6. Scientists form and refine research questions, experiments and models using observed patterns in large data sets.

7. The Standard Model provides a framework for our understanding of matter at its most fundamental level.
8. The fundamental particles are organized according to their characteristics in the Standard Model.
9. Particle physicists use conservation of energy and momentum to measure the mass of fundamental particles.
10. Fundamental particles display both wave and particle properties, and both must be taken into account to fully understand them.
11. Particle physicists continuously check the performance of their instruments by performing calibration runs using particles with well-known characteristics.
12. Well-understood particle properties such as charge, mass, momentum and energy provide data to calibrate detectors.
13. Particles that decay do so in a predictable way, but the time for any single particle to decay, and the identity of its decay products, are both probabilistic in nature.
14. Particle physicists must identify and subtract background events in order to identify the signal of interest.

LEARNING OBJECTIVES (BEGIN WITH VERB THAT CAN BE MEASURED.)

As a result of this activity, students will know and be able to:

- xxx

PRIOR KNOWLEDGE

What students should probably know before they engage in this activity

BACKGROUND MATERIAL

This is content information for the teacher, often including links for where to get more information.

RESOURCES/MATERIALS

IMPLEMENTATION

Guidelines for the teachers, activity sequence; basically, write-up of the activity – procedure. Think of this section as annotated student notes.

ASSESSMENT

Formative assessment includes discussion questions to ask students to increase conceptual understanding. Summative assessment includes tests, quizzes, oral and/or written report including the activity report that focuses on claims, evidence and reasoning. **Note:** Any assessment must address the learning objectives which means assessing what you want them to know and be able to do. Just indicating that students will write a report is insufficient. If a report is the best option, include some idea of what the report would be about. For example, an assessment about cosmic rays which follows from the questions raised in the sample description might be: What would you tell people who believe that cosmic rays originate from our sun? What evidence and reasoning would you provide to support your claim?

NOTE: WE PROVIDE TWO TEMPLATES FOR STUDENT PAGES.

GUIDELINES FOR WHICH TEMPLATE TO USE:

- For a level two or three activity, use a student report sheet and template two.
- For complex activities that require students to make a claim and provide evidence and reasoning, use a student report sheet and template two.
- An activity that addresses a claim based on observed data, such as *Mapping the Poles*, does not need a student report sheet because it is not complex. Contrast this with *Calculate the Z Mass* which requires analysis that is more complex.

- For an activity that focuses on learning a skill and/or exploring a model, a report sheet may be the only thing necessary, e.g., *Quark Workbench 2D/3D*; students make “rules” and have to back them up with reasoning, but not in the context of a scientific investigation. The activity *Dice, Histograms and Probability* explores histograms, so does not need a student report sheet: template one.

Clearly these guidelines are not hard and fast rules. Authors will have to decide for themselves which template to use. Luckily, there are several people in the review process who can act as consultants. NOTE: Some activities do not even need a student report sheet; e.g., *Dice, Histograms & Probability*. Those activities are explorations of a topic with the teacher acting as facilitator.

TITLE (TEMPLATE FOR STUDENT PAGES)
STUDENT PAGE

Template One:
Question(s), problem to solve; overall purpose of doing the activity - INTRODUCTION
Steps/guidelines; supporting content, materials, resources (including websites)

Claims, Evidence, Conclusions
For example, when the students have finished the activity, project on the screen the Elementary Particles chart again. Discuss the fact that they have investigated a small part of the Standard Model—one that describes formation of baryons and mesons. There is more to learn about the Standard Model—both for the students and for physicists.

- What rules did you discover that determine the composition of baryons? Mesons? What is the evidence for the rules? (Hint: Describe quark properties.)
- What role did quarks play in forming the mesons and baryons?
- In addition to quarks, what other particles are "fundamental"?
- What do physicists call the current theoretical framework for our understanding of matter?

The learning objectives were:
As a result of this activity, students will know and be able to:

- Identify the fundamental particles in the Standard Model chart.
- Describe properties of quarks, including color, spin, and charge.
- Describe the role of quarks in forming particles that are part of the Standard Model.
- State the rules for combining quarks to make mesons and baryons.

Template Two:
Question(s), problem to solve; overall purpose of doing the activity – INTRODUCTION
Objectives: Could be as simple as what is their task; does not have to be the learning objectives, but could be.
Student pages currently include (after a brief overview of the activity):

- What do we know?
- What tools do we need for our analysis?
- What do we do?
- What are our claims? What is our evidence?

Assessment is a student report.

Note: Edit the gray boxes to specifically address the questions in your activity. See *Calculate the Z Mass* for an example of a good report.

TITLE (TEMPLATE FOR STUDENT REPORT SHEET)

STUDENT REPORT

Research question:

Reason:

Physics principles:

Hypothesis and reasoning:

Claim:

Evaluate the accuracy of your hypothesis as an answer to the research question.

Evidence:

2–3 pieces of evidence (data, observations, calculations) that support the claim

Questions to consider: How did we test the hypothesis? What data supports the claim?

Reasoning:

Justify how and why the evidence backs up the claim. Use scientific principles to explain ***why*** you got this data. Use and explain relevant scientific terms.

Questions to consider: Why does the data compel this claim? Is anything left out?

Sources of Uncertainty in Measurement:

Question to consider: Why and to what extent can we trust your results?

How much do results vary in calculation of the Z mass? Why? Are their outliers? Why?

Practical Applications:

Questions to consider: How might this information be useful to the ATLAS and/or CMS collaborations? To the future runs of the LHC?

What is the value of what you learned?

Now, write your formal scientific conclusion statement. Combine your ideas from the previous pages into two or three well-constructed paragraphs that include the research question, your hypothesis, your evaluation of the hypothesis providing claim, evidence and reasoning, possible sources of uncertainty specific to your data and practical applications for your discovery.

ARCS Action, Relevance, Confidence, Satisfaction

Review Protocol – Revised 5/15/17

Name of Activity ____

Teacher pages _____ Student Pages _____

Date of Review ___________________________________

Review Status (e.g., 2nd review) ____

General Note: Including their own wording in the review helps make the point.

Is in line with the NGSS Framework

1 – Includes a question to address and/or problem to solve; could be developing a model to explain a phenomenon or test a model

Notes: Should be engaging/attention-getting (A in ARCS model). Sets the stage for what students will be doing. Should be on Teacher Pages somehow but crucial that it is at the start of the Student Pages.

2 – Students gather data and/or test solutions; provide claims, evidence and reasoning.

Notes: Students are asking a question, solving a problem or creating a model. For asking a question or solving a problem, CER is obvious. For creating a model they should be describing why/how it is a model and its' limitation.

3 – Students use Science and Engineering Practices (Framework p. 3)

Notes: These may agree or somewhat disagree with what the author says they are. I find authors over-sell what they address.

4 – Address Cross Cutting Concept(s) and Core Idea (Framework p. 3)

Notes: See above

Macro Design

1 – A 'big idea' (core idea) is addressed; sub-ideas support the big idea (can be concepts and/or principles)

Notes: A 'concept' is a human-made idea, usually a definition. A 'principle' is a law such as F=MA, or rule such ' I before e except after c.' QN authors most often miss this most important part of the designing an activity. This is related to but not always exactly the same as the Enduring Understanding. In science, this is most often a principle. Instructional design suggests a principle be taught using cause-effect or effect-cause analyses; concepts using examples and non-examples.

ARCS Action, Relevance, Confidence, Satisfaction

2 – Students apply science process skills and/or design technology
Notes: process skills are -–observe, contrast, evaluate, etc. Design technology is engineering so its: design, test, re-design, re-test…. These are usually addressed very well by QN authors but it's important to check. Also, an easy "very good" which is especially important if they don't do well in other categories.

3 – Format is guided inquiry
Notes: Awhile ago, most QN folks agreed that the accepted level for activities is 'guided inquiry; because the content is so advanced/complex. Now that there are '0' level activities, that might not be as important for those particular activities but should continue to be a guideline for other levels. Guided inquiry includes a lot of questions to guide understanding.

Micro Design
1 - There are behavioral objectives
Notes: Always a challenge. See below for what MJY sent to QN regarding developing objectives (easy five steps). Sometimes the biggest challenge is have authors address the objectives in their assessments,

<u>If there is an objective, it should show up in the assessment.</u>

2 – There are connections to the 'real-world' such as actual scientific exploration (modern physics) and/or skill that scientists use and/or promoting scientific literacy
Notes: Usually fairly well done. Is part of the 'R' in the ARCS model (relevance). When authors 'get into the weed' they frequently forget that not all students may think this is the greatest thing since sliced bread. Authors need to hang their enthusiasm on something real-world, which they know, but the students are unlikely to.

4 – Evaluation/assessment is based on whether or not the objectives are achieved; questions asked directly refer to the objectives (there are no distractions such as extraneous ideas)
Notes: "Write a report,' unless it is one of those developed for the activity that includes CER, will not suffice. Authors cannot be lazy about addressing the objectives. Also it is probably important to have something that addresses the EU as well. Especially for longer activities, look for formative evaluation that may include a discussion, completing a part of the report sheet for that activity, and/or reporting out.

OVERALL:
Notes: Consider which aspects of the activity are likely to lead to confidence and satisfaction ("C" and "S" of the ARCS model), Point out what was good, bad, ugly, beautiful… Let author know if you want to see it again.

ARCS Action, Relevance, Confidence, Satisfaction

Easy Five-Step Tutorial for Developing and Using Objectives:

1. What do you want teachers/students/participants to know and be able to do? (This step will be revisited as the assessment is developed, i.e., the assessment will determine the extent to which the participants have achieved the objectives.) Decide among objectives for content, skills, pedagogy (for teachers).
2. Determine which active/behavioral verb is best for assessing each behavior, which might include: explain, list, describe, interpret, compare, contrast, evaluate, predict, analyze, decide (NEVER 'understand'). Each objective must be measurable – in the assessment. If you have to ask yourself "how can I measure this?" you are on the wrong track. It should be obvious.
3. Look at your objectives to see if it isn't just a list of what you will do during the workshop. Example: look at the list of objectives for cosmic ray from Emanuel. If they are, think again—what do you actually want them to know and be able to do when they are finished with the workshop.
4. Pare objectives down to the essential four to six. You might have to think about the larger idea for some of them. Are they going to "develop a histogram" or "organize data"? But remember, again, these are what you will assess.
5. Figure out within the workshop and/or at the end how you will assess the extent to which the objectives have been achieved. It doesn't require a test but you might just have participants post how they have organized data, reported out their claims and provided evidence, listed crucial rules/principles, provided ideas for implementing in the classroom.

SHARE THE OBJECTIVES WITH PARTICIPANTS

As you continue to develop workshops and write activities, please remember to "start with the end in mind." Development comes ***after*** Step 1 (above).

QuarkNet Activity Review Narrative

March 8, 2019

Background

Jean Young, Instructional Designer, and Tom Jordan, Staff Coordinator, developed the activity templates. Jean oversaw activity review until Spring 2017 when the responsibility passed to Deborah Roudebush, Education Specialist. Jean trained Deborah in 2016. Included in the review and approval process were editors Marge Bardeen, PI, and LaMargo Gill. Jean, Marge, Deborah and Jeremy Smith, Education Specialist, developed a standard list of enduring understandings. Table 1 shows the status of the Data Activities Portfolio during 2016.

Table 1
Activity Review Status 2016

Activity	Review	#2 Review	Done	Posted
Calculate the Z Mass (T, S, R)	7/22/14	3/20/26		✓
Plotting LHC Discovery (T and S pages)	3/29/14	2/25/16	✓ 4/16	✓
Calculate the Top Quark Mass (T and S)	3/21/14	3/20/16		✓
Quark Workbench	3/20/14	3/15/16	✓	✓
Mass of U.S. Pennies (T notes, S handout)	3/10/14	2/25/16	✓	✓
Making it ‘Round the Bend (3 activities)	7/25/14	3/18/16		✓
Rolling with Rutherford (T notes)	3/10/14	2/25/16	✓ 4/16	✓
Dice, Histograms & Probability	3/19/15	4/27/16	✓	✓
Seismology				
Cosmic Muon Lifetime	8/2/16	10/11/16		
ATLAS Masterclass				
ALICE Masterclass				
CMS Masterclass				
LHCb Masterclass				
CMS Data Express *(Shift Report 8/2/16)*	7/21/14	3/15/16	✓ 4/16	✓
Cosmic Rays and the Sun (T notes)	3/17/15	2/25/16	✓	✓
TOTEM Data Express (T, S pages; report)	5/12/15	2/25/16	✓	✓
ATLAS Data Express	3/23/15	10/11/16	✓	✓
Cosmic Ray e-Lab				
LIGO e-Lab				
CMS e-Lab				

Activity Review 2017

In Spring 2017, Jean passed the review responsibilities to Deborah. Deborah focused the reviews and activity development on matching content to the template, uniformity of layout, language level for teachers with less content training, behavioral objectives and assessments directly tied to objectives. Deborah, Ken Cecire, Staff Teacher, and Shane Wood, Staff Teacher, agreed that the masterclass activities should be split since centers choose to study ATLAS Z-path, ATLAS W-path, CMS WZH-path or CMS J/Ψ-path. The team reviewed several activities again to better align them with the new guidelines.

Table 2
Activity Review Status 2017

Activity	Posted
CMS Data Express	8/17
Plotting LHC Discovery	8/17
Calculate the Top Quark Mass (T and S)	8/17
Quark Workbench	8/17
Calculate Z Mass	9/17
ATLAS Z-path Masterclass	11/17
Mass of U.S. Penny	11/17
CMS ZWH-path Masterclass	12/17

Ken, Shane and Deborah decided we could facilitate teacher usage by identifying pathways or a series of activities that follow a theme. While these pathways were a desirable goal, it became clear that there were many gaps in the skills students needed to use higher-level activities. This led to the development of new activities.

The team documented the meaning of activity levels, the list of enduring understandings, and the pathway guidance. They posted these documents in the Data Activities Portfolio in the introductory paragraphs of the webpage.

Activity Review 2018

The focus in 2018 for Deborah, Ken and Shane was on finishing the review of the previously posted activities and filling in the gaps for improved pathway guidance. The team brainstormed methods of making the pathways more accessible for teachers as well as easier to edit and maintain. Deborah worked with Joel Griffith, IT Staff, to design a modification to the Data Activities Portfolio pages to allow teachers to use a pull-down menu of topics to select a pathway. The target for completion of this feature is Summer 2019.

Table 3 lists the activities posted in 2018.

Table 3
Activity Review Status 2018

Activity	Posted
ATLAS W-path Masterclass	1/18
CMS J/Ψ	2/18
Shuffling the Particle Deck	2/18
Making It ‘Round the Bend: Qualitative*	4/18
Making It ‘Round the Bend: Quantitative*	5/18
Mapping the Poles	6/18
Signal and Noise: The Basics	6/18
Quark Workbench 2D/3D**	8/18
Signal and Noise: Cosmic Muons	9/18
Mean Lifetime Part 2: Cosmic Muons***	9/18

*Jeff Rodriguez, University of Cincinnati QuarkNet Center, developed the simulation that made these activities possible.

**Lachlan McGinness is an Australian physics teacher and visiting fellow at the Australian National University. He created the 3D puzzle activity while appointed as Teacher in Residence at CERN in 2018.

***Originally posted as Cosmic Mean Lifetime.

Activity Review 2019

The focus in 2019 for Deborah, Ken and Shane is on developing neutrino activities to support a neutrino strand and neutrino pathways. There are still five posted activities that have not undergone full review. Deborah continues to work with Joel to design a modification to the Data Activities Portfolio pages to allow teachers to use a pull-down menu of topics to select a pathway. The target for completion of this feature is Summer 2019.

Table 4 lists the activities under review in 2019.

Table 4
Activity Review Status 2019

Activity	Posted
ALICE Masterclass	
LHCb Masterclass	
Cosmic Rays and the Sun	
Cosmic Ray e-Lab	
CMS e-Lab	

Table 5 contains a list of activities currently under development. These activities are primarily to support a neutrino strand as well as strands for special relativity and uncertainty. The staff is developing a draft Level 4 activity to test with teachers and students.

Table 5
Activities Under Development 2019

Activity	Posted
Mean Lifetime Part 3: MINERvA	
Feynman Diagrams	
To Catch a Speeding Muon	
Neutrino Hide & Seek (a reworked Calculate Top Quark Mass)	
Special Relativity Holds the Answers	

Table F-1
2018-2019 QuarkNet National Workshops

QuarkNet Center	Workshop Type (e.g., Cosmic, Data, CMS e-Lab)	Workshop Dates (Chronological Order)	Staff/Fellow Leading Workshop
Kansas State University	LIGO	June 4-5	Shane Wood
Kansas State University	Cosmic	June 6-8	Martin Shaffer
University of Minnesota	Neutrino Prototype	June 13-14	Shane Wood/Ken Cecire
Texas Tech University	Cosmic	June 13-14	Martin Shaffer
Rice University/ University of Houston	CMS Data	June 25-26	Shane Wood
Rice University/ University of Houston	Neutrino Prototype	June 27-28	Shane Wood
University of Iowa/Iowa State University	CMS e-Lab	July 9-10	Marla Glover
Black Hills State University	Neutrino Prototype	July 18-19	Shane Wood
Fermilab/University of Chicago	LIGO	July 18-19	Shane Wood
Johns Hopkins University	LIGO	July 25-26	Marla Glover
Virginia Center	Neutrino Prototype	August 6-7	Shane Wood
Colorado State University	LIGO	August 8-10	Ken Cecire
University of Washington	ATLAS Data	August 17-19	Shane Wood
University of Florida	Neutrino Prototype	August 25-26	Ken Cecire

[a]Hampton, George Mason and W&M Universities

2018- 2019 Program Year

A list of nationally-led QuarkNet Workshops (led by QuarkNet staff) during the 2018-2019 program year by QuarkNet staff is shown in Table F-1. Data Camp was implemented at Fermilab from July 16-20, 2018. These are considered nationally-run workshops.

Table F-2 lists the meetings and workshops held as Center-led QuarkNet workshops and those led by the *individual centers*. Together for both tables, this represents a total of 55 centers (50 centers in year 3+ of the program); 1 virtual center; and 4 sabbatical centers (based on emails from S. Wood, K. Cecire; M. Bardeen, June 21, 2019).

2019-2020 and 2020-2021 Program Years

Table F-3 lists the meetings and workshops held during the 2019-2020 program year for both nationally- and center-led events. Similarly, F-4 lists the workshops and meeting during the 2020-2021 program years (again for both nationally- and center-led events).

The focus of these workshop summary tables is on teachers' exposure to Data Activities Portfolio activities (DAP) as evidence in support of subsequent classroom implementation. Important content and materials are likely part of these workshops as well (such as select talks on cutting edge particle physics topics and tours of labs/ experiments), but are not reflected.

Table F-2

2018-2019 QuarkNet Center-led Meetings and Workshops

Center	**2018** Meeting Dates (All days)	Center	**2018** Meeting Dates (All days)
Black Hills State University	July 10-14	University of California, Riverside	
Boston area	August 14-15	University of California, Santa Cruz	
Brookhaven National Laboratory	June 25-29	University of Cincinnati	Summer (no dates specified in annual report)
Catholic University of America	August 13-17, plus 3 days in fall	University of Florida	August 25-26
Colorado State University	August 8-10	University of Hawaii	June 2-3
Fermilab/University of Chicago	July 18-19	U of Illinois Chicago/Chicago State University	June 25-29
Florida Institute of Technology		University of Iowa/Iowa State	July 9-13
Florida International University		University of Kansas	June 11-13
Florida State University	August 1-2	University of Minnesota	June 12-14
Idaho State University	July 9-13	University of Mississippi	June 25-26
Johns Hopkins University	July 23-27	University of New Mexico	May 4 and one fall day
Kansas State University	June 4-8	University of Notre Dame	July 30 - Aug 3
Lawrence Berkeley National Laboratory/ Stony Brook University	June 18-22	University of Oregon	June 20-21
Northern Illinois University	June 25-29	University of Pennsylvania	
Oklahoma State University/University of Oklahoma	July 24-27	University of Puerto Rico-Mayaguez	Dec. 8-9; April 6, 2019
Purdue University		University of Rochester	
Purdue University Northwest	June 18-22	University of Tennessee, Knoxville	
Queensborough Community College		University of Washington	August 17-19
Rice University/University of Houston	June 25-29	University of Wisconsin-Madison	
Rutgers University	July 9-13	Vanderbilt University	June 25-29
Southern Methodist University	Aug 6-10	Virginia Center (Hampton, George Mason and William and Mary Universities)	Aug 6-8
Syracuse University	Aug 8-10	Virginia Tech University	July 23-26
Texas Tech University	June 13-15	Virtual Center	July 11-14
University at Buffalo	Aug 21-22	Wayne State University	

Table F-3
2019 QuarkNet Workshops and Meetings: National- and Center-led

Center	**2019 Dates (All days)**	**Workshop/Meeting**	**Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Black Hills State University	No activity		
Boston area	August 14-15	**Neutrino Workshop** (co-led by Center)	Mean Life Part 3: Minerva (2) Mean Life Part 2: Cosmic Muons (2) What Heisenberg Knew (1) MINERvA masterclass measurement
Brookhaven National Laboratory/ Stony Brook University	July 3	**MINVERvA Neutrino Masterclass**	MINERvA Neutrino measurement (2)
The Catholic University of America	August 5-7	CMS and Cosmics **(CMS Data Workshop)**	Shuffling the Particle Deck (0) Rolling with Rutherford (1) Calculate the Z Mass (1)
Colorado State University	July 29-31	**Neutrino Data Workshop**	Mean Lifetime Part 1: Dice (1) Mean Lifetime Part 2: Cosmic Muons (2) Shuffling the Particle Deck (0) What Heisenberg Knew (1) The Case of the Hidden Neutrino (1) Histograms: Uncertainty (1) Mean Lifetime Part 3: MINERvA (2) Implementation Plans
Fermilab/University of Chicago	July 24-26	**Neutrino Data Workshop & Student Presentations**	Shuffling the Particle Deck (0) The Case of the Hidden Neutrino (1) Mean Lifetime Part 1: Dice (1) Mean Lifetime Part 3: MINERvA (2) MINERvA Masterclass measurement (2) Histograms: The Basics (0) Histograms: Uncertainty (1) What Heisenberg Knew (1) Implementation Plans
Florida Institute of Technology	No activity		

Note. National-led QuarkNet workshops are in a bold-face font.
Information compiled from the workshop agenda posted on individual center pages on QuarkNet website.

Table F-3

2019 QuarkNet Workshops and Meetings: National- and Center-led (con't.)

Center	**2019 Dates (All days)**	**Workshop/Meeting**	**Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Florida International University	August 5-7	**CMS Workshop**	Shuffling the Particle Deck (0) Rolling with Rutherford (1) Calculate the Z Mass (1)
Florida State University	July 31- August 2	**CMS Workshop**	Shuffling the Particle Deck (0) Rolling with Rutherford (1) Calculate the Z Mass (1) Making it Round the Bend (Qualitative) (1) Making it Round the Bend (Quantitative) (2) CMS Masterclass Measurement (2)
Idaho State University Pocatello (co-conducted workshop with the University of Cinncinnati)	June 17-20	Cosmic Ray Muon Detectors (CRMD) **Neutrino Masterclass**	Assemble a complete CRMD Neutrino Masterclass
Johns Hopkins University	July 22-26	JHU Workshop	Create videos for use in the classroom Develop lesson plan/approach based on transcribed lecture recorded from a theoretical physicist
Kansas State University	March 2 April 5	Masterclass Orientation Masterclass	
	May 28-31	Cosmic Ray Workshop	Configure a cosmic ray detector Identify and describe cosmic ray e-Lab tools Create, organize and interpret a data plot Develop a plan to increase current use of data by students
Lawrence Berkeley National Laboratory	June 24-28	Physics in and through the Cosmology	The Case of the Hidden Neutrino (1) What Heisenberg Knew (1) Shuffling the Particle Deck (0) MINERvA Masterclass Measurement (2)
Northeastern University	No activity		
Northern Illinois University	June 24	Cosmic Ray Workshop	Mean Lifetime Part 1: Dice (1) Mean Lifetime Part 2: Cosmic Muons (2)

Note. National-led QuarkNet workshops are in a bold-face font.

Information compiled from the workshop agenda posted on individual center pages on QuarkNet website.

Table F-3
2019 QuarkNet Workshops and Meetings: National- and Center-led (con't.)

Center	2019 Dates (All days)	Workshop/Meeting	Data Activities Portfolio (Level) [and/or classroom use/implementation plans]
Purdue University	No activity		
Purdue University Northwest	June 13	CMS Masterclass Mini-Workshop	CMS Masterclass Measurement
Queensborough Community College		No workshop	CMS tracking detection and GPS data postings
Rice University/University of Houston	June 17-21	**CMS Data Workshop**	Shuffling the Particle Deck (0) Histograms: Uncertainty (1) TOTEM Data Express (2) Making it Round the Bend (Qualitative) (1) Making it Round the Bend (Quantitative) (2) Calculate the Z Mass (1) or Calculate the Top Quark Mass (1) CMS WWDD Measurement
Rutgers University	No date specified	Summer Research Program and 1-day Workshop	Focus on transferring summer-research material into their classrooms
Southern Methodist University	July 29-31	**Neutrino Data Workshop** (July 29-30) Center-led Workshop (July 31)	Shuffling the Particle Deck (0) The Case of the Hidden Neutrino (1) Mean Lifetime Part 1: Dice (1) Mean Lifetime Part 3: MINERvA (2) Histograms: The Basics (0) Histograms: Uncertainity (1) What Heisenberg Knew (1) MINERvA Masterclass Measurement (2)
Syracuse University	August 15-16	**Workshop with STEP UP**	Mean Lifetime Part 1: Dice (1) Mean Lifetime Part 3: MINERvA (2) New York Science Learning Standards 3D e-Lab (North County 3D Café)

Note. National-led QuarkNet workshops are in a bold-face font.
Information compiled from the workshop agenda posted on individual center pages on QuarkNet website.

Table F-3

2019 QuarkNet Workshops and Meetings: National- and Center-led (con't.)

Center	2019 Dates (All days)	Workshop/Meeting	Data Activities Portfolio (Level) [and/or classroom use/implementation plans]
Texas Tech University	June 3-7	Summer Workshop (first 3 days) **CMS Workshop** (last 2 days)	Rolling with Rutherford (1) Shuffling the Particle Deck (1) or Quark Workbench 2D/3D (1) Calculate the Z Mass (1) CMS Masterclass Measurement (2) Exploration of Level 3 DAP (CMS e-lab)
University of Buffalo, SUNY	March 30	**CMS Masterclass**	
	August 19-20	CMS Workshop	Several new ideas for cosmic data analysis with e-Lab were presented.
University of California, Riverside	No activity		
University of California, Santa Cruz	No activity		
University of Cincinnati (Workshop co-conducted with Idaho State Pocatello)	March 8	**LCHb Masterclass**	
	June 19-20	**Neutrino Data Workshop** (2 days) 1-day Workshop	Shuffling the Particle Deck (Level 0) What Heisenberg Knew (Level 1) The Case of the Hidden Neutrino (Level 1) Mean LifeTime Part 3: MINERvA (Level 2) MINERvA Masterclass Measurement (Level 2) During 1-day Workshop (and LCHb Masterclass): Rolling with Rutherford (Level 1) Marking it 'Round the Bend QuarkBench Workbench 2D/3D (Level 0) Calculate the Z Mass (Level 1) Implementation Plans
University of Florida	No activity		
University of Hawaii	No activity		
University of Illinois at Chicago/ Chicago State University	July 8-12	**CMS Workshop**	Rolling with Rutherford (1) Two separate studies (the speed of muons and the rate of multiple muons in cosmic ray air showers)
University of Iowa/Iowa State University	No activity		

Note. National-led QuarkNet workshops are in a bold-face font.
Information compiled from the workshop agenda posted on individual center pages on QuarkNet website.

Table F-3

2019 QuarkNet Workshops and Meetings: National- and Center-led (con't.)

Center	**2019 Dates (All days)**	**Workshop/Meeting**	**Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
University of Kansas	June 12-14	Computing in the Physics Classroom	Construct lesson plan Each group constructs student computing exercises Try out student computing exercise on other groups Groups report out on classroom exercise
University of Minnesota	April 6	**Neutrino Masterclass**	MINERvA Analysis
	June 12-14	**Minnesota Workshop: Neutrinos, CMS & e-Labs**	Histograms: Uncertainty (1) What Heisenberg Knew (1)
University of Mississippi	No activity		
University of New Mexico	September 7	Tour	Technical and historical tour of scientific heritage sites of Los Alamos, NM.
University of Notre Dame	Summer Weekly Meetings Special Events	**Weekly Teacher Meetings** **Summer Research** **QuarkNet Week** **ATLAS Masterclass** (March 15)	Discussions about physics and teaching ATLAS Masterclass.
University of Oklahoma/Oklahoma State	July 17-19	Workshop ATLAS Masterclass	Discussed QuarkNet materials in the classroom Conducted a masterclass for teachers and demonstrated how they can use a masterclass with their students.
University of Oregon	June 20-21	**ATLAS Data Workshop**	Rolling with Rutherford (1) Quark Workbench (1) or Shuffling the Particle Deck (1) Calculate the Z Mass (1) Mass of US Pennies (0) Atlas Z-path Masterclass Measurement
University of Pennsylvania	No activity		
University of Puerto Rico	November 2-3	Cosmic Ray	
University of Rochester	No activity		

Note. National-led QuarkNet workshops are in a bold-face font.

Information compiled from the workshop agenda posted on individual center pages on QuarkNet website.

Table F-3

2019 QuarkNet Workshops and Meetings: National- and Center-led (con't.)

Center	**2019 Dates (All days)**	**Workshop/Meeting**	**Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
University of Tennessee, Knoxville	July 12-13	**MicroBooNE Masterclass Development Workshop**	Neutrino Masterclass Status μβ Masterclass
University of Washington	No activity		
University of Wisconsin Madison	No activity		
University of Wisconsin River Falls	No activity		
Vanderbilt University	June 24-28	CMS Workshop	Using CRMD and e-lab facilities. Set up a standard CRMD in telescope configuration.
Virginia Center (College of William and Mary, Hampton University, and George Mason University)	March 9 April 6 August 5-7	**CMS Masterclass** **Neutrino Masterclass** **Workshop: Theme Data Analysis CMS**	Histograms: Uncertainty (1) Making it Round the Bend (Qualitative) (1) Making it Round the Bend (Quantitative) (2) What Heisenberg Knew (1) Energy, Momentum, and Mass (1) TOTEM Data Express (2) CMS Masterclass Measurement (2) Signal & Noise Reflections and Brainstorming
Virginia Tech	August 5-7	Catching Gravitational Waves	LIGO e-Labs Create lesson plans for e-Labs incorporated into classrooms.
Virtual Center	August 12-13	CMS Analysis and Step UP	CMS Masterclass Measurement
Wayne State	No activity		
National Program held at Fermilab	July 15-19, 2019	**Data Camp**	Rolling with Rutherford (1) Shuffling the Particle Deck (0) QuarkNet Workbench 2D/3D (0) Mass of U.S. Pennies (0) Calculate the Top Quark Mass (1)

Note. National-led QuarkNet workshops are in a bold-face font.
Information compiled from the workshop agenda posted on individual center pages on QuarkNet website (February 15, 2020)

Table F-4
2020 QuarkNet Workshops and Meetings: National- and Center-led (December 2019-September 2020)

Center	**2020 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Black Hills State University	No activity		
Boston area/Brown University	December 10 (2019)	Fall Meeting	STEP UP presentation Review of activities in the Data Activities Portfolio.
	February 25	Winter Meeting	New features of iSpy software were presented (planned to be used in a masterclass on March 28; which was cancelled because of COVID-19). Newtonian analysis applied to recent observations.
	May 5	**Wednesday Webinars** (QW2) (Zoom)	History of neutrino experiences and discoveries
	Summer	Neutrino Virtual Workshops (Six, 1.5 hour Zoom sessions)	First tried on June 22-24 (see Kansas State). Also participated in six on-line talks about the Standard Model of Particle Physics.
Brookhaven National Laboratory	No activity		
The Catholic University of America	No activity	Because of COVID-19, the center did not hold a workshop during the summer. When they reached out to teachers at the beginning of the summer; they found that most teachers were overwhelmed doing training at their schools to prepare for teaching on-line in the fall; thus no workshop.	
Colorado State University	August 5	**STEP UP Virtual Workshop** (1-day)	QuarkNet: Changing the Culture (0) QuarkNet STEP UP: Careers in Physics (1) QuarkNet STEP UP Women in Physics (2) Presentation on DUNE experiments. Implementation plans developed by teachers.
Fermilab/University of Chicago	July 28-30 (half-days)	**Muon Virtual Workshop**	Remote use of: Mean Lifetime Part 1: Dice (1) Mean Lifetime Part 3: MINERvA (2) Mean Lifetime Part 2: Cosmic Muons (2) Also engaged in Big Analysis of Muons (BAMC) and STEP UP activities in the DAP. Implementation plans developed by teachers.

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.

Table F-4 (con't.)

2020 QuarkNet Workshops and Meetings: National- and Center-led (December 2019-September 2020)

Center	2020 Dates (All dates except where noted)	Workshop/Meeting	Brief Summary of Activities and Data Activities Portfolio (Level) [and/or classroom use/implementation plans]
Florida Institute of Technology	No activity		
Florida International University	No activity		
Florida State University/ (University of Florida)	July 22-24 (half days)	**Virtual Workshop** (last day of workshop shared with University of Florida)	Focus on distance learning adapting: Rolling with Rutherford (1) The Case of the Hidden Neutrino (1); and, other activities Share-A-Thon Machine learning and artificial intelligence. Implementation plans developed by teachers.
Idaho State University	No activity		
Johns Hopkins University	August 3-6	Summer Workshop	A series of talks, e.g., introduction to particle physics; machine learning in particle physics; dark matter; gravity waves; and sharing of best practices and favorite tools/tech. Simulation activity with a partnering teacher.
Kansas State University	February 29	Masterclass Orientation	In preparation for CRMD research project.
	June 22-24 (half days)	**Neutrino Virtual Workshop**	Mean Lifetime Part 1: Dice (1) Mean Lifetime Part 3: MINERvA (2) The Case of the Hidden Neutrino (1) Histograms Uncertainty (1) What Heisenberg Knew (1) Share-A-Thon Implementation plans developed by teachers.

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.

Table F-4 (con't.)

2020 QuarkNet Workshops and Meetings: National- and Center-led (December 2019-September 2020)

Center	**2020 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Lawrence Berkeley National Laboratory	June 29 to July 24	Physics in and Through Cosmology (Virtual Workshop) 3 times a week for 3 hours	Rolling with Rutherford (1) Presentations by several LBNL scientists. Small group work included creating a 60-second History of the Universe; a Scientist Interview Project; and, analyzing data from ATLAS. Also a cosmic ray detector demonstration.
	July 13, 15, 16	**Big Analysis of Muons (ATLAS) BAMA**	
Northern Illinois University	No activity		
Oklahoma State University/University of Oklahoma	July 29-31 (half days)	**STEP UP Virtual Workshop**	QuarkNet: Changing the Culture (0) QuarkNet STEP UP: Careers in Physics (1) QuarkNet STEP UP Women in Physics (2) Share-A-Thon (distance learning successes) Implementation plans developed by teachers.
Purdue University	No activity		
Purdue University Northwest	No activity		
Queensborough Community	Summer	Virtual Workshop 2-week workshop with a 3-hour session each day	Activities included for example: learning about the design, assembly, and functionality of a cosmic ray data acquisition circuit, DAQ, being built by students and teachers in the QCC cosmic ray lab.
Rice University/University of Houston	No activity		
Rutgers University	Summer	Virtual Workshop	Introducing the basic concepts of quantum mechanics and quantum computing and developing methods for introducing this material into high school classrooms. Unable to hold masterclass or 2-week high school student program because of COVID.

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.

Table F-4 (con't.)

2020 QuarkNet Workshops and Meetings: National- and Center-led (December 2019-September 2020)

Center	**2020 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Southern Methodist University	July 13-15 (afternoons) July 16-17	**STEP UP Virtual Workshop**	QuarkNet: Changing the Culture (0) QuarkNet STEP UP: Careers in Physics (1) QuarkNet STEP UP Women in Physics (2) Teachers shared physics activities for the remote classroom, e.g., electricity role cards; electric circuits; virtual lab on measurement error and the Hydrogen Spectrum.
Syracuse University	August 20-21 (half days)	**CMS Data Virtual Workshop**	Activities for remote learning: Shuffling the Particle Deck (0) Rolling with Rutherford (10 Making Trends I: Cloud Chamber (0) Making Trends II: Bubble Chamber (1) Calculating the Z Mass (1) BAMC (Big Analysis of Muons in CMS) Implementations plans developed by teachers.
Texas Tech University	No activity		
SUNY University at Buffalo	No activity		
University of California at Riverside	No activity		
University of California Santa Cruz	No activity	No program this year because of COVID but the center is looking forward to launching new remote programs in 2020-2021.	
University of Cincinnati	August 3-5	Virtual Workshop Not able to participate in LHCb Masterclass because of COVID.	Remote learning and how to use Python-based Jupyter Notebooks to engage physics students in high school. Implementation plans developed by teachers.

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.

Table F-4 (con't.)

2020 QuarkNet Workshops and Meetings: National- and Center-led (December 2019-September 2020)

Center	**2020 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
University of Florida	July 22-24 (half days)	**CMS Data Analysis Virtual Workshop**	Making Tracks I (0) Rolling with Rutherford (1) Shuffling the Particle Deck (0) Calculating the Z Mass (1) Implementation plans developed by teachers.
University of Hawaii	~~March 14~~ ~~March 15~~	~~**CMS Masterclass**~~ ~~**Muons in the Classroom Workshop**~~	Both of these programs were cancelled because of COVID.
University of Illinois Chicago/ Chicago State University	July 13-15 (half days)	**Cosmic Ray Virtual Workshop**	Performed analyses and plotted data. Implementation plans developed by teachers.
University of Iowa/Iowa State University	No activity		
University of Kansas	July 7-8	Modeling Random Processes Virtual Workshop	Focus on computing physics in the classroom (e.g., particle decay and math behind exponential decays and half lives). Computational exercises including random numbers and exponential decays. Share-A-Thon on-line teaching.
University of Minnesota	~~April 4~~	~~**Neutrino Masterclass**~~ ~~**MINERvA Analysis**~~	Masterclass cancelled because of COVID.
	July 13-15 (half days)	**STEP UP Virtual Workshop**	QuarkNet: Changing the Culture (0) QuarkNet STEP UP: Careers in Physics (1) QuarkNet STEP UP Women in Physics (2) NOvA Detector Neutrino Oscillation Share-A-Thon (engaging students in distance or hybrid learning environments) Implementation plans developed by teachers.
University of New Mexico	No activity		

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.

Table F-4 (con't.)

2020 QuarkNet Workshops and Meetings: National- and Center-led (December 2019-September 2020)

Center	2020 Dates (All dates except where noted)	Workshop/Meeting	Brief Summary of Activities and Data Activities Portfolio (Level) [and/or classroom use/implementation plans]
University of Notre Dame	July 6-10 (half days)	Course 1	Rolling with Rutherford (online) (1) Calculating the Z Mass (1) Basic physics and up to particle physics using data from the BAMC (Big Analysis of Muons CMS) Masterclass.
	July 13-17 (half days)	Course 2	Deep study of particle physics; programming and analyses using CMS data and Python
	August 3-5	QuarkNet Week	Learning to use Phyphox and Colab to collect, visualize and analyze phone sensor data. Review activities in Data Activities Portfolio. Implementation plans developed by teachers.
University of Pennsylvania	No activity		
University of Puerto Rico - Mayaguez	June 20		
University of Rochester	No activity		
University of Tennessee Knoxville	No activity		
University of Washington	September 10-11	CMS Virtual Masterclass	Conducted muon and electron data analysis; discussed with QuarkNet staff and lead teachers.
University of Wisconsin - Madison	No activity		
Vanderbilt University	June 22-24 (half days)	Virtual Workshop	Talks on CMS (gravitational wave detection) and relativistic heavy ion experiments. Using Cosmic Ray Muon detectors
	June 25-26 (half days)	**Neutrino Data Virtual Workshop**	understanding flow to signal. The Case of the Hidden Neutrino (1) What Heisenberg Knew (1) MINERvA masterclass measurement Implementation plans developed by teachers.

Note. National led QuarkNet workshops are in a bold face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.

Table F-4 (con't.)
2020 QuarkNet Workshops and Meetings: National- and Center-led (December 2019-September 2020)

Center	2020 Dates (All dates except where noted)	Workshop/Meeting	Brief Summary of Activities and Data Activities Portfolio (Level) [and/or classroom use/implementation plans]
Virginia Center (Hampton University, the William and Mary, and the George Mason University)	February 6	CMS J/Psi Masterclass	Teachers and students conducted data analysis and sharing of data through J/Psi masterclass.
	February 29	Spring Meeting	New features of the Data Activities Portfolio Teachers worked on implementation plans.
	August 3-5	Summer Virtual Workshop	Talks on future colliders; Xeonon IT. QuarkNet: Changing the Culture (0) QuarkNet STEP UP: Careers in Physics (1) QuarkNet STEP UP Women in Physics (2) BAMC (Big Analysis of Muons in CMS) masterclass measurement
Virginia Tech University	No activity	The summer workshop was cancelled because teachers were working on-line with their individual schools to prepare for on-line learning in the fall.	
Virtual Center	August 12-14 (2½ days)	Neutrino Data, STEP UP and Online Learning Workshop	Group met monthly throughout the year. Mean Lifetime Part 1: Dice (1) Mean Lifetime Part 3: MINERvA (2) The Case of the Hidden Neutrino What Heisenberg Knew (1) Histograms: Uncertainty (1) MINERvA masterclass measurement Implementation plans developed by teachers.
Wayne State University	No activity		
Data Coding (Data Camp)	July 6-10 July 23-31	Coding Camp: Virtual	Introducing Jupyter notebook; coding and machine learning. Implementation plans developed by teachers.

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on Quark

Table F-5

2021 QuarkNet Workshops and Meetings: National- and Center-led (December 2020-September 2021)

Center	**2021 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Black Hills State University	June 21-25	QN Cosmic, QN Neutrino Data & Dark Matter	Shuffling the Particle Deck (0) Making Tracks I (Cloud Chamber) (0) Making Tracks II (Bubble Chamber) (1) The Case of the Hidden Neutrino (1) Mean Life Part 1: Dice (1) Mean Life Part 2: MINERvA (2) Mean Life Part 3: Cosmic Ray Muons (2) Implementation discussion and plan
Boston Area/Brown University	May 18	QuarkNet Zoom Meeting	
	August 3-4	Summer Workshop (in-person)	Implementation discussion and plans
Brookhaven National Laboratory	July 6-9	Summer Virtual Workshop	Coding exercises for Artificial Intelligence/machine learning/quantum computing, MINERvA Masterclass Implementation discussion and plans
The Catholic University of America	August 16-18	Summer Workshop (August 16, 18 online August 17 in person)	Cosmic Ray e-Lab (3) Implementation discussion and plans
Colorado State University	July 26-27	**CMS Data Workshop**	Shuffling the Particle Deck (0) Rolling with Rutherford (1) Calculate the Z Mass (1) Quark Workbench 2D/3D (0) Making Tracks I (Cloud Chamber) (0) Making Tracks II (Bubble Chamber) (1) Implementation discussion and plans

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.

Table F-5 (con't.)

2021 QuarkNet Workshops and Meetings: National- and Center-led (December 2020-September 2021)

Center	**2021 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Fermilab/University of Chicago	August 3-5 (half days)	Teaching with Data Virtual Workshop	Introduction to Coding Practice Coding for Physics Classes Implementation discussion and plans
Florida Institute of Technology	No activity		
Florida International University	~~August 5-6~~	~~Neutrino Data~~	
Florida State University/(University of Florida)	July28-30	**CMS Update & Coding Workshop**	Shuffling the Particle Deck (0) Rolling with Rutherford (1) Making Tracks I (0) Quark Workbench (0) Making Tracks II (1) Signal to Noise: The Basics (0)
Idaho State University	June 28-July 1	Summer Workshop	Shuffling the Particle Deck (online) (0) Quark Workbench (online) (0) What Heisenberg Knew (1) Totem Data Express (2)
Johns Hopkins University	July 26-30	Summer Workshop: Astrophysics	Select 3 DAP Activities Level 0: Mapping the Poles; Signal & Noise; Making Tracks I; Histograms; STEP UP Select 2 DAP Activities Level 1: Particle Transformation and Signal & Noise II or the Case of the Hidden Neutrino; or What Heisenberg Knew; STEP UP II or Making Tracks II CMS Express Data (2)
Kansas State University/University of Kansas	March 13	Masterclass Orientation	In preparation for CRMD research project.
	April 23	Orientation	
	August 2-4	Cosmic Ray Workshop the Storm Project	CMS activities and Cosmic Ray Muon detectors

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.

Table F-5 (con't.)

2021 QuarkNet Workshops and Meetings: National- and Center-led (December 2020-September 2021)

Center	**2021 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Lawrence Berkeley National Laboratory	June 28-July 23	Four Week Virtual Workshop	A total of 7 teachers and 59 students participated.
	July 12 (prep) July, 16, 19, 21	Summer Workshop (3 days, 3 hours each)	Teachers engaged in fundamental particle activity and analyzed data from ATLAS
Northern Illinois University	No activity		
Oklahoma State University/University of Oklahoma	July 20-22	**ATLAS Data Workshop**	Rolling with Rutherford (1) Shuffling the Particle Deck (0) Mass of U. S. Pennies (0) Calculate Mass of Z (1) Quark Workbench (0) Making Tracks I (cloud chamber) (0) Making Tracks II (bubble chamber) (1) Signal to Noise: Basics (0) Particle Transformation (1) Implementation discussion and plan
Purdue University	No activity		
Purdue University Northwest	June 21-25	Workshop	Rolling with Rutherford (1) Quark Workbench (0) CMS data collection and analysis (masterclass-like_
Queensborough Community	No dates	Workshop	Focus of workshop: How to program an Arduino Mega microcontroller board.

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.

Table F-5 (con't.)

2021 QuarkNet Workshops and Meetings: National- and Center-led (December 2020-September 2021)

Center	**2021 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Rice University/University of Houston	June 14-18	**CMS, Cosmic and STEP UP**	Shuffling the Particle Deck (0) Rolling with Rutherford (1) Calculate the Mass of Z (1) Signal and the Noise: The Basics (0) Making Tracks I (Cloud Chamber) (0) QuarkNet STEP UP: Careers in Physics (1) QuarkNet STEP UP: Women in Physics (2) Implementation discussion and plans
Rutgers University	No dates	2-week introductory workshop	Quantum computing
	No dates	1-week advanced workshop	Topics included quantum information and black holes
Syracuse University	August 16-18	**Particles, Detectors, and Neutrino Data**	Shuffling the Particle Deck (0) Quark Workbench (0) Making Tracks I (Cloud Chamber) (0) Making Tracks II (Bubble Chamber) (1) The Case of the Hidden Neutrino (1) What Heisenberg Knew (1) Histograms: Uncertainty (1)
Southern Methodist University	July 12-14	**Enquiry-based Learning Virtual Workshop (Coding)**	On-line activities: Shuffling the Particle Deck (0) Quark Workbench (0) Rolling with Rutherford (1) MINERvA masterclass intro
Texas Tech University	June 29- July 2 July 1 July 6	Annual Workshop **STEP UP Workshop** Virtual Workshop	STEP UP: Women in Physics (2) STEP UP: Changing the Culture (0) Classroom Implementation discussion and plans

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.

Table F-5 (con't.)

2021 QuarkNet Workshops and Meetings: National- and Center-led (December 2020-September 2021)

Center	**2021 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
University at Buffalo –SUNY	February 27	Masterclass No workshop due to COVID	
University of California at Riverside	No activity		
University of California Santa Cruz	No activity		
University of Cincinnati	~~Aug 3, 4or 5~~	~~**STEP UP Workshop**~~	Because of COVID no workshops or masterclasses were held
University of Florida	No activity		
University of Hawaii	No activity		
University of Illinois Chicago/ Chicago State University	July 9-12	**Virtual Workshop**	Assessing the design of the moon shadow experiment
University of Iowa/Iowa State University	July 5-9	Summer Workshop	Mean Lifetime Part 1: Dice (1) Mean Lifetime Part 2: MINERvA (2) Mean Lifetime Part 3: Cosmic Muons (2) Implementation discussion and plans
University of Kansas	No activity		
University of Minnesota	March 6	Virtual MINERvA Workshop	Masterclass analysis
	August 11-13	Summer Workshop	Totem I-III activities (in development) Implementation discussion and plans
University of New Mexico	Sept 18-19	Summer Workshop	Shuffling the Particle Deck (0) Rolling with Rutherford (1) Making Tracks I (0)

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.

Table F-5 (con't.)

2021 QuarkNet Workshops and Meetings: National- and Center-led (December 2020-September 2021)

Center	2021 Dates (All dates except where noted)	Workshop/Meeting	Brief Summary of Activities and Data Activities Portfolio (Level) [and/or classroom use/implementation plans]
University of Mississippi	June 21	Ole Miss Workshop	Implementation notes
University of Notre Dame		Cosmic Watch Project	
	July 16	Discovery at LHC	Shuffling the Particle Deck (virtual) (0) Quark Workbench (virtual) (0)
University of Oregon	No activity		
University of Pennsylvania	No activity		
University of Puerto Rico - Mayaguez	March 3	MINERvA Masterclass	
University of Rochester	No activity		
University of Tennessee Knoxville	No activity		
University of Washington	No activity		
University of Wisconsin - Madison	No activity		
Vanderbilt University	June 21-25 June 23-24	Summer Workshop Coding Portion	Speed of light experiment General reintroduction to CRMDs Introduction and Coding with Phyton
Virginia Center (Hampton University, the William and Mary, and the George Mason University)	August 2-4	Coding Virtual Workshop	Totem Data Express (2) Particle Transformation (1) Implementation discussion and plans
Virginia Tech	August 2-4	Virtual Workshop	STEP UP: Changing the Culture (0) STEP UP: Careers in Physics (1) STEP UP: Women in Physics (2)
Virtual Center	July 22-23	Quantum Computing and Coding	
Wayne State University	No activity		
Data Coding (Data Camp)	June 21-25 and June 28-July 2	Coding Camp: Virtual	Probability and histograms using dice Modeling and graphing projectiles with air resistance Calculate the mass of a muon using CMS data Big CMS dataset analysis

Note. National led QuarkNet workshops are in a bold face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.

Table F-6

2022 QuarkNet Workshops and Meetings: National- and Center-led (December 2021-October 2022)

Center	**2022 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Black Hills State University	July 6-9	**Coding Workshop**	Coding Sessions 1-4 Implementation plans and discussion
Boston Area/Brown University	January 27	Winter Meeting	Teachers presented favorite lessons in physics Demonstration of DAP Calculate Z-Mass (1) Calculate the Top Quark Mass (1)
	May 19, 2022	Spring Meeting	Presentation by teachers of favorite class presentations, demonstrations, and lab projects
	August 10-11	Nuclear Fusion Workshop	Discussion of energy units; tackling specific calculations that students could use in hydrogen fusion
Brookhaven National Laboratory – Stony Brook University	June 27-29 June 30	**Cosmic Ray Workshop** Talks and Tours	Cosmic ray detector testing, reconditioning and adjustments Shuffling the Particle Deck (0) Implementation plans and discussion
The Catholic University of America	July 19-22	Summer Workshop	Shuffling the Particle Deck (0) Cosmic Ray e-Lab (3) Where's Higgs? Calculate the Z-Mass (1) Time of Flight measurement of muons Presentations on classroom implementation and inquiry-focused curriculum planning; aligning NGSS standards with interactive projects (e.g., e-Labs)
Colorado State University	September 24-26	Workshop	Share-a-Thon Teachers from this center participated in Data Camp (one) and Coding Camp I (one).

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.

Table F-6 (con't.)

2022 QuarkNet Workshops and Meetings: National- and Center-led (December 2021-October 2022)

Center	**2022 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Fermilab/University of Chicago/College of DuPage	August 2-4	**CMS Masterclass Workshop: Teaching with Data**	CMS Masterclass measurement Resources (DAP activities): Rolling with Rutherford (1) Calculate the Z Mass (1) Quark Workbench (0) Mass of U.S. Pennies (0) STEP UP Lessons 1 -3 Cosmic Ray Muon Detectors Shuffling the Particle Deck (0) Implementation Plans
~~Florida Institute of Technology~~[a]			
Florida International University	July 18-19	**Neutrino Data Workshop**	Shuffling the Particle Deck (0) Mean Lifetime Part 1: Dice (1) Mean Lifetime Part 3: MINERvA (2) The Case of the Missing Neutrino (1) Implementation Plans and Discussion
Florida State University/University of Florida	July 19-20 July 21 July 22	Summer Workshop **Neutrino Data (NOvA)** **Higgs@10**	The Case of the Missing Neutrino (1) Shuffling the Particle Deck (0) Higgs Search in CMS data Implementation Plans and Discussion
Idaho State University	July 11-14	**Coding Workshop**	Cosmic Ray e-Lab; classroom implementation
Johns Hopkins University	July 25-29	Summer Workshop	Constant motion testing experiment Drawing spacetime diagrams and student-friendly examples What does Goddard (space flight center) have for high school teachers
Kansas State University/University of Kansas	March 5	Masterclass Orientation	In preparation for CRMD research project.
	April 1	Masterclass	CMS
	May31 June 1-3	**Cosmic, Neutrino Data, & Higgs@10 Workshop**	Shuffling the Particle Deck (0) Mean Lifetime Part 3 MINERvA (2) MINERvA Masterclass measurement The Case of the Missing Neutrino (1) Implementation Plans

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.
[a]QuarkNet staff members are hoping to merge this center with the University of Florida and University of Central Florida (Cecire via email October 15, 2022).

Table F-6 (con't.)

2022 QuarkNet Workshops and Meetings: National- and Center-led (December 2021-September 2022)

Center	**2022 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Lawrence Berkeley National Laboratory	June 24 June 27 June 28	**Particle Physics Data Activities** (1 hour session each day)	Particle Cards (virtual) Quark Workbench Search for Higgs in CMS data
	June 21-July1	Physics in and through the Cosmology Two Week Virtual Workshop (3 hours per day)	A total of 6 teachers and 46 students participated. Discussion on cosmic rays and how a cosmic ray detector works. Presentation by Nobel Prize winner Saul Perlmutter
Northern Illinois University	No activity		
Oklahoma State University/University of Oklahoma	July 18-19 July 20-21	**Coding Workshop** **Higgs Boson, ATLAS, CMS**	Coding Project/Implementation Plan Shuffling the Particle Deck (0) Quark Workbench (0) Where's Higgs Calculate the Z Mass (1) Implementation plan and discussion Brainstorming how center can help in teachers' classrooms
Purdue University	September 8	Modern Physics Remote Teacher Workshop (1/2 day)	Introduction to the Data Activities Portfolio Making Tracks I Prep for In-person full-day workshop in October 22 Shuffling the Particle Deck (0) Quark Workbench (0)
Purdue University Northwest	No date(s)	Summer Workshop	Produced a week-long curriculum Students designed a long-term water shielding study for CRMD's Create a new logo for the PNW Center for High Energy Physics Create a poster for the QuarkNet Center Particle simulation Calculate the Top Quark (1)

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.

Table F-6 (con't.)
2022 QuarkNet Workshops and Meetings: National- and Center-led (December 2021-October 2022)

Center	**2022 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Queensborough Community College	April 29	Research Symposium	Measuring cable attenuation Cosmic ray Arduino data
Rice University/University of Houston	June 6-7 June 6-9 June 10	**Coding** **Neutrino Data** **Higgs@10**	The Case of the Hidden Neutrino (1) Shuffling the Particle Deck (0) Histograms: The Basics (0) Where's Higgs? Neutrino masterclass measurement MINERvA/NOvA measurement Implementation plans and discussion
Rutgers University	March	MINERvA Masterclass	4 teachers and 25 students
	2 weeks (no dates)	Summer Program on Fundamental Physics	Analyzing data from MINERvA experiment Measurements on Cosmic Ray muons using Cosmic Ray Detectors; student presentations
Southern Methodist University	June 20-21 June 22-23 June 24	**Neutrino Data** **CMS Data** **Higgs@10**	Shuffling the Particle Deck (0) The Case of the Hidden Neutrino (1) Mean Lifetime Part 1: Dice (1) Mean Lifetime Part 2: Cosmic Ray Muons (2) Mean Lifetime Part 3: MINERvA (2) Making Tracks I (Cloud Chamber) (0) Making Tracks II (Bubble Chamber) (1) Calculate the Mass of Z (1) CMS Masterclass measurement Totem (1); Totem (2) Implementation plans and discussion
Syracuse University	August 8-10 August 9	Summer Workshop **Higgs@10**	Rolling with Rutherford (1) Mass of U.S. Pennies (0) Shuffling the Particle Deck (0) Making it 'Round the Bend: Qualitative (1) or Quantitative (2) Mapping the Poles (0) Higgs@10

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.

Table F-6 (con't.)
2022 QuarkNet Workshops and Meetings: National- and Center-led (December 2021-September 2022)

Center	**2022 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Texas Tech University	July 11-13 (each full day) July 14-15 (each 1/2 day)	Summer Workshop	Cosmic Ray detector reassembly Teachers worked on various DAP activities (not specified) and several e-Lab sites
University at Buffalo –SUNY	April 2	CMS Masterclass (2 teachers/4 students)	Students shared findings with other participating QuarkNet centers via videoconference facilitated by Fermilab moderator
	August 22 August 23-24	**Summer Workshop: Higgs Coding**	Shuffling the Particle Deck (0) Where's the Higgs? Dice, Histograms & Probability (0) Introduction to Coding Using Jupyter Implementation plans and presentations
University of California Irvine	July 7-8	**Summer Workshop**	Shuffling the Particle Deck Mean Lifetime Part 1: Dice (1) Mean Lifetime Part 2: Cosmic Muons (2) Mean Lifetime Part 3: MINERvA (2) The Case of the Missing Neutrino (1) Implementation discussion
~~University of California at Riverside~~[b]			
University of California Santa Cruz	March 5	Masterclass Remote (2 students) and in-person (5 students)	Video conference held with masterclass students from LBNL and facilitated by Fermilab ATLAS and BAMA activity held at local high school (Scotts Valley)
University of Cincinnati	June 14-16	Artificial Intelligence, Machine Learning and STEP UP	Introduction to machine learning STEP UP: Careers in Physics (Lesson 2) (1) STEP UP: Women in Physics (Lesson 3) (2) Calculate the Z mass (1) QuarkNet World Wide Data Day CMS masterclass LHCb masterclass

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.
bMentors have been unable to gather teachers for masterclasses (Cecire via email October 15, 2022).

Table F-6 (con't.)

2022 QuarkNet Workshops and Meetings: National- and Center-led (December 2021-September 2022)

Center	**2022 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
University of Florida	No activity		
University of Hawai`i	March 12	Masterclass	3 teachers and 20 students
	October 6-7	**Workshop and APS FWS Meeting**	Shuffling the Particle Deck (0) Calculate the Z Mass (1) Introduction to: CMS Ray e-Lab; W2D2 measurement; Introduction to Coding Implementation Discussion
University of Illinois at Chicago/Chicago State University	August 10-11	**Cosmic Ray** **Higgs@10**	
University of Iowa/Iowa State University	No activity		
University of Kansas	No activity		
University of Minnesota	April 23	**NOvA Masterclass Pilot**	NOvA measurement Part 1 & 2
	June 13-14 June 15 Jun 16	**Summer Workshop Cosmic Ray** **Neutrino Data Update** **Higgs@10**	Cosmic Ray studies and discussion NOvA Part 1 NOvA Part 2 Shuffling the Particle Deck (0) Where's the Higgs? Implementation plans and discussion
University of Mississippi	May 27-28	**QN@FPCP**	Shuffling the Particle Deck (0) MINVERvA Neutrino Masterclass Introduction Mean Lifetime Part 1: Dice (1) Mean Lifetime Part 3: MINERvA (2)
	July 9	Particle Detection	Building a simple detector

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.

Table F-6 (con't.)

2022 QuarkNet Workshops and Meetings: National- and Center-led (December 2021-September 2022)

Center	2022 Dates (All dates except where noted)	Workshop/Meeting	Brief Summary of Activities and Data Activities Portfolio (Level) [and/or classroom use/implementation plans]
University of New Mexico	July 26-29	**Cosmic Ray & ATLAS Data Workshop**	Shuffling the Particle Deck (0) Making Tracks: 1 (0) Rolling with Rutherford (1) Cosmic Ray Sessions 1, 2 & 3 Mass of U. S. Pennies (0) Calculate the Z Mass (1) ATLAS analysis (BAMA) Implementation discussion
University of Notre Dame	March 31	MINERvA Masterclass	Introduction and masterclass measurement Video conference with Sanford, South Dakota
	August 1-5	**Workshop** (Virtual Center)	Shuffling the Particle Deck (0) Calculate the Z Mass (1) Implementation and Discussion Plans
University of Oregon	June 22	Series of Talks	Talks on scientific research in high-energy physics and astrophysics (e.g., recent updates and progress),
~~University of Pennsylvania~~[c]			
University of Puerto Rico - Mayaguez	March	Masterclass Orientation	
	March 26	MINERvA Masterclass	
~~University of Rochester~~[c]			
~~University of Tennessee Knoxville~~[e]			
University of Washington	No activity		
University of Wisconsin - Madison	No activity		
Vanderbilt University	June 21-24 July 27	Summer Workshop then Additional Short Workshop	Shuffling the Particle Deck (0) Where's Higgs? Using CRMDs and discussion on how to use in classroom
Virginia Center (Hampton University, the William and Mary, and the George Mason University)	August 1 August 2 August 3	**What's New** **Neutrino Data** **Higgs@10**	Shuffling the Particle Deck (0) Where's Higgs? Totem activities STEP UP: Careers in Physics (Lesson 3) (2) Calculate the Z Mass (1) Implementation Plans & Reflections

Note. National led QuarkNet workshops are in a bold face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.
[c]No longer an active QuarkNet center.

Table F-6 (con't.)

2022 QuarkNet Workshops and Meetings: National- and Center-led (December 2021-September 2022)

Center	**2022 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Virginia Tech	no date	Spring Meeting	Lead teacher gave presentation on online adaptation of DAP activities
	June 27	Zoom 1-day link with BNL	CMS e-Lab introduction and exploration
	June 28-29	**Neutrino Data Workshop**	Shuffling the Particle Deck (0) Mean Lifetime Part 1: Dice (1) Mean Lifetime Part 2: Cosmic Muons (2) Mean Lifetime Part 3: MINERvA (2) The Case of the Missing Neutrino (1)
Virtual Center	August 3-5	**Summer Virtual Workshop** (with Notre Dame)	Shuffling the Particle Deck (0) Calculate the Z Mass (1) Implementation Discussion and Plans
~~Wayne State University~~[c]			
Coding Camp	June 13-17	**Coding Camp 1** (Held virtually)	Introduction to how to: Code in Python Analyze particle physics data Integrate into classroom
	July 24-29	**Coding Camp 2**[d]	In-depth experience with fundamental computer programming skills and applications with particle physics used as the context
Data Camp	July 10-15	**Week-long Workshop** held at Fermilab	How We Roll CMS calibration Quark Workbench (0) Rolling with Rutherford (1) Calculate the Top Quark Mass (1) Mass of U.S. Pennies (0) Overview of masterclasses & QuarkNet events

Note. National led QuarkNet workshops are in a bold face font. Compiled from agenda and final reports posted on QuarkNet website by individual center.

[c]No longer an active QuarkNet center.

[d]Funded through a grant from IRIS-HEP.

Assessment of Program Outcomes at the National and Center Levels: Full Teacher Survey

The Full Teacher Survey was developed to assess teacher-level program outcomes at the national and center levels as perceived by participating teachers. As implied, the unit of measure is the individual teacher. The full survey is shown in this appendix for the origin and the modified version is shown in Appendix H (both in a PDF format). Teachers participated in the survey electronically through a SurveyMonkey link. Teachers are encouraged to complete the survey using their own electronic device, although the use of their personal cell phone is not recommended.

There are six segments to the survey, questions about: 1) who is completing it; 2) level of QuarkNet participation; 3) classroom use of activities from the Data Activities Portfolio; 4) opportunities to be exposed to QuarkNet program strategies, including big-picture and community-building strategies; 5) teacher-level outcomes and the degree to which QuarkNet may have influenced these; and 6) (their) student-level outcomes and the degree to which QuarkNet may have influenced this engagement.

To begin, teachers are asked to provide information about themselves (e.g., *How many years have you been teaching?*) brief information about their school (e.g., *What best describes the location of your school?)* (Segment 1)*;* as well as the nature and extent of their participation in QuarkNet (e.g., Which *QuarkNet Workshops or Programs have you participated in*?) (Segment 2). The central thesis of the survey incorporates questions related to the use of DAP activities in their classrooms (Segment 3); exposure to core program strategies (segment 4); teacher-level program outcomes (Segment 5); and student-level outcomes articulated in the PTM (Segment 6).

A detailed description of strategies and program outcomes covered in this survey is shown in Table 12 (in the narrative of this report). Specifically, teachers are asked their perspectives on the degree to which they were exposed to or engaged in the program strategies listed in the table (and reflected in the PTM) (e.g., *QuarkNet provides opportunities for me to: a. Engage as an active learner, as a student.*). Then, teachers are asked their perceptions as to how (or if) they have applied what they have experienced or learned through their QuarkNet participation in their classrooms (e.g., *Demonstrate how to use, analyze and interpret authentic data*). Also, they are asked to reflect on the degree to which they think QuarkNet has influenced these behaviors. Finally, teachers are asked to reflect on student-level outcomes based on perceived student classroom engagement and the degree to which QuarkNet has influences these behaviors as well (e.g., *Discuss and explain concepts in particle physics*).

Throughout the survey there is a full array of response options, with many opportunities for open-ended responses. A 5-point, Likert-like scale is used to gather teacher perspectives on questions related to exposure to core program strategies (Poor, Fair, Average, Good or Excellent); teacher program outcomes that are event-based in the classroom (Almost Always, Very Often, Sometimes, Not Very Often, or Rarely); and student classroom engagement (Very High, High, Moderate, Low or Very Low). When used, a “Not Applicable” option carried a value of zero. These responses were coded such that the higher the value, the more positive the response.

In support of the Teacher Survey, an email blast was sent in early spring (2019) to active centers to underscore the importance of evaluation efforts prior to the planned summer (2019) workshops (and then repeated in subsequent program years). Evaluation requests were also included on their “must do” list (which included information for teachers to receive their stipend). Mentors, fellows and facilitators were asked to include time to complete the survey in the agenda of the event as well (including the SurveyMonkey link). Teachers were encouraged to self-identify on the survey to facilitate the linking of this survey information to program participation levels. Thus, evaluation requests and requirements were embedded along with other program announcements and actions.

The first administration of the Full Teacher Survey occurred during QuarkNet workshops and programs implemented during the 2019-2020 program year. Teachers were asked to complete the survey during their at-site QuarkNet event. Time to complete the survey was incorporated into most workshop agendas and many workshop facilitators announced and emphasized the importance of survey participation. According to Survey Monkey, it took (and will take) an estimated 16-18 minutes to complete.

The survey is a planned annual event; however, a given teacher is asked to complete the full survey only once during this grant period. Starting in spring 2020, if a teacher had completed the Full Teacher Survey, he or she was asked to complete the short Update: Teacher Survey (see Appendix I). The update focused on the use (or planned use) of activities in the Data Activities Portfolio in the classroom; teacher-level outcomes and their perceptions about (their) student outcomes. The update was rolled out to coincide with the 2019-2020 program year and continued during each subsequent program year. (There is also a Spanish language version.) Teachers access it through a SurveyMonkey link with an estimated 6-minute completion time. Time to complete this update is also incorporated into the agenda.

2019 QuarkNet Teacher Survey

QuarkNet Survey

We appreciate your participation in this survey and we will use this information to inform the funders of the program as well as to help guide our thinking about program changes and improvements. Please take the time to tell us about your QuarkNet experience(s) and how and in what ways your QuarkNet engagement may have helped to change or improve your classroom instruction. Please answer all questions to the best that you can; your answers will be kept confidential. We ask that you provide your name for tracking and follow-up purposes only.

1. Today's Date

2. Your Email Address *(optional)*

3. Your Name *(optional)*

4. Your Gender

5. For how many years (approximately) have you participated in QuarkNet (including today or your most recent participation)?

6. What is the name/brief description of the QuarkNet program/workshop that you participated in today (or most recently)?

7. What is the name of the QuarkNet center (university/institution) where you have participated?

8. What is the name of the school (or district) where you teach?

9. What best describes the location of your school?

- ○ Rural
- ○ Urban, central city
- ○ Urban
- ○ Suburban

10. For how many years have you been at this school?

11. How many years have you been teaching?

12. Do you teach physics?

- ○ Yes
- ○ No

13. *If yes, please specify year (e.g., 9th, 10th) and whether General or Conceptual, AP, Honors.*

14. Can we contact you for a follow-up interview to talk with you about your approach to teaching?

- ○ Yes
- ○ No
- ○ Other (please specify)

Your Participation in QuarkNet Workshops/Programs

15. Which QuarkNet Workshops or Programs have you participated in? *(Check all that apply. If not on the list, please provide a brief description.)*

- [ ] Data Camp
- [ ] ATLAS Data Workshop
- [ ] CMS Data Workshop
- [ ] CMS e-Lab Workshop
- [ ] Cosmic Ray e-Lab Intro Workshop
- [ ] Cosmic Ray e-Lab Advanced Topics Workshop
- [ ] Neutrino Data Workshop
- [ ] ATLAS Masterclass
- [ ] CMS Masterclass
- [ ] Neutrino Masterclass
- [ ] CERN Summer Program
- [ ] W2D2
- [ ] International Cosmic Day
- [ ] International Muon Week
- [ ] Other (please specify)

16. Of these, which do you think have been most helpful to you in your teaching? *Please briefly describe why.*

2019 QuarkNet Teacher Survey

Your Use of the Data Activities Portfolio

The Data Activities Portfolio is QuarkNet's online compendium of instructional materials and suggested instructional pathways.

17. Have you used any of the activities in the Data Activities Portfolio in your classroom?

◯ Yes ◯ No

18. Please give us an example(s) of which of these activities in the Data Activities Portfolio you have used most often and/or that you think have been most helpful in teaching physics related to content and/or pedagogy.

19. Would you recommend (or have you recommended) the Data Activities Portfolio to other high school physics or physical science teachers?

◯ Yes ◯ No

20. Please tell us why you would or would not recommend instructional materials in the Data Activities Portfolio.

Your Assessment of QuarkNet

Please rate the following strategies based on your current QuarkNet program experience and, if applicable, on your previous involvement in QuarkNet programs to date. If you have participated in QuarkNet for many years, please respond based on what you think the cumulative effect of this participation has been over the past two years.

21. QuarkNet provides opportunities for me to:

	Poor	Fair	Average	Good	Excellent	N/A
a. Engage as an active learner, as a student.	◯	◯	◯	◯	◯	◯
b. Do science the way scientists do science.	◯	◯	◯	◯	◯	◯
c. Engage in authentic particle physics investigations (that may or may not involve phenomenon known by scientists).	◯	◯	◯	◯	◯	◯
d. Engage in authentic data analysis experiment(s) using large data sets.	◯	◯	◯	◯	◯	◯
e. Develop explanations of particle physics content.	◯	◯	◯	◯	◯	◯
f. Discuss the concept of uncertainty in particle physics.	◯	◯	◯	◯	◯	◯

22. QuarkNet provides opportunities for me to:

	Poor	Fair	Average	Good	Excellent	N/A
a. Engage in project-based learning that models guided-inquiry strategies.	○	○	○	○	○	○
b. Share ideas related to content and pedagogy.	○	○	○	○	○	○
c. Review and select particle physics examples from the Data Activities Portfolio instructional materials.	○	○	○	○	○	○
d. Use the pathways, suggested in the Data Activities Portfolio, to help design classroom instructional plan(s).	○	○	○	○	○	○
e. Construct classroom implementation plan(s), incorporating experience(s) and Data Activities Portfolio instructional materials.	○	○	○	○	○	○
f. Become aware of resources beyond my classroom.	○	○	○	○	○	○

23. Please use the space below to tell us anything you would like us to know regarding your ratings of the strategies mentioned above.

Your Assessment of QuarkNet (con't.)

Please rate the following big-picture strategies based on your current QuarkNet experience and, if applicable, on your previous involvement in QuarkNet programs to date. If you have participated in QuarkNet for many years, please respond based on what you think the cumulative effect of this participation has been over the past two years.

24. QuarkNet provides opportunities for me to be exposed to:

	Poor	Fair	Average	Good	Excellent	N/A
a. Instructional strategies that model active, guided-inquiry learning (related to NGSS science and engineering practices).	○	○	○	○	○	○
b. Big Idea(s) in Science (cutting-edge research) and Enduring Understandings (in particle physics).	○	○	○	○	○	○

25. Provide opportunities for teachers and mentors to:

	Poor	Fair	Average	Good	Excellent	N/A
a. Interact with other scientists and collaborate with each other.	○	○	○	○	○	○
b. Build a local (or regional) learning community.	○	○	○	○	○	○

26. Please use the space below to tell us anything you would like us to know regarding your ratings of the big-picture strategies mentioned above.

Your Assessment of QuarkNet (con't.)

The next set of questions will ask about classroom instruction and QuarkNet's influence.

27. In thinking about your approach to teaching, please rate the frequency in which you engage in each of the following in your classroom.

	Almost Always	Very Often	Sometimes	Not Very Often	Rarely	N/A
a. Discuss and explain concepts in particle physics.	◯	◯	◯	◯	◯	◯
b. Engage in scientific practices and discourse.	◯	◯	◯	◯	◯	◯
c. Use particle physics examples, including authentic data, when teaching subjects such as momentum and energy.	◯	◯	◯	◯	◯	◯
d. Review and use instructional materials from the Data Activities Portfolio.	◯	◯	◯	◯	◯	◯
e. Selecting these lessons guided by the suggested pathways.	◯	◯	◯	◯	◯	◯
f. Facilitate student investigations that incorporate scientific practices.	◯	◯	◯	◯	◯	◯

28. Now, indicate the degree to which you think QuarkNet has contributed to your implementation of these instructional strategies in your classroom.

	Very High	High	Moderate	Low	Very Low	N/A
a. Discuss and explain concepts in particle physics.	◯	◯	◯	◯	◯	◯
b. Engage in scientific practices and discourse.	◯	◯	◯	◯	◯	◯
c. Use particle physics examples, including authentic data, when teaching subjects such as momentum and energy.	◯	◯	◯	◯	◯	◯
d. Review and use instructional materials from the Data Activities Portfolio.	◯	◯	◯	◯	◯	◯
e. Selecting these lessons guided by the suggested pathways.	◯	◯	◯	◯	◯	◯
f. Facilitate student investigations that incorporate scientific practices.	◯	◯	◯	◯	◯	◯

29. In thinking about your approach to teaching, please rate the frequency in which you engage in each of the following in your classroom.

	Almost Always	Very Often	Sometimes	Not Very Often	Rarely	N/A
a. Use active, guided-inquiry instructional practices that align with science practice standards (NGSS and other standards).	○	○	○	○	○	○
b. Use instructional practices that model scientific research.	○	○	○	○	○	○
c. Ilustrate how scientists make discoveries.	○	○	○	○	○	○
d. Demonstrate how to use, analyze and intepret authentic data.	○	○	○	○	○	○
e. Demonstrate how to draw conclusions based on these data.	○	○	○	○	○	○
f. Become more comfortable teaching inquiry-based science.	○	○	○	○	○	○

30. Now, indicate the degree to which you think QuarkNet has contributed to your implementation of these instructional strategies in your classroom.

	Very High	High	Moderate	Low	Very Low	N/A
a. Use active, guided-inquiry instructional practices that align with science practice standards (NGSS and other standards).	○	○	○	○	○	○
b. Use instructional practices that model scientific research.	○	○	○	○	○	○
c. Illustrate how scientists make discoveries.	○	○	○	○	○	○
d. Demonstrate how to use, analyze and interpret authentic data.	○	○	○	○	○	○
e. Demonstrate how to draw conclusions based on these data.	○	○	○	○	○	○
f. Become more comfortable teaching inquiry-based science.	○	○	○	○	○	○

Your Assessment of QuarkNet (con't.)

31. Please respond to the following statements.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
a. I use resources (including QuarkNet resources) to supplement my knowledge and instructional materials and practices.	◯	◯	◯	◯	◯
b. I have increased my science proficiency.	◯	◯	◯	◯	◯
c. I have developed collegial relationships with scientists and other teachers.	◯	◯	◯	◯	◯
d. I think my students have become more comfortable with inquiry-based science.	◯	◯	◯	◯	◯

Your Assessment of QuarkNet (con't.)

This last set of questions asks about your students' classroom engagement and how QuarkNet may have influenced (through your participation and/or your students) this engagement. In your judgment, please indicate ...

32. My students are able to:

	Almost Always	Very Often	Sometimes	Not Very Often	Rarely	N/A
a. Discuss and explain concepts in particle physics.	○	○	○	○	○	○
b. Discuss and explain how scientists develop knowledge.	○	○	○	○	○	○
c. Engage in scientific practices and discourse.	○	○	○	○	○	○
d. Use, analyze and interpret authentic data.	○	○	○	○	○	○
e. Draw conclusions based on these data.	○	○	○	○	○	○

33. Now, indicate the degree to which QuarkNet (either because of your participation and/or theirs) has contributed to your students' engagement. QuarkNet has helped my students to:

	Very High	High	Moderate	Low	Very Low	N/A
a. Discuss and explain concepts in particle physics.	○	○	○	○	○	○
b. Discuss and explain how scientists develop knowledge.	○	○	○	○	○	○
c. Engage in scientific practices and discourse.	○	○	○	○	○	○
d. Use, analyze and interpret authentic data.	○	○	○	○	○	○
e. Draw conclusions based on these data.	○	○	○	○	○	○

34. Please use the space below for anything else you would like us to know about your QuarkNet experience or your approach to teaching science in your classroom. *Thank you for your participation. We appreciate it!*

UPDATE: QuarkNet Teacher Survey

IMPORTANT. ***Please complete this UPDATE only if you have completed the 2019 QuarkNet Teacher Survey, which you should complete only once. Please answer all questions (a total of 10) to the best that you can; your answers will be kept confidential. We ask that you provide your name for tracking and follow-up purposes only. Thank you for your participation, we appreciate it!***

1. Today's Date

2. Your E-mail Address (Optional)

3. Your Name (Optional but very helpful to know)

4. What is the name of the QuarkNet Center where you have participated today (or most recently)?

UPDATE: QuarkNet Teacher Survey

The next set of questions asks about how you intend to use (or have used) QuarkNet content and materials as a teacher in your classroom.

5. Briefly describe how you intend to incorporate (or have incorporated) your QuarkNet experiences into your classroom (e.g., Cosmic Ray, LHC, neutrinos, e-labs; masterclass) when teaching, for example, conservation laws, uncertainty, the standard model or something else.

6. Using QuarkNet content and materials in my classroom, when teaching physics (or related science) I am able to: (*Check all that applies*.)

	Almost Always	Very Often	Sometimes	Not Very Often	Rarely	N/A
a. Discuss and explain concepts in particle physics.	○	○	○	○	○	○
b. Engage in scientific practices and discourse.	○	○	○	○	○	○
c. Use particle physics examples, including authentic data, when teaching subjects such as momentum and energy.	○	○	○	○	○	○
d. Review and use instructional materials from the Data Activities Portfolio (DAP).	○	○	○	○	○	○
e. Select (DAP) lessons guided by suggested sequencing.	○	○	○	○	○	○
f. Faciliate student investigations that incorporate scientific practices.	○	○	○	○	○	○

7. *To Continue*: Using QuarkNet content and materials in my classroom, when teaching physics (or related science) I am able to: (*Check all that applies.)*

	Almost Always	Very Often	Sometimes	Not Very Often	Rarely	N/A
g. Use active, guided-inquiry instructional practices that align with science practice standards (NGSS and other standards).	○	○	○	○	○	○
h. Use instructional practices that model scientific research.	○	○	○	○	○	○
i. Illustrate how scientists make discoveries.	○	○	○	○	○	○
j. Demonstrate how to use, analyze and interpret authentic data.	○	○	○	○	○	○
k. Demonstrate how to draw conclusions based on these data.	○	○	○	○	○	○
l. Become more comfortable teaching inquiry-based science.	○	○	○	○	○	○

Other (please specify)

UPDATE: QuarkNet Teacher Survey

The last set of questions asks about the use of activities from the Data Activities Portfolio, your perceptions about student engagement, and final thoughts.

8. Which activities from the Data Activities Portfolio have you used (or will use) in your classroom? *(Please list up to three activities. If you don't plan or haven't used these activities, please provide a short explanation as to why not.)*

9. Using QuarkNet content and/or materials, which of these behaviors do you think your **students** will be able to do (or are able to do) in your classroom? *(Check all that applies.)*

	Almost Always	Very Often	Sometimes	Not Very Often	Rarely	N/A
a. Discuss and explain concepts in particle physics.	○	○	○	○	○	○
b. Discuss and explain how scientists develop knowledge.	○	○	○	○	○	○
c. Engage in scientific practices and discourse.	○	○	○	○	○	○
d. Use, analyze and interpret authentic data.	○	○	○	○	○	○
e. Draw conclusions based on these data.	○	○	○	○	○	○

Other (please specify)

10. What else would you like to tell us about your QuarkNet experience as you reflect on applications in your classroom?

Assessment of the Sustainability of Program Centers: Based on Center-level and Sustainability Outcomes – Center Feedback Template

Given that most teachers experience the QuarkNet program through their engagement of the program at a specific center, the center provides an important context in which the teachers experience the program and at the same time, centers are a source of outcomes in their own right. To this end, the Center Feedback Template was designed to assess this program context, assess center-level outcomes (see Table 13); and gather information on success factors as a means to assess sustainability outcomes (see Table 14).

The Center Feedback Template is a 4-page form divided into four sections (see Appendix J). Information about the Center (who is participating in this effort and who is completing this form) is requested in Section I. Section II asks about program events over the past two years. Section III gathers information about center-level outcomes (described in Table 13); and Section IV is focused on the Success Factors listed in Table 14. Finally, there is an optional fifth page for Centers to add any additional comments, if desired.

Given that this template is more complicated than a survey per se, we adopted the following protocol. First, relying on help from QuarkNet's staff teachers, centers were selected on a rolling basis. More on this rolling process will be presented in a subsequent section of this report.

To help ease the task, a draft of Section II was completed by the evaluator using information gathered from existing annual reports and agenda(s) for a given center over the past two years, for example, 2021 and 2020 program years. Each of these draft summaries were reviewed by a QuarkNet staff teacher who had worked with that center and who has direct knowledge about it. Each summary was revised as needed. (Figure 5 shows a blank Section II.) Then, the mentor was sent an email suggesting that an initial conference call was likely necessary to help the center fulfill this request. In practice, this conference call ran about an hour and typically had included a QuarkNet staff teacher, the mentor and lead teachers from the center and the evaluator. During discussion, Section II was reviewed but the focus of the call was on helping the center complete Sections III and IV after the call (see Figures 6 and 7). (Not all centers elected to participate in this conference call, completing the form on their own.) An agreed upon completion deadline was set. Once the center completed the form a short summary of teacher survey responses (from their center) was emailed to them as a thank you and to help guide future program plans.

At the start of this process, a center was selected because a QuarkNet staff teacher has been/is very familiar with the center and has good rapport with its mentor(s) and lead teachers. These early selections tended to represent centers that have successfully implemented QuarkNet over the years; in part because these selected centers tend to reflect the national program (and likely align well with the Program Theory Model) through active participation in programs such as workshops (either national or center-led), e-Labs, and/or Masterclasses.

As we moved through this process, it was likely that selected centers reflected QuarkNet engagement that is both strong in some areas and in need of reflection in other areas (which may be the case for centers that were selected early as well). In addition to serving the evaluation needs that have been described, we hoped that this information was of value to the centers – as a means to reflect on program engagement (past or present) – as well as helpful to QuarkNet staff as they think about current or future needs of the center. Also, we hoped that this process offered a summary of broader impacts of the program for centers to use for other purposes.

As mentioned, we linked teacher responses from the survey to program participation data captured through the Center Feedback Template, as well as other program operations data so that teacher and center responses can be understood in the context of the degree and type of program engagement.

QuarkNet Center Feedback

Your help is important. Please respond to this information request based on your current QuarkNet program experience and, if applicable, on your previous involvement in QuarkNet programs at your Center. If your Center has participated in QuarkNet for many years, please respond based on what you think the cumulative effect of this participation has been over the ***past two years****. We will ask you to complete this form only once. We can help clarify something if needed and we can aid in helping you complete this form if necessary.*

We are asking that this form be completed only once. With help from QuarkNet staff and the evaluator, we are asking for a conference call with person(s) at your center most familiar with these program efforts, such as the mentor(s), fellows and/or lead teachers in order to complete the requested information. Section I asks for information about you, your Center and who is completing this form and for what time period. Section II asks to specify what QuarkNet events your Center has participated in; we have started this process by including engagement information based on agendas from previous workshops and past annual reports that your Center has posted on the QuarkNet website. Section III asks for a reflection on outcomes; and Section IV asks about effective practices that align with the sustainability of the program. (Use an additional page for any comments you may have.) If you have any questions, please email Kathryn Race at race_associates@msn.com.

I. **Center Information**: *Please provide information about the Center and who is completing this form.*

Date:

Which Center? (*please specify name and location of center*):

Who completed this form? (*Please indicate all individuals who helped to complete this form):*

What time period is covered by these observations? (*e.g., 2017-2018; 2018-2019*):

How many years (approximately) has your Center participated in QuarkNet?

II. **QuarkNet Program Activities**: *Please indicate which of the following QuarkNet programs have been implemented at your Center in the past two years, based on your Center's typical engagement in this program. (Check all that apply).*

Check, if yes ✔	*QuarkNet Program Component*	*Held during the summer (✔ or indicate dates)*	*Held during the calendar year (✔ or indicate program year)*	*Other (please specify)*
	National Workshop (facilitated by national program staff or fellows) Workshop list at https://quarknet.org/page/summer-workshop-opportunities-quarknet-centers			
	Center-run Workshop (facilitated by center with center-focused topics/interests)			
	Data Camp:			
	1. Center-level teacher(s) participates at Fermilab			
	2. Teacher(s) introduces activity/methods at Center (based on Data Camp experience)			
	Data Activities Portfolio: Activities at https://quarknet.org/data-portfolio			
	1. Work through and reflect on activity/ities (in the portfolio) at the center.			
	2. Present/discuss examples of classroom implementations based on these activities			
	Masterclass(es): Held one or more at center			
	Cosmic Ray Detector *(e.g., assemble, calibrate)*			
	Other *(please specify any other center-led or center-wide event)*			

QuarkNet Websites: https://quarknet.org/; https://quarknet.org/page/summer-workshop-opportunities-quarknet-centers; https://quarknet.org/data-portfolio

III. **Center-level Outcomes**: *Please indicate which of the following QuarkNet program outcomes have been evident, by whom and the degree of QuarkNet's influence at your Center in the past two years. (Check all that apply.)*

Center-level Outcomes	Who?						QuarkNet's Influence?					
	Almost All	Most	Some	A Few	Rarely	Don't Know	Very High	High	Moderate	Low	Very Low	Does Not Apply
Engage Teachers as Active Learners, as Students (across workshops/events)												
During National/Center-run Workshops or Programs, Teachers Experience Active, Guided-inquiry Instruction through:												
1. Asking questions and defining problems.												
2. Developing and using models.												
3. Planning and carrying out investigations.												
4. Analyzing and interpreting data.												
5. Using mathematics and computational Thinking.												
6. Construct explanations and designing solutions.												
7. Engaging in argument from evidence.												
8. Obtaining, evaluating, and communicating information.												
Networking/Community Building:												
1. Teachers engage/interact with mentors and other scientists.												
2. Teachers engage/interact with other teachers.												
Teachers as Leaders:												
1. Provide leadership at local centers.												
2. Attend and/or participate in regional and national professional conferences sharing their ideas and experiences.												
Teachers and Mentors: Form lasting collegial relationships through interactions and collaborations at the local level and through engagement with the national program.												
Mentors: Become the nexus of a community that can improve their teaching, enrich their research and provide broader impacts for their university.												

Figure 5. Section III of the Center Feedback Template.

IV. **Center-level Success Factors:** *Please view the center's QuarkNet engagement through the lens of the Success Factors related to effective practices as described below.*

Effective Practices/Success Factors[a]	Meets Criteria?				Comments: Please use this space (and additional space if needed) to explain your ratings or to indicate action that may need to occur.
	Yes	Yes, but[1]	No	Unsure	
1. *Program provides opportunities for a **strong teacher leader**.* (Teacher provides leadership in areas of content and/or is a technical expert; models exemplary pedagogical skills; able to provide organizational skills. These characteristics may be present in one or a team of teacher leaders.)					
2. *Program provides opportunities for a **strong mentor**.* (Mentor provides leadership skills mainly of content and/or technical expertise; understands education and professional development -- working with teacher leaders as needed; models research.)					
3. *Participants meet regularly*. (QuarkNet model is for a summer session with follow-up during the academic year or sessions during the academic year. Follow up includes working with the national staff and collaboration within and across centers. Mentors and teachers have flexibility to set the annual program locally.)					
4. *Meaningful activities* (The standard for meaningful activities is focusing topics in modern physics, discussing how to implement this content in classrooms, conducting research and discussing scientific inquiry methods; using Data Activities Portfolio instructional materials.)					
5. *Directly addresses classroom implementation of instructional materials for all teachers.* (Time for teachers to discuss Data Activities Portfolio instructional materials and pathways; to consider NGSS, AP, IB or other science standards; presentation(s) from veteran teachers on classroom implementation experiences or similar engagement.)					
6. Program is able to provide regular contact and support with teachers. (Specific support and or follow up from staff; staff teachers are available and/or volunteers who support teachers, especially related to classroom implementation.)					
7. Money for additional activities or additional grants. (Seeking additional funding to fulfill the mission/objectives of the center; providing supplemental or complementary support for QuarkNet e.g., providing transportation, lodging, buying equipment; providing food.)					
8. Stable participant base.(A stable participant base can provide an expert group that can help other teachers, support outreach, and provide organizational leadership.)					
9. Addresses teacher professionalism. (The standard is to provide opportunities for at least a few teachers to attend professional meetings; support teachers taking leadership roles in their school, school districts, outreach, and highlight PD opportunities for continuing development.)					
10. Establish a learning community. (The standard is forming a cohesive group where teachers learn from one another; engage with mentors and other scientists; provide outreach to other teachers.)					

[a]This section of the protocol has been adapted from M.J. Young & Associates (2017, September). *QuarkNet: Matrix of Effective Practices.*

[1]Needs work or fine tuning; or, there are notable caveats.

Please use an additional page for any comments you may have. Thank you for your participation.

Scale Development in Support of Analyses Related to Teacher (and their Students) Outcomes

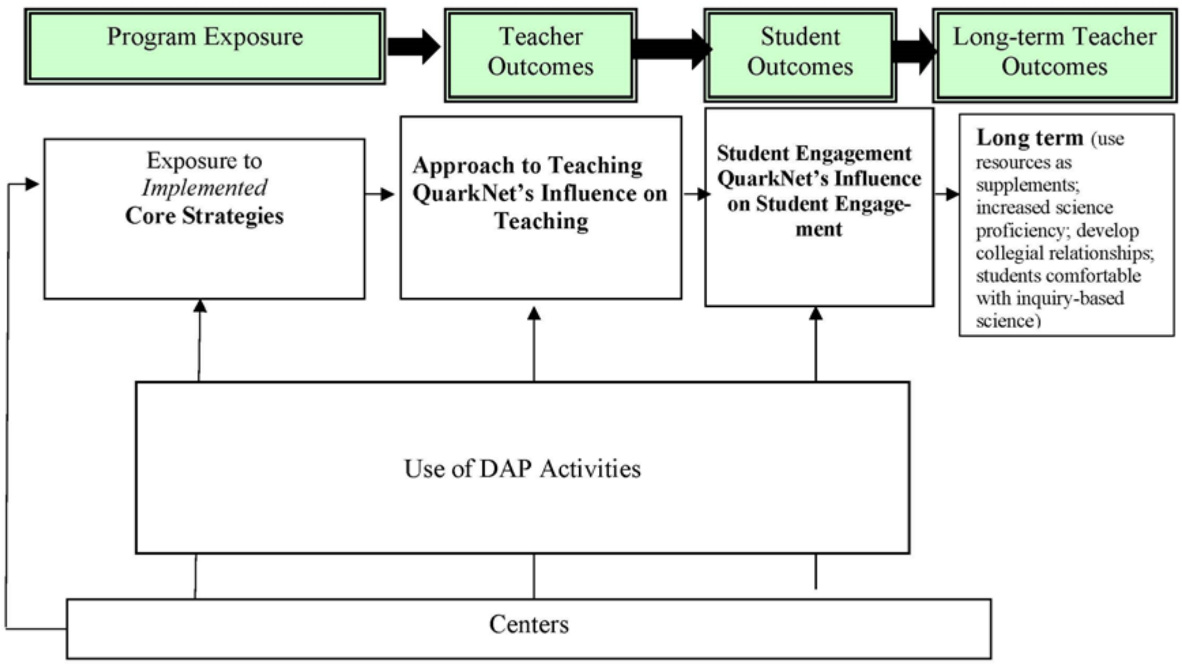


Figure 8. Teacher (and their Students) and Long-term Outcomes: Overview of Analyses

As stated in the narrative of this report, we have explored the relationship between engagement in QuarkNet and exposure to core program strategies; and, subsequently the potential impact this involvement may have on teacher outcomes, student engagement, and more recently long-term outcomes. And as stated in the full report, at times a given measure may serve as the dependent measure in a set of analyses; and in turn, a given measure may be used as a "predictor" variable as we build a model toward understanding teachers' approach to teaching and use of activities in the Data Activities Portfolio. Because of this complexity, the above figure (noted here and in the narrative of the report as Figure 8) provides an overview of these analyses as a means of offering a road map to their logic.

To help simplify these analyzes and to use data with measured reliability (internal consistency) several scale scores were created. These are: Core Strategies; Approach to Teaching; QuarkNet's Influence on Teaching; Student Engagement; and, QuarkNet's Influence on Student Engagement. A *new* scale score has been added, that is, Long-term Outcomes: Teachers. All are based on self-reported responses by teachers to individual items from the full Teacher Survey. Each of these analyses is presented and discussed separately in the next several sections. Please keep in mind that these scale scores help us explore the association of exposure to core strategies through QuarkNet programs and outcomes; and, that this association is not intended to imply causality.

Program Fidelity:
Perspective of Teachers on Exposure to Program Core Strategies

Given the logically links between articulated core program strategies and expected program outcomes as suggested by the PTM, teachers were asked about their exposure to such strategies during their QuarkNet program engagement. This is seen as a measure of the fidelity of the *implemented* program as compared to the program as *designed*. To this end, in the Full Teacher Survey, teachers were asked to reflect on their exposure to core program strategies; the instructions were:

> *Please rate the following strategies based on your current QuarkNet program experience and, if applicable, on your previous involvement in QuarkNet programs to date. If you have participated in QuarkNet for many years, please respond based on what you think the cumulative effect of this participation has been over the past two years.*

Table K-1
Items Used to Form a **Core Strategies** Scale based on Teacher Responses

Exposure to QuarkNet Strategies
QuarkNet provides opportunities for me to:
21a. Engage as an active learner as a student.
b. Do science the way scientists do science.
c. Engage in authentic particle physics investigations.
d. Engage in authentic data analysis experiments using large data sets.
e. Develop explanations of particle physics content.
f. Discuss the concept of uncertainty in particle physics.
QuarkNet provides opportunities for me to:
22a. Engage in project-based learning that models guided-inquiry strategies.
b. Share ideas related to content and pedagogy.
c. Review and select particle physics examples from the Data Activities Portfolio instructional materials.
d. Use the pathways, suggested by the Data Activities Portfolio, to help design classroom instructional plan(s).
e. Construct classroom implementation plan(s) incorporating experience(s) and Data Activities Portfolio instructional materials.
f. Become aware of resources beyond my classroom.

The items in Table K-1 (Q21 and Q22 from the survey) align with the core program strategies presented in the PTM. These items were rated on a 5-point, Likert-like scale from (1= Poor, 2 = Fair, 3= Average, 4 = Good, and 5= Excellent). For analysis purposes, items were summed to create a **Core Strategies** scale, with *the higher the scale score, the more positive the response.* Descriptive statistics based on actual scores from this 12-item scale, based on an N=574, ranged from 12 to 60, with a Mean = 53.94 (Standard Deviation, SD = 6.96); and an alpha = 0.85 (reliability coefficient, Cronbach's alpha).

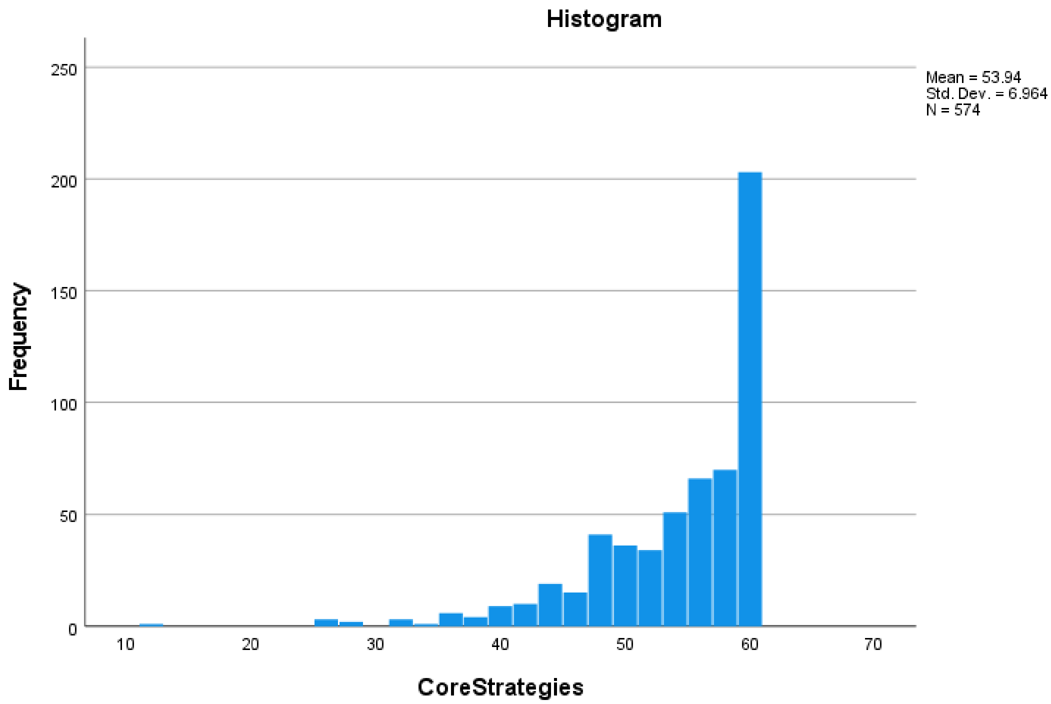


Figure K-1. Distribution of Core Program Strategies scale scores.

These statistics suggest that this scale can be used as a measure of program fidelity, with a skewed distribution as shown in Figure K-1. These data suggest that participating teachers were exposed to a high level of core program strategies (based on their perceived experiences).

Program Outcomes: Approach to Teaching and QuarkNet's Perceived Influence

Several scales were created from questions in the Teacher Survey related to teacher (and their students) outcomes and the perceived influence of QuarkNet on these behaviors. The first of these scales was **Approach to Teaching**, directed toward teacher-outcomes articulated in the PTM. To this end, in the full Teacher Survey, teachers were asked to reflect on classroom instruction, as follows:

> *In thinking about your approach to teaching, please rate the frequency in which you engage in each of the following in your classroom.*

Table K-2/K-3
Items Used to Form an **Approach to Teaching/QuarkNet's Influence** Scale based on Teacher Responses

Approach to Teaching Outcomes
27a. Discuss and explain concepts in particle physics.
  b. Engage in scientific practices and discourse.
  c. Use physics examples including authentic data when teaching subjects such as momentum and energy.
  d. Review and use instructional materials from the Data Activities Portfolio.
  e. Selecting these lessons guided by the suggested pathways.
  f. Facilitate student investigations that incorporate scientific practices.
29a. Use active guided-inquiry instructional practices that align with science practices standards (NGSS and other standards).
  b. Use instructional practices that model scientific research.
  c. Illustrate how scientists make discoveries.
  d. Demonstrate how to use, analyze and interpret authentic data.
  e. Demonstrate how to draw conclusions based on these data.
  f. Become more comfortable teaching inquiry-based science.

The items in Table K-2 (Q27 and Q29 from the survey) were rated on a 5-point, Likert-like event scale from (5= Almost Always, 4 = Very Often, 3= Sometimes, 2= Not Very Often, and 1= Rarely. (A "Not Applicable" option was scored as a zero.) Similarly, for analysis purposes, items were summed to create an **Approach to Teaching** scale, with *the higher the scale score, the more positive the response.* Descriptive statistics based on actual scores from this 12-item scale, based on an N=528, ranged from 14 to 60, with a Mean of 42.24 (SD = 8.66); and an alpha of 0.87 (reliability coefficient). Figure K-2 shows the distribution of these scores, suggesting an approximate normal distribution. We have concluded that this scale can be used as a measure in subsequent analyses (either as an outcome or a predictor).

QuarkNet's Influence on Approach to Teaching

In the Teacher Survey, teachers were asked:

> *Now, indicate the degree to which you think QuarkNet has contributed to your implementation of these instructional strategies in your classroom.*

The items in Table K-3 (now Q28 and 30) were repeated but this time these items were rated on a 5-point, Likert-like scale from (5= Very High, 4 = High, 3= Moderate, 2 = Low, 1= Very Low) measuring the perceived QuarkNet influence on these behaviors. (A "Not Applicable" option was scored as zero.) As in previous scales, items were summed to create a **QuarkNet's Influence on Approach to Teaching** score, with *the higher the score, the more positive the response.* Descriptive statistics based on actual scores from

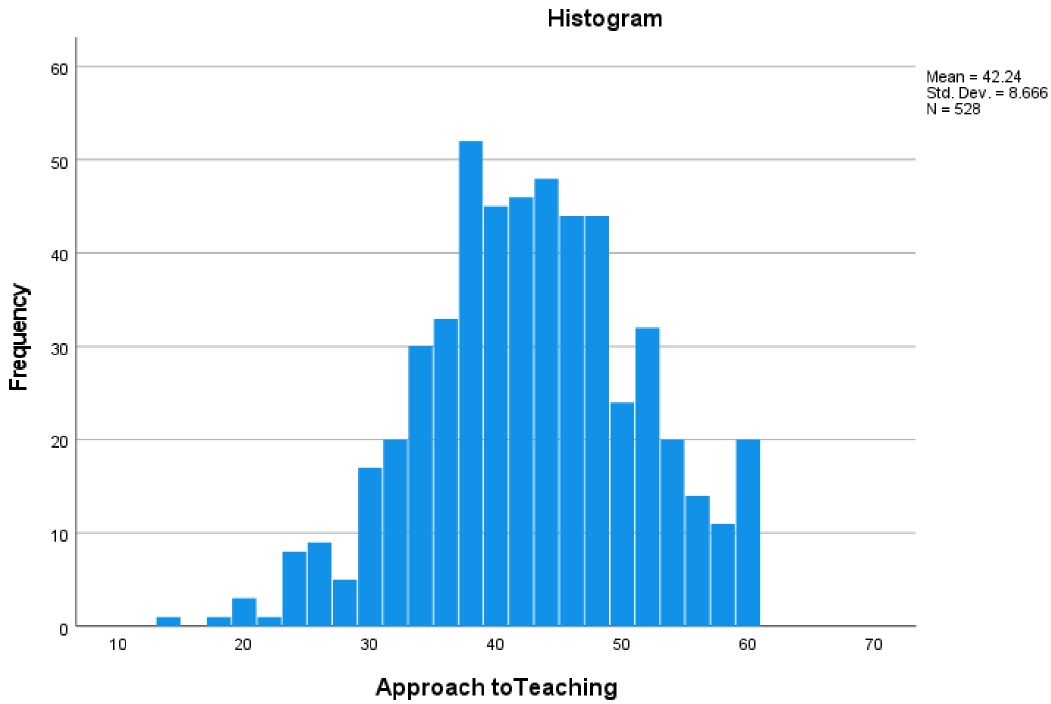


Figure K-2. Distribution of Approach to Teaching scale scores.

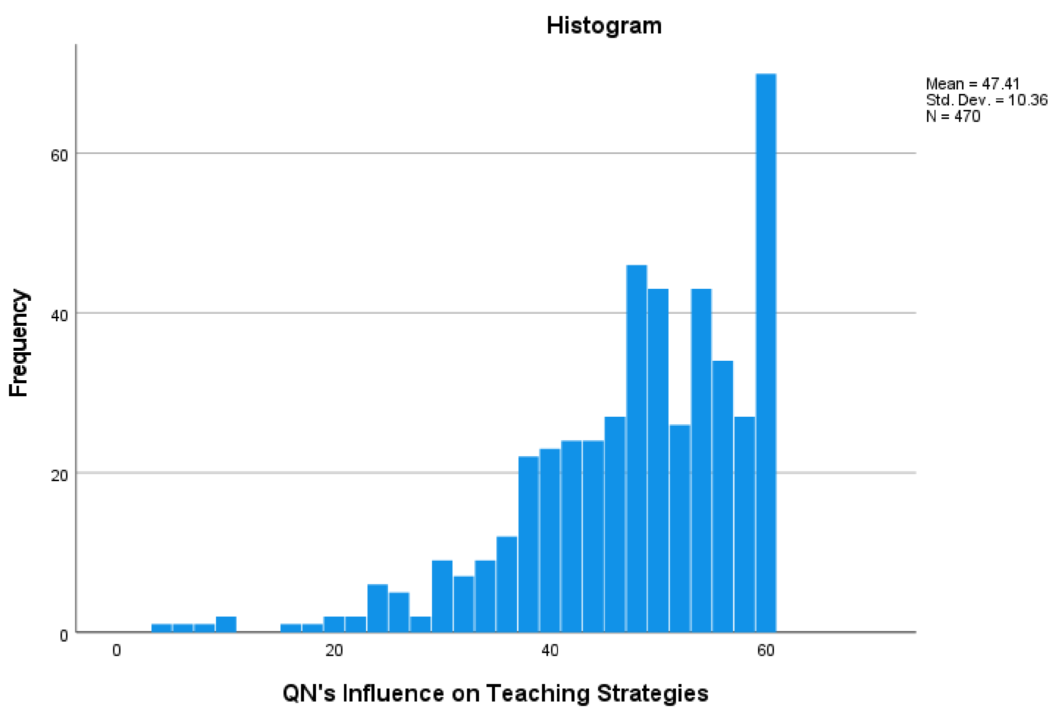


Figure K-3. Distribution of QuarkNet's Influence of Teaching scale scores.

this 12-item scale, based on an N= 470, ranged from 4 to 60, with a Mean of 47.41 (SD = 10.56); and an alpha of 0.93 (reliability coefficient). (See Figure K-3 previous page.)

Student Engagement

In the Teacher Survey, teachers were asked to assess perceptions of their Student Engagement in their classrooms, and their judgment as to QuarkNet's Influence on this engagement. Accordingly, teachers were instructed:

> *This last set of questions asks about your students' classroom engagement and how QuarkNet may have influenced (through your participation and/or your students) this engagement. In your judgment, please indicate ...*

Table K-4/K-5
Items Used to Form a **Student Engagement/QuarkNet's Influence** Scale based on Teachers' Perceptions

Student Engagement (*My students are able to …*)
32a. Discuss and explain concepts in particle physics.
b. Discuss and explain how scientists develop knowledge.
c. Engage in scientific practices and discourse.
d. Use, analyze and interpret authentic data.
e. Draw conclusions based on these data.

The items in Table K-4 (Q32 from the survey) were rated on a 5-point, Likert-like scale from (5= Almost Always, 4 = Very Often, 3= Sometimes, 2= Not Very Often, and 1= Rarely. (A "Not Applicable" option was scored as zero.) Again, for analysis purposes, items were summed to create a **Student Engagement** scale, with *the higher the scale score, the more positive the response.* Descriptive statistics based on actual scores from this 5-item scale, based on an N=498, ranged from 2 to 25, with a Mean of 18.17 (SD = 3.72); and an alpha of 0.83(reliability coefficient). Figure K-4 shows the distribution of these scores, suggesting a measure with natural variability that is approaching a normal distribution.

QuarkNet's Influence on Student Engagement

The items in Table K-5 (now Q33) were repeated but this time these items were rated on a 5-point, Likert-like scale from (5= Very High, 4 = High, 3= Moderate, 2 = Low, 1= Very Low) measuring the perceived QuarkNet influence on these behaviors. (A "Not Applicable" option was scored as zero.) As in previous scales, items were summed to create a **QuarkNet's Influence on Student Engagement** score, with *the higher the score, the more positive the response.* Descriptive statistics based on actual scores from this 5-item scale, based on an N= 415, ranged from 2 to 25, with a Mean of 18.98 (SD = 5.16); and an alpha of 0.94 (reliability coefficient). (See Figure K-5.)

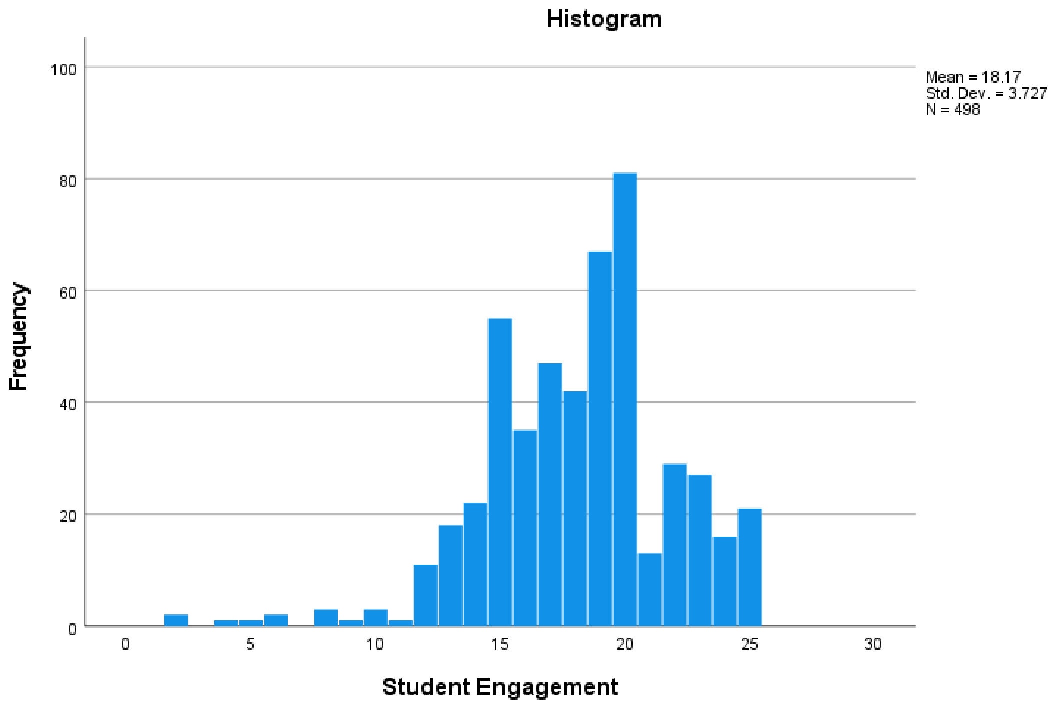


Figure K-4. Distribution of Student Engagement scale scores.

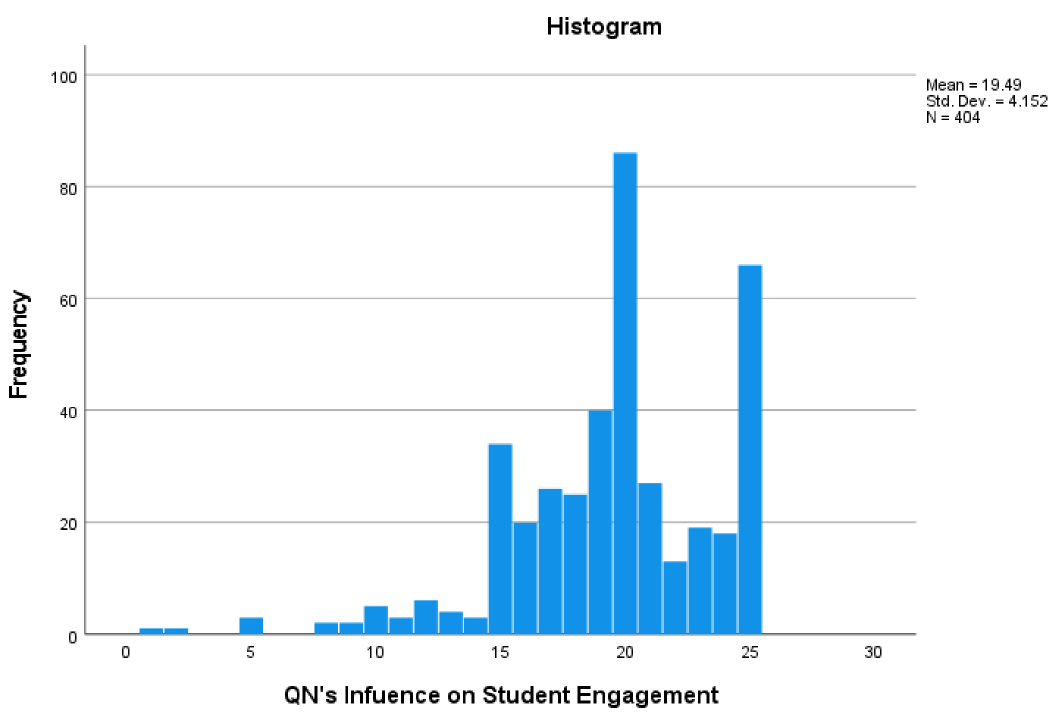


Figure K-5. Distribution of QuarkNet's Influence on Student Engagement scale scores.

Table K-6
Items Used to Form a **Long-term Outcomes: Teachers** Scale based on Teachers' Responses

31. Please respond to the following statements: a. I use resources (including QuarkNet resources) to supplement my knowledge and instructional materials and practices. b. I have increased my science proficiency. c. I have developed collegial relationships with scientists and other teachers. d. I think my students have become more comfortable with inquiry-based science.

Long-term Outcomes: Teachers

In the full Teacher Survey, teachers were asked to reflect on longer-term outcomes with items that describe overarching behaviors that relate to use of resources, development of collegial relationships, increasing one's science proficiency, and students' comfortable with engagement in inquiry-based sciences. These items are shown in Table K-6. Each was rated on a 5-point, Likert-like scale from 5= Strongly Agree, 4 = Agree, 3= Neutral, 2= Disagree, and 1= Strongly Disagree. As for all previous scales, items were summed with *the higher the scale score, the more positive the response.* This scale has been named, **Long-term Outcomes: Teachers.** Descriptive statistics based on actual scores from this 4-item scale, based on an N=531, ranged from 6 to 20, with a Mean of 17.45 (SD = 2.49); and an alpha of 0.81 (reliability coefficient). See Figure K-6.

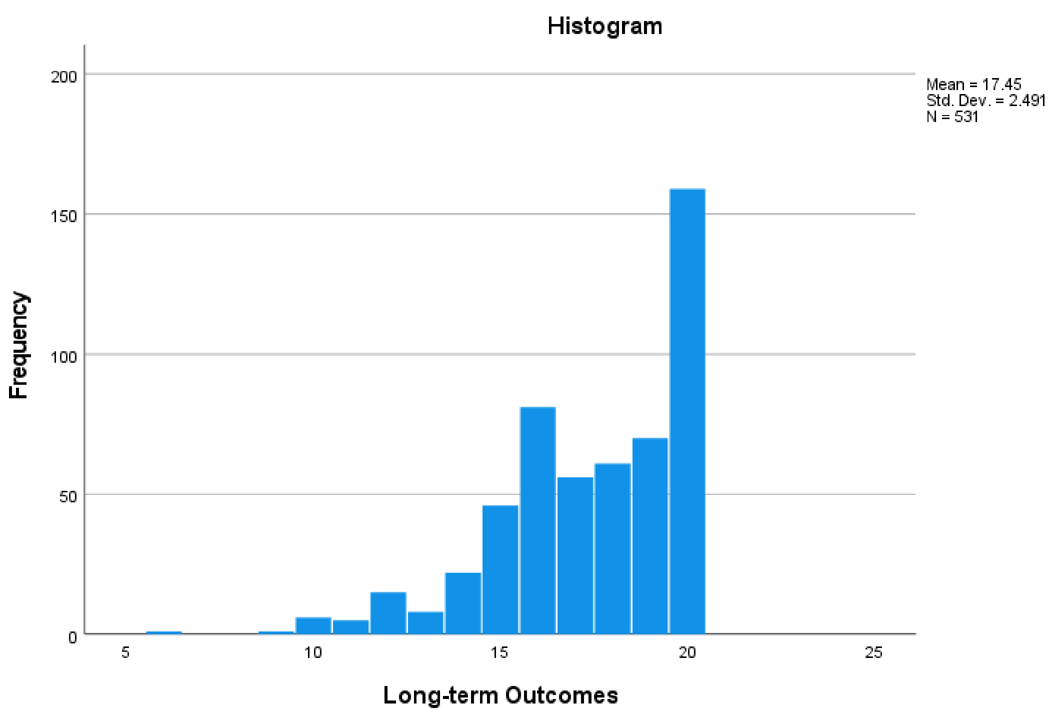


Figure K-6. Distribution of Long-term Outcomes: Teacher scale scores.

Center-Level Portfolio: Johns Hopskins University

The following table, proposed implementation plans by participating teachers, and when available other examples are intended to provide an overall narrative about how and in what ways program participation has influenced teachers on their use of QuarkNet content and materials in their classrooms (and in-after class events). We see the value of these qualitative reviews as expanding on the instructional practices measured quantitatively via Teacher Survey responses to specific sets of questions and self-reported by teachers providing narrative examples of implemented or planned instructional practices in teachers' classrooms and school environments. This evaluation approach is consistent with the use of *authentic assessment* as a means to evaluate performance, "teaching for understanding and application rather than for rote recall" (Darling-Hammond & Snyder, 2000, p. 523).

In keeping with Darling-Hammond, Hyler and Gardner (2017), we do not naively expect a single workshop (or event) to have a measurable impact on teachers' knowledge and subsequent classroom implementation. A characteristic of effective professional development is a program of sustained duration, providing "multiple opportunities for teachers to engage in learning around a single set of concepts or practices; that is rigorous and cumulative" (Darling-Hammond, et al., 2017, p. 15). As such, the table summarizes responses by teachers over the course of several program years and likely several QuarkNet programs and/or events.

These responses come from the Teacher Survey (either the full or update version) where each row represents the responses to open-ended questions from the same teacher over time. Also, each row starts with the original responses to the first time a teacher completes his/her full teacher. If a particular box in the table is blank, it likely means that that teacher did not participate in an event for that program year (or, the center may not have had a major event that year). The table provides the essence of these responses; a given response, as presented, may be a direct quote, a paraphrase, or lightly edited; the intent is to convey the overall idea or its essence from that particular teacher.

Because these are responses to open-ended questions, teachers are free (and encouraged) to provide information that he or she thinks most relevant. Each highlighted response is intentionally anonymously to respect the principles of collecting evaluation data (*Guiding Principles for Evaluators*, American Evaluation Association) and to help encourage teachers to respond frankly to these questions. If a reader is familiar with a given center, it may be possible to "reverse engineer" the identify of a particular teacher. We encourage readers to respect this anonymity. At various times, we may have identified a given teacher by name and/or school; when this happens the written approval of that teacher has been obtained. It is also important to note that the full breath of a response by a given teacher may not be fully articulated in this table. For example, responses related to how QuarkNet may have advanced the knowledge of a given teacher or bolstered a collegial network among participants are likely discussed elsewhere in subsequent evaluation reports.

The table is followed by examples of implementation plans, and at times teacher presentations and student presentations when available. The intent of providing these examples is to deepen the narrative as to what and how teachers have planned (and have used) QuarkNet content and materials in their classrooms and in-after class events (e.g., Physics Club). Examples from Annual Center annual reports may be highlighted as well.

Table _

Self-reported Use of Data Activities Portfolio Activities: Based on Reponses from the Full Survey and then Responses from the Update Survey in Subsequent Years **Johns Hopkins University**

Center	Program Year (Year of Full Survey)	Subsequent Program Year	Subsequent Program Year	Subsequent Program Year	Subsequent Program Year
Johns Hopkins University	2019	2020	2021	2022	2023
	Rolling with Rutherford. It's the most approachable, with a small amount of prep for students.	I am going to consider new physics principles, such as pulsars and microwave telescopes. Example: Rolling with Rutherford	I will use some of the new cosmology lessons with my Astronomy class. I teach them about the Big Bang, black body radiation and the HR diagram. I will use DAP activities as well as conservation tools. Examples: Signal and noise 1, signal and noise 2, and histograms. Rolling with Rutherford		Rolling with Rutherford is great - we gather data together as a class and analyze the results. QuarkNet has been a wonderful experience and a source of many high-quality lessons and activities. They have benefited my students greatly over the years.
	I have not had the opportunity to really share with other teachers and, unfortunately, in today's test happy society, it is difficult to fit these topics into class and to convince others to fit them into class.		I plan on using the spectral analysis activities we were working on this past week into my ninth-grade physics course. Examples: Mass of the pennies; What Heisenberg knew; CMS masterclass.	When teaching forces, I have a unit on the fundamental forces of nature where I present and the students explore the standard model and the reason why we have Fermilab and the LHC. The first lab is based on the Millikan experiment using histograms and searching for patterns.	Millikan experiment developing histograms. The projects based leaning with an inquiry approach drives my classroom instruction.
	Top Quark mass	I plan to teach a unit on particle physics using activities from the data portfolio and the cosmic ray detector in my classroom. Examples: Top quark mass, mean lifetime, shuffling the particle deck	I teach particle physics and astrophysics/ cosmology in my Physics course. I will use many of the activities we worked on this week including from the Data Portfolio and new activities developed at JHU. Examples: Top Quark Mass, Hidden Neutrino, Particle Transformations	I teach a unit on quantum physics including particle physics. This includes the standard model and activities from the data activities portfolio. Examples: Top quark mass, Hidden Neutrino, Quark workbench.	Top quark mass, Rolling with Rutherford, Histograms These activities allow students to explore particle physics concepts using physics they are learning in introductory courses.
	The I2U2 site examples, specifically modern physics puzzle	1. Use of the materials in classroom is great: The subparticle puzzle to start modern physics 2. Masterclass involvement and implementation 3. Standard model discussions, etc. Examples: 1. Quark puzzle/map involving learning color charge, bosons, etc. 2. Penny/coin activity	I have used a significant number of resources involving the QuarkNet workbench, some investigations and more. Overall, my last 10+ years at QuarkNet have really increased my knowledge of certain areas. Examples: The quark workbench, masterclass, J psi (occasionally)	I intend to use my QuarkNet experiences in my own modern physics unit with all physics classes as well as having my Science National Honor Society students to listen to some of the speakers who come to our high school. Examples: The Quark Puzzle, Z mass activities, missing momentum, etc.	Quark puzzle workbench and the mass of the top quark

Table _

Self-reported Use of Data Activities Portfolio Activities: Based on Reponses from the Full Survey and then Responses from the Update Survey in Subsequent Years **Johns Hopkins University**

Center	Program Year (Year of Full Survey)	Subsequent Program Year	Subsequent Program Year	Subsequent Program Year	Subsequent Program Year
Johns Hopkins University	2019	2020	2021	2022	2023
	I think Rolling for Rutherford is an easy way for them to understand the experiment through experience and inquiry. I would adapt it to more than just rolling a marble at dice. I would also have them roll a marble at a mystery shape underneath a piece of cardboard and predict what the shape was.	This year, we did more related to online learning because of the circumstances related the pandemic. Having content that can be used virtually, like the QuarkNet e-Labs, will be super useful. Examples: Rolling with Rutherford; The one where you use the detector information.	Next year I will be teaching astronomy in addition to physics, so the cosmology topics and activities that we just happen to focus on this year will be particularly helpful. The new ones I will incorporate are: Mapping the Poles and Particle Transformation.	I was doing Coding Camp 1. The obvious thing from this experience is that I would incorporate is the coding in Python. I will have some introductory coding activities, but ultimately I envision it as a tool that they will be using to help them with labs, homework or projects. I would love to do the muon decays or the leptonic mass coding activities if we get that deep into particle physics.	
	Rolling with Rutherford, calculating energy and momentum, quark puzzle activity	Conservation laws, the standard model. Examples: Rolling with Rutherford, conservation of energy and momentum, quark model	I plan to use the blackbody radiation activity and the Hubble's law activity as culminating activities for my introductory physics class. Examples: Cosmic microwaves, Hubble's law	Rolling with Rutherford, calculating energy and momentum, quark puzzle activity	
	Program Year (Year of Full Survey)		Subsequent Program Year	Subsequent Program Year	
	2020		2021	2022	
	Indicated use of DAP activities but no examples provided.		We have discussed the standard model and uncertainty while describing atomic theory. Examples: Mass of Pennies, Dice, Histograms, and Probability and Signal and Noise.		
	I love the dice rolling activities. I always use the dice rolling as an intro to the course because it gives them an intro to data but also problem solving. I plan to use all the lessons we looked at and the race discussions we talked about. Everything was extremely useful this year. I really enjoyed it. Examples: Dice rolling, Rutherford, Cosmic ray muons		I use the data activities portfolio activities pretty often. I also use the coding activities. Examples: Histograms, coin toss, quark workbench.		

Table _

Self-reported Use of Data Activities Portfolio Activities: Based on Reponses from the Full Survey and then Responses from the Update Survey in Subsequent Years **Johns Hopkins University**

Center	Program Year (Year of Full Survey)	Subsequent Program Year	Subsequent Program Year	
Johns Hopkins University	2020	2021	2022	
	Z Boson - It serves as a great conservation of momentum 2-D lab. I can also have students research particle physics before or after.		I have used coding activities to introduce experimental design, resistive forces, and worked with LHC data to show the conservation laws. I will attend World Wide Data Day with my classes and offer Masterclass to my students. I have muon detectors to extend students access to particle physics. Examples: 1. I used my implementation plan for the “Mass of Z boson” and my work at data and coding camp to have students complete the activity in Google Colab. 2. I use “quark workbench” to introduce science practices or the E & M unit.	
	Program Year (Year of Full Survey)	Subsequent Program Year		Subsequent Program Year
	2021	2022		2023
	I have used the top quark mass activity the most often, not only as an approachable way to teach detector physics but also as an example of 2D momentum conservation. I use the quark workbench fairly often with my AP class as an introduction to particle physics. With my new conceptual class, I plan to use the rolling with Rutherford activity to show the students how we develop a model for the atom. If I can get kids interested this year, I'd like to use several of the muon activities in there (except for signal and noise #1 because it's terrible, which I am allowed to say because I wrote parts of it and am not happy with it)	QuarkNet shows up pretty much anywhere you want to put it. The top quark activity is a nice fit for not only vectors but also conservation of energy and momentum. Muon detectors are a cool way to test a constant velocity model and get a very surprising value for its speed. The use of histograms can help a 9th grade biology or physical science class understand that pennies have discreet mass. Examples: Top Quark, Pennies, Rolling with Rutherford, Dice Histograms Signal and Noise (once I fix that awful one I wrote). We are all partly-finished sculptures. I hope that QuarkNet continues to shape me into what a good science teacher looks like. .		Top quark - use it for 2D momemtum conservation in AP physics; penny histogram - use it in intro biology courses for data representation; rolling with rutherford - use it with low level physical science courses for atomic theory and also showed it to the chem teachers; quark workbench - use it sporadically as a low pressure introduction to the rules of the standard model
				Sunspot graphing

Note: Each row presents responses from the same individual teacher from a given center. Empty table cells indicate that the teacher did not participate in QuarkNet in that subsequent program year(s). Or, less likely did not complete the Update Survey; or did not answer specific questions about the use of DAP activities in their classrooms. (Out of a total of 15 teachers.)

Table _

Self-reported Use of Data Activities Portfolio Activities: Based on Reponses from the Full Survey and then Responses from the Update Survey in Subsequent Years **Johns Hopkins University**

Center	Program Year (Year of Full Survey)
Johns Hopkins University	2022
	My favorite is the Quark Workbench and Mass of Top Quark activities.
	Rolling with Rutherford, histogram dice roll, and meson/boson activity
	Program Year (Year of Full Survey)
	2023
	I have not taught this topic yet which is why I am here! I feel so much more prepared and feel that there are a lot of resources. I am overwhelmed with how to successfully implement this BUT I feel very confident that I have met several professionals here that will help me if I reach out if needed. I really got a lot out of these short 3 days!
	I have not had a chance to do any activities yet since this is my first summer in QuarkNet. Many of the activities are easy ways to incorporate particle physics throughout the school year.
	First year. From the activities that I've seen, these seem to be engaging understandable for students.
	First year.
	This is my first time at QuarkNet and have not had a chance to put this information into practice.

Note: Each row presents responses from the same individual teacher from a given center. Empty table cells indicate that the teacher did not participate in QuarkNet in that subsequent program year(s). Or, less likely did not complete the Update Survey; or did not answer specific questions about the use of DAP activities in their classrooms. (Out of a total of 22 teachers.)

Table

Johns Hopkins University Summer Workshop July 23-28, 2023 Implementation Plans/Coding Projects

<table>
<tr><th>Plan #</th><th>Title</th><th>Brief Description</th><th>Implementation Plan</th></tr>
<tr>
<td>1</td>
<td>Spring Mass</td>
<td>Understand how masses behave on (vertical) springs as well as how to create and apply code to express this behavior.

Brief Summary: This is a modified Mass on a Spring JupyterLite notebook. The use of the Lite notebook is for educators whose students are not able to access normal Jupyter notebooks due to security/IT issues.

The Mass on a Spring has been modified for use in an AP Physics 1 and AP Physics C mechanics class. This will serve not as an introduction to the topic but instead is more of a culminating set of activities to incorporate coding with physics</td>
<td>Mass On A Spring with JupyterLite

<table>
<tr><th>Topic</th><th>Comments</th></tr>
<tr><td>Intro to Physics, Kinematics and Projectile Motion</td><td>Possible use of the Graphing notebooks and/or the Falcon9 notebook to introduce coding with physics</td></tr>
<tr><td>All Basic Forces, Pulleys, Ramps</td><td>Possible use of Pulley notebook adjusted with ramp activities</td></tr>
<tr><td>Energy</td><td></td></tr>
<tr><td>Momentum</td><td>Use of QuarkNet workbench activities (Top Quark)</td></tr>
<tr><td>Rotation and Angular</td><td></td></tr>
<tr><td>Simple Harmonic Motion</td><td>Use of Spring code notebook as presented here</td></tr>
</table>

Spring Notebook Background:
This collaboration Spring notebook is serving as a summary experience for students that takes place near the end of the Simple Harmonic Motion topic. It is taking place as a mini coding activity for students to demonstrate competence of spring motion and the relationships governing the position of a spring mass. Furthermore, the coding aspects of the activity serve to help the student navigate the difficult parts of spring motion analysis.

The students will have access to a separate document they will use to answer the questions and paste their code analysis and results. I leave it to the reader to decide whether to have this as an individual project or a pair collaboration project.

Students are expected to be able to determine the spring constant of a basic vertical spring with mass on it through the analysis of a graph based on student created data. In addition, students will be able to graph the position of a mass on a spring as a function of several different variables, and be able to justify how changing a variable affects the positions outcome over time.

Spring Notebook Application:

Students will be introduced to the Spring notebook with at least 45 minutes in the period. A class wide conversation will introduce this notebook and the goals behind it, along with the importance of being able to represent the physics ideas involved through a coding approach. From there, students will be introduced to the actual task. From there, students have a number of built-in checks for students to come to the instructor that will serve as a way to judge student progress.</td>
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</table>

Table 14 (con't.)

Johns Hopkins University Summer Workshop July 23-28, 2023 Implementation Plans/Coding Projects

Plan #	Title	Brief Description	Implementation Plan
2	Position Time Graphs	JuptyerLite Notebook Section 1 - Position Time Graphs: Modeling In this activity, you'll use the *position function* to model different types of motion. Section 2 - Position Time Graphs: Data Table In this activity, you'll use a csv file and pull in data to create your position-time graph. First you'll have a data set to use, then you can create your own Part 2A: Plot data that you collect Part 2B: Import data that you collect (*OPTIONAL*) In this example, we have measured the position of a ball rolling off a table (Video Link) The data is stored in a separate csv file.	Implementation Plan for Using Code in Physics Beginning of year • Use the Intro to Code notebook to get students familiar with the code and the process of using JupyterLite. • Use the Probability notebook to show students histograms and how coding can graph data. Kinematics Unit • Use the Position v time graph notebook to graph student data from inquiry-based activity of constant velocity cars. This is the one I modified to add to my graphing motion lesson. Force Unit • Adapt/Create a notebook to graph F = ma. Maybe have students create one, using the Position v time as a model. Put in data for F and A then scatterplot with line of best fit to get value for m. Scaffold according to Energy Unit • Adapt the Mass of Spring notebook. I use a hands-on lab and a phet simulation. Instead of simulation, I want to give the option of using the code. Or • Adapt the Pendulum notebook. Momentum Unit • Use the Mass of Z QuarkNet lesson for conservation of momentum. Going forward after using/modifying notebooks, offer to students to use their coding skills to graph/analyze their data from other labs for the rest of the units. If time permits and we get to E &M, discuss particle accelerators and how Electric and magnetic fields are used and then use Muon Mass notebook or Plotting CMS data for more advanced data analysis.

Table

Johns Hopkins University Summer Workshop July 23-28, 2023 Implementation Plans/Coding Projects

<table>
<tr><th>Plan #</th><th>Title</th><th>Brief Description</th><th>Implementation Plan</th></tr>
<tr><td>3</td><td>Periodic Trends (using the periodic tool to predict major trends)</td><td>Sequence:
Coding basics:
(Introduction to Coding Notebook)
Half-life Coin Flip Lab:
(Probability Notebook)
Periodic Table:
(Elements and the Periodic Table Notebook)</td><td>

Lesson Plan: Periodic Trends

Rationale:
Students can use the periodic table as a tool to predict major trends, allowing for students to predict elemental placement based on elemental properties.

Objectives:
When you have completed this activity, students can:
1. Construct a model using trend data.
2. Use a model to describe the trends in several physical properties of the elements.
3. Use code to help represent trend data in graphs.
4. Relate these trends to the electron configuration of the elements, and its position on the periodic table.

Sequence:

Unit	Timeframe	Topic	Notebook
Introduction	**30 mins in the 1st week**	**Coding basics**	**Introduction to Coding**
Nuclear	**1 class period**	**Half life: Coin flip lab**	**Probability**
Nuclear	**1 class period**	**Periodic Trends**	**Elements and the periodic table**

Engagement:
1. Quick review of groups vs periods, electron configuration, and valence electron understanding.
2. Show video demoing reaction rates based on location on periodic table. https://youtu.be/K7ZdajBz4ak.

Exploration:
1. Periodic Trends Straw Lab https://docs.google.com/document/d/1K5MgCFzG0m3ROouFdO7V8n3ZRaHg6hP/edit?usp=sharing&ouid=103024363023706119199&rtpof=true&sd=true
2. Build straw model of atomic radius, ionization energy, and electronegativity.
3. Analyze model based on straw length with electron configuration.

Explanation:
1. Have the students go into the Elements and the periodic table notebook and work through the code.
2. Students will be focusing on the relationship of 3 trends (atomic radius, electronegativity, and ionization energy).
3. They will code so that they can graph the data of the elements that they had made the models for (Hydrogen to Argon). They will then also import those graphs into the lab report for support.

Elaborate:
1. Have the students watch this video to take another look at periods and rose of the periodic table. **https://youtu.be/Regufd-yibQ**
2. Have the students code to see all of the elements and have them explain what they are observing in the transitional metal section.

Evaluation:
1. Students should be comfortable to complete this worksheet only using position on the periodic table and explain why they are placing them in that order and relationship. https://drive.google.com/drive/folders/0B0aTluJykUXBfmVJWUtFd2JqdDZPNERVV01sZHVTeFg4TGJJc1N1WXpmeWc4eDZNMnA2aEk?resourcekey=0-EydH0bkazJas-qrqOFP6vA

</td></tr>
</table>

Table

Johns Hopkins University Summer Workshop July 23-28, 2023 Implementation Plans/Coding Projects

Plan #	Title	Brief Description	Implementation Plan
4	Constant Velocity and Coding (Developed by two teachers)	Graphing motion of an Object Moving at a Constant Velocity Unit This unit is designed for classes that are 80 minutes in length.	**Day 1:** • Objectives - o Understand and demonstrate knowledge of using a graph to determine an object's velocity o Calculate slope to find velocity of a non-accelerating object • Activities - o Lecture on constant velocity. o Have students practice finding velocity for an object moving with constant velocity. o Discuss graphing position vs. time o Phet Moving Man Activity • Assessments – o The Phet Moving Man Activity will be collected and graded as an assessment for the class. **Day 2:** • Objectives - o Understand and demonstrate knowledge of using a graph to determine an object's velocity o Collect data that will be useful for determining the velocity of an object • Activities - o Discuss Moving Man Activity from previous day o Introduce Physics 500 Lab o Give students time to collect data for toy car, marble, person walking backwards • Students will record data in a data table o Ask students how they think we can determine the average velocity of our moving objects from today's measurements. Guide students to previous day's discussion on graphing position vs. time. o Collect student data for tomorrow's activity. • Assessments – o Use end of class discussion as a formative assessment of student understanding. **Day 3:** • Objectives - o Understand the basics of coding o Graph data using coding to determine the velocity of a moving object • Activities - o Intro to Coding Activity ▪ Students use this as an introduction to coding o Physics 500 Graphing Activity ▪ Students work in pairs as driver and navigator to input data from previous day's data table and create a line of best fit for each of the three objects in the lab o Discuss velocities that students find. Ask them if they seem reasonable. • Assessments – o As students find their velocities, check student results as a formative assessment of their progress. **Day 4:** • Objectives - o Students will demonstrate their understanding of finding velocity from a position vs. time graph • Activities - o Conclude Physics 500 Activity ▪ Give students time to finish lab reports ▪ Discuss student results from lab reports. ▪ Ask students which objects traveled the fastest in the lab ▪ Ask students how they know which objects travel the fastest o Graphing/velocity assessment • Assessments – o The graphing/velocity assessment will be a summative assessment of what they learned from the lab activity.

Table

Johns Hopkins University Summer Workshop July 23-28, 2023 Implementation Plans/Coding Projects

Plan #	Title	Brief Description	Implementation Plan
5	Balancing Chemical Reactions	Implement this activity for sophomore Chemistry students who have already been introduced to balancing chemical reactions in class. Student have already been introduced to the underlying concepts behind why we balance chemical reactions (law of conservation of matter, counting particles using “moles.” Notebook after students had with a Phet simulation.	Balancing Chemical Equations… with Python! **Overview** This notebook is designed for students with little to no coding experience. The primary focus of the activity is to introduce best practices and conventions with coding in Python (focus: writing descriptive comments). There is no intended age group that this notebook was written for. The only prerequisite is that students should have some exposure to Chemistry before using this notebook. **Rationale** I plan to implement this activity for sophomore Chemistry students who have already been introduced to balancing chemical reactions in class. Students have already been introduced to the underlying concepts behind why we balance chemical reactions (law of conservation of matter, counting particles using “moles”). **Objectives** 1. By the end of this lesson, students will be able to balance chemical equations by developing their own strategy to solve a balancing problem. 2. By the end of this lesson, students will recognize and implement best practices and conventions of coding in Python, with a primary focus on writing descriptive comments. 3. By the end of this lesson, students will be able to analyze, edit and use Python code to solve a problem. **Sequence** The notebook will be used after students have already worked with a Phet simulation (Balancing Chemical Equations), during which they will recognize patterns while balancing reactions. Students will determine their own strategies for balancing chemical reactions, whether it is keeping track of the count of each element/ion in their head or writing the counts down, and students will be asked to complete a problem set for balancing chemical reactions. **Lesson Plan** - Balancing Chemical Equations (80 min period) 1. 40 mins - Phet Simulation (Balancing Chemical Equations) 1. Students may work in groups or individually. 2. Students will complete a packet that guides them through the activity 2. 20 mins - Problem Set 1. Students will work individually on the problem set 2. If students get stuck on a problem, they are encouraged to mark that problem and return to it later 3. **20 mins - Python Notebook** (Balancing Chemical Equations… with Python!) 1. Students may work in groups or individually when they have completed both the Phet simulation and the problem set 2. Students are encouraged to use the Python notebook as a way to check their work from the problem set

Table

Johns Hopkins University Summer Workshop July 23-28, 2023 Implementation Plans/Coding Projects

Plan #	Title
6	Kinematics Unit (adding coding notebooks to several lessons throughout the year)

Implementation Plan

Implementation Plan Overview

I plan on adding coding notebooks to several lessons throughout the year instead of having a specific coding unit.

Rationale -

1. Coding notebooks are a cross platform tool that can be used to teach students about data analysis and coding
2. Coding notebooks have applications in a wide range of fields, not just physics
3. Coding notebooks are accessible as long as there is internet access. Absent or remote learners have full access to the content.
4. Allows students to work together to solve problems using code.
5. Allows students to interact with real-world data sets.
6.

Unit	Timeframe	Coding Notebook Implementation
Beginning of School Year (before Kinematics)	First or second day of school	Intro notebook activity - get students acquainted with coding notebooks
Kinematics	September - October	After students have conducted lab investigations involving the creation and analysis of graphs from objects moving with constant velocity, constant acceleration, and free fall, a coding notebook lab will be used as a review and extension activity.

Specific Implementation - Kinematics Unit

Lesson Objective: Students will be able to use evidence to justify a claim about a rocket's motion.

NSTA Position Statement:
PreK–12 teachers of science, school and district leaders, and other key stakeholders should embrace the following key points:

- PreK–12 teachers of science should recognize the compelling and inherent opportunities of aerospace to strengthen and support the teaching of science and mathematics education, and where possible, integrate aerospace into the curriculum.

Engagement: Think/Pair/Share

- If a ball is thrown straight upwards from Earth's surface, what would the P vs T and V vs. T graphs look like for its motion? Explain your reasoning.
- If a drone takes off from the surface of Earth and *accelerates* upwards, what would the P vs. T and V vs. T graphs look like for its motion? Explain your reasoning.

Exploration: Coding Notebook Activity

- Students work through these notebooks (position graphs, velocity graphs, and Falcon 9 Rocket stuff), recording their responses, evidence, and reasoning on this Google Doc.
- This notebook combines parts of the following notebooks:
  - Matching Position Graphs
  - Matching Velocity Graphs
  - Falcon 9 Rocket Data

Explanation/Evaluation:

- Students individually make claims about why the Velocity vs. Time and Acceleration vs. Time graphs for the Falcon 9 rocket look the way they do. Specifically, what is happening around 160 seconds?
- Each student shares their claim, evidence, and reasoning with their small group. Each group then discusses their collective claims and produces a brief presentation (one slide of a Jamboard used by the whole class).
- Several groups share their findings with the class.

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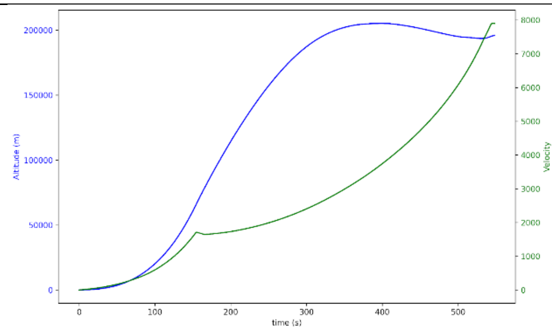
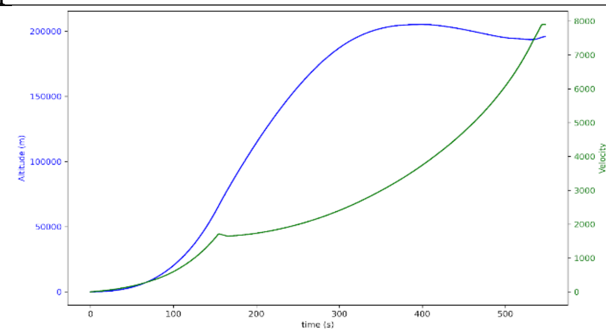
6 (con't.)	Kinematics Unit (adding coding notebooks to several lessons throughout the year)	 

Center-Level Portfolio: Catholic University of America

The following table, proposed implementation plans by participating teachers, and when available other examples are intended to provide an overall narrative about how and in what ways program participation has influenced teachers on their use of QuarkNet content and materials in their classrooms (and in-after class events). We see the value of these qualitative reviews as expanding on the instructional practices measured quantitatively via Teacher Survey responses. The table presents answers to select open-ended questions providing narrative examples of implemented or planned instructional practices by teachers in their classrooms and school environments. This evaluation approach is consistent with the use of *authentic assessment* as a means to evaluate performance, "teaching for understanding and application rather than for rote recall" (Darling-Hammond & Snyder, 2000, p. 523).

In keeping with Darling-Hammond, Hyler and Gardner (2017), we do not naively expect a single workshop (or event) to have a measurable impact on teachers' knowledge and subsequent classroom implementation. A characteristic of effective professional development is a program of sustained duration, providing "multiple opportunities for teachers to engage in learning around a single set of concepts or practices; that is rigorous and cumulative" (Darling-Hammond, et al., 2017, p. 15). As such, the table summarizes responses by teachers over the course of several program years and likely several QuarkNet programs and/or events.

These responses come from the Teacher Survey (either the full or update version) where each row represents the responses to open-ended questions from the same teacher over time. Also, each row starts with the original responses to the first time a teacher completes his/her full teacher. If a particular box in the table is blank, it likely means that that teacher did not participate in an event for that program year or skipped the question (or, the center may not have had a major event that year). The table provides the essence of these responses; a given response, as presented, may be a direct quote, a paraphrase, or lightly edited; the intent is to convey the overall idea or its essence from that particular teacher.

Because these are responses to open-ended questions, teachers are free (and encouraged) to provide information that he or she thinks most relevant. Each highlighted response is intentionally anonymously to respect the principles of collecting evaluation data (*Guiding Principles for Evaluators*, American Evaluation Association) and to help encourage teachers to respond frankly to these questions. If a reader is familiar with a given center, it may be possible to "reverse engineer" the identify of a particular teacher. We encourage readers to respect this anonymity. At various times, we may have identified a given teacher by name and/or school; when this happens the written approval of that teacher has been obtained. It is also important to note that the full breath of a response by a given teacher may not be fully articulated in this table. For example, responses related to how QuarkNet may have advanced the knowledge of a given teacher or bolstered a collegial network among participants are likely discussed elsewhere in subsequent evaluation reports.

The table is followed by examples of implementation plans, and at times teacher presentations and student presentations when available. The intent of providing these examples is to deepen the narrative as to what and how teachers have planned (and have used) QuarkNet content and materials in their classrooms and in-after class events (e.g., Physics Club). Examples from Annual Center annual reports may be highlighted as well.

Table C-3
Self-reported Use of Data Activities Portfolio Activities: Based on Reponses from the Full Survey and then Responses from the Update Survey in Subsequent Years **Catholic University**

Center	Program Year (Year of Full Survey)	Subsequent Program Year	Subsequent Program Year	Subsequent Program Year	Subsequent Program Year
Catholic University	2019	2020	2021	2022	2023
	Data collection and analysis.				
	I plan to use 6 activities from the Data file (*not specified*). I learned so much and was welcome to wonder out loud. A safe space for learning and growing.				
	We are going to be using the class tool to create a camp. Last year was too overwhelming for me to do a project on my own, especially since I do not teach physics, but this year we have the building tools to create a physics camp for Title 1 students.				
	While this was my first year at QuarkNet, I plan to implement much of what I have learned! I also hope to take an on-line Particle Physics I class.				
	Data Analysis: AP Statistics Univariate data analysis, numerical summaries, boxplots, histograms, hypothesis testing Trigonometry: 4-vectors, right-triangle trigonometry (close & form the right triangle), component-wise addition Intro. to Computer Science: This has the potential of using Python to analyze the data contained in .csv files				
	My first year at QuarkNet, I plan to implement much of what I have learned. (My focus is as a STEM teacher - after-school and non-school hours)				
	Use of tracker. Z mass				
	Dice Histograms, Shuffling the Particle Deck, and Rolling with Rutherford				

Table C-3
Self-reported Use of Data Activities Portfolio Activities: Based on Reponses from the Full Survey and then Responses from the Update Survey in Subsequent Years **Catholic University**

Center	Program Year (Year of Full Survey)	Subsequent Program Year	Subsequent Program Year	Subsequent Program Year	Subsequent Program Year
Catholic University	2019	2020	2021	2022	2023
	I have used the Mass of Pennies lab in chemistry previously for average mass determination. I have worked with something similar to the Mapping Magnetic Fields lab, but with electric fields and carbon paper.		Virtual Coding: From this activity, I want to pull in the coding-specific lesson design to my physics classes. I'd like to target on-level physics students with coding-based activities. Excited to use many of the histogram-related activities. I am also EXTREMELY excited to incorporate the STEP UP activities in my classroom and evangelize them to my department	Coding will come up in a big way in my AP Physics C classes this year. I intend to implement them as a standard way to do data analysis throughout the school yar. I hope to incorporate QuarkNet particle physics activities near the end of the year in my Honors Physics class. I also hope to incorporate some cross-curricular with our art department or marker space to bring particle physics forward in our community. I hope to use the Energy, Momentum and Mass activity (hopefully the quantitative version) with my AP students in this year. As time allows, I intend to use one or more of it Making It Round the Bend both in AP Physics but also honors physics at the end of the year when we reach magnetism.	Most recently the STEP UP Women in Physics activities were adapted for use in my physics classes. I have also used the Coding in Jupyter Notebooks to frame lesson design around coding implementation in Colab notebooks.
	Program Year (Year of Full Survey)	Subsequent Program Year		Subsequent Program Year 2023	
	2021	2022			
	Classes have not yet begun, e-Labs and the data provided will be of great use; understanding detector construction will allow a more thorough explanation of function of iPad cosmic collection apps.	In discussion of em radiations during space unit (grade 6) and energy unit (grade 7). These factors play a role in the units previously discussed.			
	Mass of a penny; shuffling the particle deck; rolling with Rutherford.				
	None at present as this is my first year.				
	Data is continually updated and data from new experiments is uploaded regularly			Data bases for use in creating analytical graphs and histograms; select e-labs adapted to grade; Quark Net presentations on cosmic rays and cosmic ray detectors	

Table C-3

Self-reported Use of Data Activities Portfolio Activities: Based on Reponses from the Full Survey and then Responses from the Update Survey in Subsequent Years **Catholic University**

Center	Program Year (Year of Full Survey) Subsequent Program Year	Subsequent Program Year	Subsequent Program Year	Subsequent Program Year
Catholic University	2022	2023		
	I will. The program to present posters it will help the students with displaying the scientific method and presenting data.			
	Program Year (Year of Full Survey)			
	2023			
	Use of data, analysis and graphing. Too advanced (DAP) but we can easily convert it to other topics we teach.			
	I intend to bring this learning and experience to my High School students so they can see the relevance of modern physics and find some real world connections with the content they learn in classroom.			
	I haven't had an opportunity to do some of the activities, yet. However, I do plan to attempt to do these activities in my AP Stats class this year. QuarkNet has contributed to my understanding of analyzing particle physics data; however, it is just that I have an extremely tight and regimented curriculum that does not allow for that much deviation.			

Note: Each row presents responses from the same individual teacher from a given center. Empty table cells indicate that the teacher did not participate in QuarkNet in that subsequent program year(s). Or, less likely did not complete the Update Survey; or did not answer specific questions about the use of DAP activities in their classrooms. (Out of a total of 14 teachers.)

CUA Lesson Implementation July 2023

8th grade- Physical science- Teacher #1

Goals: Enduring understanding • Our understanding of the atom has changed over time reflecting the nature of science. • Atoms are composed of subatomic particles, each with their own location and characteristics. • The periodic table is a tool used to organize information about elements.	**Standard/ Unit:** Atoms (unit 3) and Periodic Table
How to assess learning? - Quiz/test using canvas - Group work & presentation - Construct and use models and simulations to represent the structure of atoms; evaluate the limitations of models used (PS.2 a)	**Guiding questions:** How has the atomic model changed over time and what role has technology played in it? Why do we need models of atoms and what are their limitations? What role does organization play in the design of the periodic table?
Learning Experiences:	1. **Partner discussion:** • What is matter made out of? • What is the smallest particle you know? • How do you think scientists have arrived at this knowledge? 2. **Presentation:** I will use and include pictures of our field trip- Videos: • The Standard Model of Particle Physics • Just how small is the atom? 3. **Group research:** Voyage through time…***Frayer Model Poster*** A. Greek philosophers B. J. Dalton C. J. J. Thompson D. N. Bohr (Chadwick) E. ______ **Differentiation:** quantum particles cards- research and exploration- JLAB, Fermi lab, etc Blog Mayan Muons and unmapped rooms 3. Construct a model or simulation to represent the structure of atoms- limitations • Tinkercad • Physical model • pHet lab

Video for Matter: Nature of Matter **unit 2**- also incorporates measurement, metric units and prefixes in the instrumentation and practices.
Unit 6: Electricity and Magnetism- practical applications- differences between electronics and electrical circuits.

- Science at home from Jlab- Electromagnets

Teacher #2

Physics Coding Module #4 - Particle Physics Datasets

Colab Notebook Link

Rationale

This module is intended to follow a basic introduction to using Python and Colaboratory notebooks to analyze large data sets and transfer those skills to work with large particle physics data sets.

Target Audience

This module is primarily for students in a physics course of any level. Differentiation within the module itself is accomplished through clarity in levels of difficulty.

Learning Goals

- Import CMS (Compact Muon Solenoid) data
- Create overlaid histograms to analyze data

Extension Goals

- Presentation and argumentation using data.

CUA Lesson Implementation July 2023

Teacher #3

Standard Learning Goals	Assessments	lesson/unit ideas
• Understand energy on Macroscopic as well as Atomic scale • Analyze momentum conservation • Data analysis by collecting data and graphing it • Make real world connections with particle physics	• Students will do some sort of data analysis from CERN data (I have heard it's available) • Perform muon detector lab (Cosmic watch lab, demonstrated by Ken) • Have students explore the activities from the Quarknet website. (showed by Ken)	These activities will be incorporated in units of energy, energy and momentum conservation, graphing and data analysis!! Show videos on Standard Model in particle physics Share the quarknet net experience, Jefferson lab presentation
If there's time … I would like to talk about the mayan pyramids and how the secret chambers are detected via cosmic ray detectors to address CROSS-DISCIPLINARY SKILLS		Show videos, share presentations

Teacher #4

12th grade - Research Practicum - Physical Sciences

Student learning Goals:

- Develop an understanding of the Standard Model in general, Muons in the context of cosmic rays in particular (using video(s)) and of muon tomography (using pyramid example → annotated bibliography)
- Be able to present data graphically (scatter plots, histograms) and interpret graph
- Be able to describe and calculate the mean of a set of data
- Be able to describe and calculate the measures of the spread of data (variance, standard deviation)
- Be able to conduct and interpret hypothesis tests for two population means.

Assessment:

- Application to data collected during a Physics lab in the previous year
- Ongoing

CUA Lesson Implementation July 2023

Teacher #5

Level	Unit	Goal	QuarkNet-related Activity
sc6	Astronomy Meteorology Geologic Time	1) identify evidence the existence of extraterrestrial sources of energy 1) Explain why the thermosphere affects the ability of life to live on earth's surface !) Use a model of radioactive decay to date samples	• Use om Apple app- muon detector to demonstrate existence of cosmic rays • "cosmic compass" would be more accurate: experiment to determine angle of particle source • Use of cloud chamber to illustrate paths of charge particles • Use of quarknet resource:**https://www.i2u2.org/elab/cosmic/content/CosmicExtremes.pdf** • **Adaptation of Quarknet lab https://www.i2u2.org/elab/cosmic/home/project.jsp** •
sc7	Energy Atoms Analysis of Data	1) Describe the effects of magnetic fields on matter 2) identify the properties of an atom's particles 3) using histograms to analyze data	• Introduction to particle detectors https://particleadventure.org/modern_detect.html • Demo- glass/plastic ornament with mystery objects inside-in zip lock baggie smashed against surface • Use of magnetic fields to control motion ○ Demo- static charges' effect on flowing water ○ Video: cathode-ray tubes (as in old TV) • Quark Net database for histograms:
sc8	Genetics	1)Explain the effects of radiation on the structure of DNA	•

CUA Lesson Implementation July 2023

Teacher #6

Introduction to Quantum Concepts

Unit	**After Unit Concept**	**Activity/Lab**
Kinematics	Nanotechnology	Nano Technologies https://www.youtube.com/watch?v=LUE7jCGQr1E
2D Kinematics	Cosmic Rays	Cosmic Watch Cosmic Ray Detector
Forces	Quantum: Superposition	Polarizers Intro to Waves Double Slit Experiment (with lasers and fog machine) https://www.youtube.com/watch?v=v_uBaBuarEM
Energy	Quantum: Historical figures and Energy Quantization	Photoelectric Effect Lab If You Don't Understand Quantum Physics, Try This! https://www.youtube.com/watch?v=Usu9xZfabPM&t=685s 9:24 "Where does the name 'quantum' come from?" Max Planck Einstein - Photoelectric Effect https://www.arborsci.com/blogs/cool/electroscope-photoelectric-effect
Momentum	Quantum:	The Standard Model https://www.youtube.com/watch?v=Unl1jXFnzgo
Circular Motion	Particle Accelerator Labs	Fermi Lab https://www.youtube.com/@fermilab CERN https://home.cern/ Thomas Jefferson National Accelerator Facility https://www.jlab.org/
Gravitation	Quantum: Uncertainty Principle	Heisenberg's Uncertainty Principle https://www.youtube.com/watch?v=qwt6wUUD2QI
Rotational Motion	Quantum Computing	Quantum Computing https://www.youtube.com/watch?v=lY3jhUhVxK0 https://www.youtube.com/watch?v=X8MZWCGgIb8 Interferometer?
Simple Harmonic Motion	Quantum Mechanics	MIT https://www.youtube.com/watch?v=lZ3bPUKo5zc&list=PLUl4u3cNGP61-9PEhRognw5vryrSEVLPr Professor Allen Adams

CUA Lesson Implementation July 2023

Modern Physics Course: Physics

A pacing guide is not included for this unit; teachers are expected to teach some of this material but not all.

STAGE 1 – DESIRED RESULTS	
Modern Physics Big Ideas (*concepts/themes*): complexity	
HRL Framework Components	
Enduring Understandings: *Students will understand that…* **(Intellect)**	**Essential Questions:** Students will answer the questions…
• The study of modern and non-Newtonian physics can be applied in varied technological applications. • Newtonian physics doesn't adequately describe phenomena at the extremes of small size or high speed. As modern physics has explored areas of extreme speeds and subatomic particles, new paradigms have been created.	• What are examples where Newtonian physics breaks down? • How do we know that wave particle duality must exist? • How do light waves differ from mechanical waves?
Students will know…	
From VDOE Framework	

The teacher should select areas based on student interest and their own understanding of physics concepts. Possible topics include:

- *wave/particle duality;*
- *quantum mechanics and uncertainty;*
- *relativity;*
- *nuclear physics;*
- *solid state physics;*
- *nanotechnology;*
- *superconductivity;*
- *the standard model; and*
- *dark matter and dark energy*

Modern Physics Course: Physics

Learning Targets: *I can…*	**Assessment Evidence (Stage 2)**	**Resources for the Learning Plan (Stage 3)**
evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described by either a wave model or a particle model, and that for some situations one model is more useful than another (PH.9 a, b) communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy (PH.9 a, b)	Formative Assessments: Summative Assessments:	Resources:
provide examples of technologies used to explore topics in modern physics (PH.9, b, c, d, e, f, g, h, i) compare classical physics and modern physics at the extremes of speed and size (PH.9 a, b, c, d, e, f, g, h, i) explore the connections between and the benefits of the pursuit of pure science and subsequent applications (PH.9 a, b, c, d, e, f, g, h, i)	Formative Assessments: Summative Assessments:	Resources:

Center-Level Portfolio: University of Oklahoma/Oklahoma State

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Self-reported Use of Data Activities Portfolio Activities: Based on Reponses from the Full Survey and then Responses from the Update Survey in Subsequent Years **Oklahoma State University/University of Oklahoma**

Center	Program Year (Year of Full Survey)	Subsequent Program Year	Subsequent Program Year	Subsequent Program Year
Oklahoma State University/ University of Oklahoma	2019	2020	2021	2022
	I have not used the Data Activities yet, but would like to learn more about how to integrate them into my classroom.			
				I will definitely bring students to the Masterclass. I like the Polar Bear activity and the Rolling with Rutherford activity.
	None	I use many QuarkNet activities already in my classroom. I will certainly use the Step Up activities this coming year. Examples: Card Game, Rolling with Rutherford, Calculating z particles		
	Dice, Histograms, and Probability Mass of US Pennies			
	I have taken students to a master class at Oklahoma state university	I plan on using Step Up plans as a new item to work with as we move forward. I have used other lessons for years from the QuarkNet program.		
	Quark workbench, Rolling with Rutherford, Isotopes of Pentium, various games with dice	Use cosmic ray detector as example of real time data gathering and large data sets. Used top quark mass to introduce particle accelerator and reinforce vectors as an analysis tool. Use quark work. Examples: Quark workbench Penny mass Top Quark mass		
	Quark workbench, particle deck, calculating top quark mass, particle adventure website, z-path, phyching out the system			
	I have used these for chemistry not physics class. I think that QuarkNet needs to expand their thinking about just wanting physics teachers. It has helped me go deeper into my lessons with chemistry students when talking about the atom. Before, it was so superficial. I have a better understanding and therefore I think my kids will too. This can be the first step toward a better physics class that students take the following year. I have used the marbles and dice, mass of pennies, and particle deck.			

Table _

Self-reported Use of Data Activities Portfolio Activities: Based on Reponses from the Full Survey and then Responses from the Update Survey in Subsequent Years **Oklahoma State University/University of Oklahoma**

Center	Program Year (Year of Full Survey)	Subsequent Program Year	Subsequent Program Year	Subsequent Program Year	Subsequent Program Year
Oklahoma State University/ University of Oklahoma	2019	2020	2021	2022	2023
	I have really only pulled information to help/work with individual students.				Mass of pennies, histograms, uncertainty, roll with it. Good way to introduce how "real" science works from experiment design to data collection to what you expected vs. what you got. Some of the material is too in depth for some levels for the students (i.e.. Physical Science students not quite ready for some of the material). This is a wonderful opportunity for resources for me and resources to pass along to my students.
	Quark Workbench Determining the mass of the top quark Determining the mass of the Z boson Deck of Particle Cards Rolling with Rutherford			I use the quark workbench, particle physics deck, Rolling with Rutherford experiment, particle adventure website, and determining the mass of the Z boson, and top quark activities. I have gone to Masterclasses in the spring and I plan to go again. I also have done World Wide Data Day with students in the fall, and I was able to go to Fermilab for Data Camp. From this year I would like to begin introducing some coding to my students, but as of now my district has refused to allow Google Colab to be used on the district computers. So, I need to iron out issues with the district before I know what I will be able to do in the future in the classroom. Examples: I use the quark workbench, particle physics deck, Rutherford experiment, particle adventure website, and determining the mass of the Z boson and top quark activities. I have gone to masterclasses in the spring, and I plan to go again. I also have done the day of data with students in the fall, and I was able to go to Fermilab for the data camp. From this year I would like to begin introducing some coding to my students, but as of now my district has refused to allow Google Colab to be used on the district computers. So, I need to iron out issues with the district before I know what I will be able to do in the future in the classroom.	Particle Deck Quark Puzzle Mass of Z Boson Mass of top quark Rutherford Experiment Dice Rolling. Connecting science process and real data to concepts we are already covering in the classroom. I have shared the curriculum with multiple teachers. Coding: cannot use google. This year another teacher showed me replit so that I can use it to run the curriculum.

OU Implementation 2023

Please enter the implementation plans for your group to the appropriate slide. If you need more space, add a slide!

Group 1

For Biology and ACT using histograms to graph and synthesize data.

AP Physics - use the Case of the Missing Neutrino event data as an addendum to a two-dimensional collisions lab.

AP Research - utilizing the History of Science Collection at OU to investigate the history of research in science.

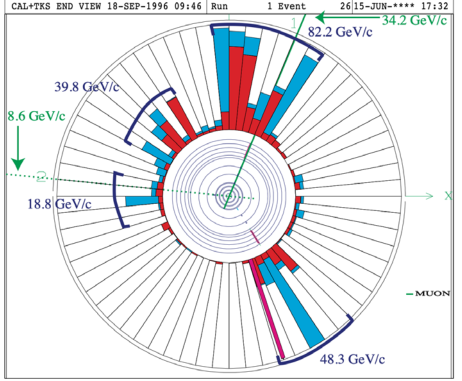
Science club - utilization of masterclass

Physical Science-exposure to scientific thinking and graphing, Dice, histograms

Group 2

- Physics
  - Muon Particle Detector will come back into use.
  - Probability of radioactivity decay.
- Chemistry
  - Examination of the Standard Model looking at the exotic particles.
  - Modeling quantum numbers
- All labs
  - Include error on predictions and measurements using bar graphs and bell curves
  - Virtual labs: Cosmic Ray Studies, Phydemo, Falstad, PhET
  - Use eV/c^2 as a dimensional analysis exercise

Group 3



What are you looking to do?

Data collection and analysis through Histograms (FWHM for uncertainty)

Dice Probability tied into Coin Probability. Exploring misconceptions of Probability between single and compound events

Using Fermilab data to measure momenta via vector addition in 2D to discover evidence of particles(momentum)

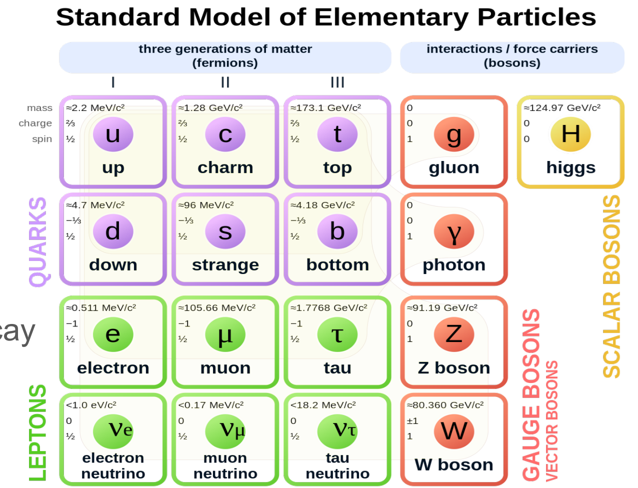
Introduction to Standard Model/Particle Physics (Shuffle the Deck Activity)

What class?

Physical Science, Chemistry, Physics

What unit?

Lab/Data Skills, Conservation of Momentum/Energy Units, Waves and Radioactive Decay



Group 4

Physics/ Chemistry/ Physical Science

- The “Dice, Histograms, and Probability” activity supports student data collection, graphing, and analysis skills. This can also be applied for radioactive decay.
- After introducing subatomic particles and quarks, the “Shuffling the Particle Deck” data activity is a great way to introduce the standard model.
- As a possible extension activity, students could be placed into groups and have them research different neutrino experiments such as ATLAS, NOvA, DUNE, MINERva, LHC, etc. being conducted around the world.
- For high school physics students, the “Case of the Missing Neutrino” activity is a great application of conservation laws to a more interesting situation than two carts on a track.

Group 5

Teacher #1 - I plan on using the muon detector to collect data and show to my astronomy students. For my Physical Science students, I will use the data collected from the detector for basic graphing of information. It was also very helpful to get the latest information on Neutrino experiments as well as updates on Dark Matter research. I learned a lot about Dark Photons this meeting.

Teacher #2 - I am going to start making use of the stuff in the quarknet data activities portfolio. The dice and histograms and probability activity will be really useful for helping physics students understand how averages work out over time.

Teacher #3 - The physics students will use a dice roller to show the distribution of data. I also liked the use Replit in place of some of the software that is available to me at my school. This was shown to me by Jessica.