QuarkNet

Evaluation of the QuarkNet Program: Evaluation Report 2020-2021

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Evaluation of the QuarkNet Program:
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Executive Summary

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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). There are approximately 50 plus such centers across the United States.

Program Goals

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

Overview of Report

This report is a prototype of the final evaluation report of this program to be submitted at the end of this award period; as such, it presents a draft of the final evaluation report (although as an interim report it is final). In serving as a prototype, the present report and its review demonstrate the shift in evaluation efforts from formative (and summative) assessment to an outcomes-based evaluation. One advantage of this early look is that it gives QuarkNet program staff members opportunities to better understand this shift and to share in this process. And, it has offered opportunities for staff to identify principal needs and concerns that the evaluation may be able to be responsive to; and to give the evaluator time to adjust to these needs and suggestions proposed by staff to help aid in the usefulness of evaluation findings and recommendations.

The evaluation focused on the following: (1) Develop (and use) a Program Theory Model (PTM); (2) Assess program outcomes at the national and center levels through teacher-level outcomes; and, (3) Assess the sustainability of program centers based on center-level and sustainability outcomes.

The fully-articulated PTM is complete. Both the process used to create it and the PTM have been described in detail in this report. Ideally, a program theory model offers a cohesive and representative picture of the program, "an approximate fit" of the program as *designed*. We have sought consensus on the representativeness of this model with key stakeholders and will revisit the PTM over the course of the award period, as this is needed.

To a large extent the PTM elaborates on how change is expected to occur, based on the 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).

We have used the PTM to direct the evaluation including the development of evaluation measures and methods designed to address the remaining two goals. To this end, we have created three evaluation measures, these are: a Full Teacher Survey, an Update Teacher Survey, and a Center Feedback Template. As implied, the first two measures assess teacher-level outcomes; and the third measure assesses center-level outcomes. The first administration of the Teacher Survey coincided with the start of summer workshops that occurred in 2019; and the roll-out of the Center Feedback template began in September 2019. To coincide with the 2020-2021 program year, we have added an Update: Teacher

Survey to continue to capture information from participating teachers and to focus on classroom implementation of QuarkNet content and instructional materials.

Based on 2019 and 2020 survey efforts, 355 teachers have completed the full Teacher Survey (this represents a unique count). A total of 90 teachers completed the Update Survey with 69 of these responses matched with responses from the original full survey. This represents a 78% response rate for 2019; and, 72% for 2020. We are grateful to QuarkNet staff who have added time to participate in the survey into nationally-led workshop agendas (and encouraged this for center-led workshops); and to teachers for their thoughtful responses to these survey requests.

Our approach to analysis has been to explore, preliminarily, teacher perspectives based on scale scores created from like items on the full Teacher Survey. These are self-reported exposure to Core Strategies of the program; Approach to Teaching; QuarkNet's Influence on Teaching; Student Engagement; and, QuarkNet's Influence of Student Engagement. We also looked at self-reported use of activities from the Data Activity Portfolio. The Update Survey focuses on subsequent classroom implementation of these activities as well as revisiting the teacher-level outcomes of Approach to Teaching and Student Engagement. These results are supplemented with information gathered from the QuarkNet Center Feedback process (15 Centers are presently included in the analysis mix) to help provide the context in which the teachers engage in the program and to assess center-level outcomes in their own right. We have focused on exploring consistent patterns in the data and to use multiple sources whenever possible (e.g., teacher responses, center responses, and information from workshop agendas and annual reports of active centers).

In preliminary analyses ….

Regarding **Core Strategies**, program engagement and exposure to core program strategies (as perceived by teachers) were shown to be related in a meaningful way. That is, more engagement by type of QuarkNet event was related to perceived higher exposure to core strategies; and more reported use of activities from the Data Activities Portfolio in the classroom. This speaks to the fidelity of the *implemented* program as compared to the program as *designed* as perceived by participating teachers; and, to the usefulness of this measure in subsequent outcomes analyses.

Regarding, **Approach to Teaching,** teaching outcomes were shown to be related to *perceived* QuarkNet's Influence on Teaching, Use of DAP activities in the classroom, and exposure to Core Strategies (based on results from multiple regression analyses). Of importance, Use of DAP activities and Core Strategies scores can serve as surrogate measures for degree of engagement in a variety of QuarkNet programs (e.g., Data Camp, Variety of Workshops, and Masterclass engagement) and degree of exposure to strategies seen as core to the program; this helps to simplify the model. A split-half analysis (based on teachers from 15 centers) suggests that this model is stable; and, thus Use of DAP activities and Core Strategies can be used as measures shown to be statistically related to teachers' Approach to Teaching. We continue to explore the use of center-level measures to help improve this model and to better understand the impact of offering teachers QuarkNet programs nested within partner-centers.

Regarding, **Student Engagement,** Approach to Teaching and QuarkNet's Influence on Student Engagement (at least) were shown to be related to perceived student engagement in inquiry-based science. This model, however, was less stable, based on a split-half analysis; thus, we continue to work to build a representative model of the impact of the program on student engagement as perceived by QuarkNet teachers.

Although preliminary, the weight of analyses (based on single-variable analyses and multiple regression models) suggests that there is a positive relationship between engagement in QuarkNet (the type and degree of program engagement and use of activities from QuarkNet's Data Activities Portfolio), exposure to Core Strategies, perceived influence of QuarkNet on Teaching; and teacher outcomes (Approach to Teaching). Regarding the engagement of their students in inquiry-based science (that aligns with the NGSS Science and Engineering practices), teachers' perceived Approach to Teaching and QuarkNet Influence on Student Engagement (at least) were shown to be related to Student Engagement. We continue to explore ways in which these statistical models can be improved including integrating center-level assessments into this process.

In assessment of the process of conducting center-level information through the Center Feedback Template, results from the pilot test and two additional rounds of outreach suggest that this process has been helpful for QuarkNet staff teachers, the centers themselves (mentors and lead teachers), and the evaluation (based on 15 centers to date). Using information from this process, along with information obtained from workshop agendas, and annual reports from active centers we have explored responses based on individual teacher perceptions and center-level assessments. In the main, there has been concurrence across information sources. For example, results from the teacher survey and feedback from centers suggest that teachers typically engage in activities as active learners. Similarly, both individual teachers and centers report opportunities for teachers to interact with other teachers, mentors and other scientists and to help foster collegial, long lasting, relationships. Moreover, activities from the Data Activities Portfolio, *as designed,* align well with the Next Generation Science Standards science practices, and *as implemented* through QuarkNet workshops (based on workshop agendas) and as evidenced by center-level assessment of these practices by participating teachers at their center.

Finally, responses from the Update Survey have provided a preliminary look on what (and how) activities from the Data Activity Portfolio are used (or planned to be used) by QuarkNet teachers in their classrooms. Although currently presented at the raw response level, we seek to integrate this information – either qualitatively or quantitatively – to help inform the outcomes analyses described in this report.

Program Summary and Recommendations

It is important to note that nearly all of the 2020 workshops and masterclasses, with few exceptions, were conducted in a virtual environment – and all occurred during a turbulent time of considerable uncertainty as to the severity and longevity of the COVID-19 pandemic. We have described how COVID-19 (coronavirus) has impacted the implementation of the 2020 QuarkNet program year; and how this has continued into the 2021 program year. Virtual workshops held in 2020 were reduced in scope focused on core concepts; and converted, for example, to half-day sessions with small-group breakout sessions, separate off-line time to work on specific tasks, and breaks built into the agenda. Programs in 2021 were held (or planned to be held) in in-person and/or virtual environments. With important input from QuarkNet staff, we have outlined the long-term possible implications of many of these program modifications.

The following program summary and recommendations are proffered:

1. 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 been invited to attend these weekly meetings, and she has regularly attended the staff-wide meeting. Of importance, these weekly meetings have been especially helpful in discussing and planning program content and delivery modifications as a result of coronavirus, COVID-19 during the 2020 and 2021 program years. The staff-wide meeting has provided 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. Continue to hold these meetings as feasible by everyone's schedule as these are of value to both the program and the evaluation.
2. Starting in the 2019-2020 program year, 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. This is 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.
3. Documenting workshop agendas and center annual reports – and posting these on-line -- have been extremely helpful in gathering information useful to the evaluation. Specifically, the workshop agendas improved our ability to identify which (and how) activities from the Data Activities Portfolio (DAP) have been incorporated into workshops, especially nationally-led workshops and to a lesser extent but still notable for 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 *as designed* and *as implemented* comparisons; and in comparing individual teacher- and center-level response similarities/differences. For

these reasons (plus benefits noted in 2) continue to encourage centers to use the agenda template options to create their own.

4. DAP activities, collectively, have been shown to align well with Next Generation Science Standards Science and Engineering Practices. QuarkNet staff has provided operational definitions to support how this alignment is determined and has also shown the alignment of these activities with Enduring Understandings of Particle Physics. Of importance, these activities are a bridge for teachers to implement QuarkNet content and materials into their classrooms. As a result of COVID-needed modifications, many of these activities can now be implemented in on-line environments expanding implementation options for teachers. Continue 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 either in-person, on-line (or both).
5. Starting with the 2020-2021 program year, staff created a guide 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 its use in center-run workshops. Based on early results, this structured approach has helped teachers reflect on classroom plans in meaningful ways. This information along with responses gathered from the Update Teacher Survey is very valuable to the outcomes evaluation. Continue to support this effort.
6. The number (and the quality) of activities in the DAP has increased dramatically from 2017 (the end of the past grant period) to the new program-award period. 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 work-load for their development and eventual use. Consider adding a Project Coordinator position to QuarkNet staff in the future renewal funding. This person could help the education specialist with DAP activity development as well as have other responsibilities related to gathering and updating program-operations data such as helping to track participation related to registration, updating teacher profiles on the QuarkNet website; and subsequent stipend payment.
7. When feasible, 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 remote meetings via Zoom during the 2020 and 2021 program years may help centers move in this direction.
8. 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 program. The brief one-page summary of the PTM and preliminary evaluation results might help in this effort.
9. Kudos 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 planned to be continued in subsequent program years). Given that all QuarkNet centers are mature, staff realized that there was need to clarify the roles and responsibilities of lead teachers and to give these teachers a platform to exchange ideas on these possibilities.

10. Continue to support the evaluation and its efforts as reasonable; and continue to work with the evaluator, as planned, to help embed evaluation efforts and requirements within the structure and delivery of the program.

Evaluation Summary and Recommendations

The following evaluation summary and recommendations are proffered:

1. The response rates for the full Teacher Survey and the Update Survey remain high over the 2019 and 2020 program years (78% and 72%, respectively). 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.
2. Working with QuarkNet staff, the Update Teacher Survey dovetails well with the guidelines for teachers in the development of classroom implementation plans. As the number of teachers who complete the Update Teacher Survey grows, we anticipate using this information to help illuminate how and in what ways teachers have planned or have used QuarkNet program content and practices in their classrooms. And, to the degree possible we will link this implementation to the type and degree of engagement by teachers in QuarkNet, either qualitatively or quantitatively.
3. Continued efforts to distribute and collect center-level information through the Center Feedback Template suggest that this process has been helpful for QuarkNet staff, Center level mentors and lead teachers, and the evaluation. To date, we have information from 15 Centers that have been incorporated into analyses. Additional centers will be added into the mix and incorporated into future analyses.
4. Preliminary analyses from the Teacher Survey suggest that there is a meaningful link between exposure to program strategies and program engagement; and that this engagement along with use of activities from the Data Activities Portfolio and teachers' perceptions of QuarkNet's Influence on Teaching are related to teacher outcomes. Perceived student engagement was shown to be related to teachers' Approach to Teaching and QuarkNet's Influence on Student Engagement.
5. Data analyses suggest agreement between center-level perceptions and teacher-level perceptions. This is evident when looking at information about teachers experiencing activities as active learners (as students); and, exposure to opportunities to develop and maintain collegial relationships with other teachers, mentors and other scientists. We have also shown that activities from the Data Activities Portfolio, *as designed*, align well with the Next Generation Science Standards Engineering Practices and *as implemented* based on workshop agendas as well as the perceptions of participating teachers and feedback from QuarkNet centers.
6. Continue to incorporate center-level outcomes data (from the Center Feedback Template process), in analyses of teacher-level outcomes (and in particular the regression models). Add sustainability outcomes into the mix as the number of participating centers grows.

7. 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. The one-page summary of the PTM and evaluation results may help in this process.
8. Continue to be mindful of the many responsibilities that program staff, mentors and teachers have. 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.
9. Work to ferret out the benefits and challenges of implementing QuarkNet programs (workshops, masterclasses) in a virtual environment and work with QuarkNet staff to highlight positive long-term implications of this over time.
10. 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, participating teachers, NSF and others who may be interested in QuarkNet.

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This report highlights the continuing evaluation efforts, which began anew in 2018-2019, with the advent of the current funding cycle from the National Science Foundation (NSF). As such, portions of this report will draw from previous evaluation reports to reflect the continuity of these evaluation efforts (Race, 2019; Race, 2020).

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 will 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 approximately 50 plus 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 or laboratory, serving primarily teachers who live in the nearby

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[1] Until this award period, QuarkNet had been co-sponsored by the National Science Foundation and the Department of Energy. In addition to NSF funding, funding is also provided by U.S.CMS and U.S. ATLAS. In-kind support is provided by Fermilab during this current award period as well.

catchment area. In addition to these centers, there is the Virtual Center, which provides a home for teachers who do not live proximal to a particle physics research group. At these 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).

During this award period, 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). (The "active" status of each QuarkNet center will be presented later in this report.)

We will discuss the effect of the COVID-19 pandemic on QuarkNet program modifications made during the summer of 2020 and its potential impact on the program and its outcomes later in this report.

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

As already stated, the QuarkNet program is not new but the external evaluator is -- starting with the 2018-2019 program year. Accordingly we have proposed a new direction with the evaluation focused on the following: (1) Develop (and use) a Program Theory Model (PTM); (2) Assess program outcomes at the national and center levels through teacher-level outcomes; and, (3) Assess the sustainability of program centers, based on center-level and sustainability outcomes. Based on the PTM, new evaluation measures have been created and, when relevant, existing evaluation measures from previous evaluation efforts have been modified; these have been implemented to assess teacher-level program outcomes, center-level outcomes and program-center sustainability. These data 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). We will draw on QuarkNet program and evaluation history when relevant.

Develop (and Use) a Program Theory Model (PTM)

A Program Theory Model (PTM) was developed during the first year of this funding cycle. Because of its significance, we present again the rationale for why it was developed and highlight the important components of the program (and its model). The process used to develop the model is highlighted in Appendix B. In short, we drew from the relevant literature; Next Generation Science Standards (especially the Practices); defined our use of the term "Guided Inquiry;" 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.

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 intend 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, Hasci, Petrosino & Huebner, 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 will be 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).

PTM Program Anchors

The complexity of the program, its network of partners, and its longevity suggested that the development of such a PTM was warranted. Largely, the creation of this Program Theory Model 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. The PTM was anchored by relevant literature on effective professional development; the Next Generation Science Standards (and other relevant standards); and, our defined use of the term "Guided Inquiry." We also included a framework that adds program sustainability strategies and outcomes into the mix.

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**.

Professional Learning Communities, which will be discussed more fully in subsequent evaluation reports, are seen as an important means in which to embed these PD characteristics (Darling-Hammond, Hyler & Gardner, 2017).

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

Characteristic of Effective PD	Brief Description
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)
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)
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)
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)
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)
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)
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)

Source. This table directly quotes and paraphrases descriptions contained in Darling-Hammond, Hyler & Gardner (2017).

Program's Alignment with NGSS Standards

Clearly the QuarkNet program 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 the Disciplinary Core Ideas and Crosscutting Concepts (NGSS) were included as well. These are:

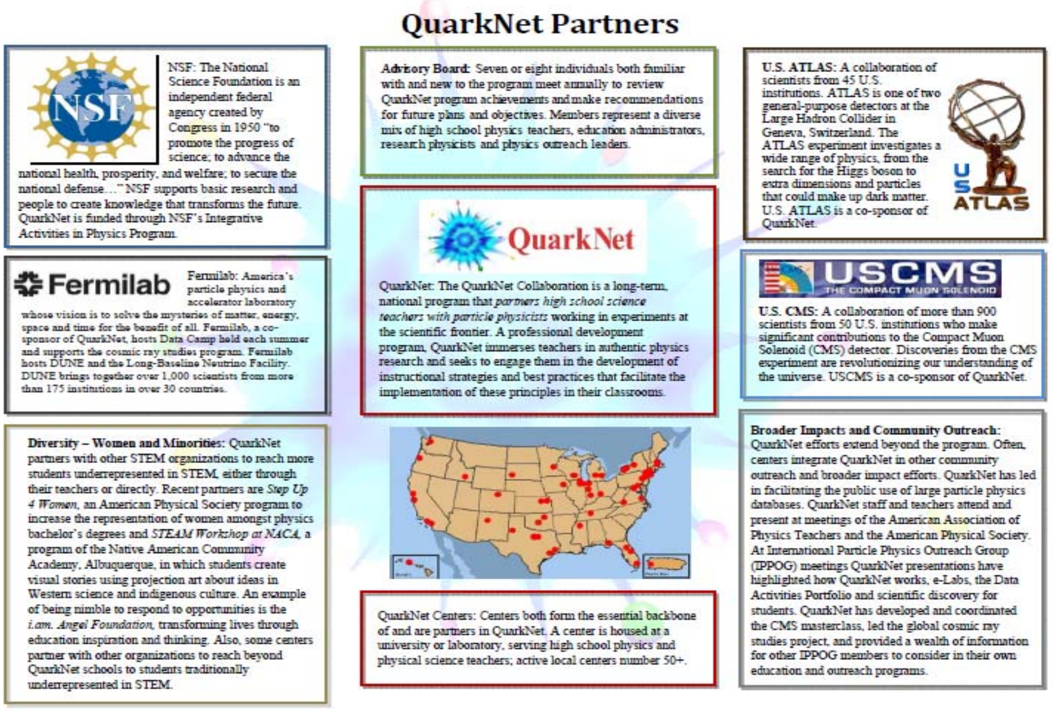
1. Patterns
2. Cause and Effect
3. Scale, Proportion and Quantity
4. Systems and System Models
5. Energy and Matter in Systems
6. Structure and Function
7. Stability and Change of Systems

(See NGSS at https://www.nextgenscience.orghttps://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).

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 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.

Diversity – Women and Minorities: QuarkNet partners with other STEM organizations to reach more students underrepresented in STEM, either through their teachers or directly. Recent partners are *Step Up 4 Women*, an American Physical Society program to increase the representation of women amongst physics bachelor's degrees and *STEAM Workshop at NACA*, a program of the Native American Community Academy, Albuquerque, in which students create visual stories using projection art about ideas in Western science and indigenous culture. An example of being nimble to respond to opportunities is the *i.am. Angel Foundation*, transforming lives through education inspiration and thinking. Also, some centers partner with other organizations to reach beyond QuarkNet schools to students traditionally underrepresented in STEM.

Advisory Board: Seven or eight 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+.

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.

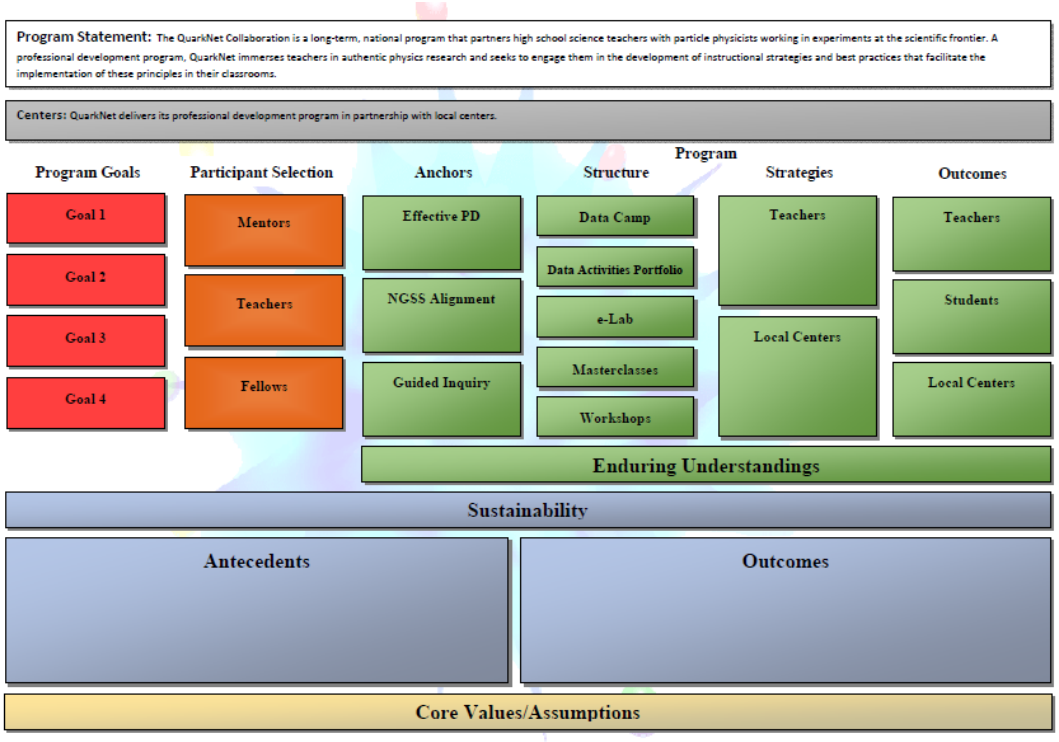
Broader Impacts and Community Outreach: QuarkNet efforts extend beyond the program. Often, centers integrate QuarkNet in other community outreach and broader impact efforts. QuarkNet has led in facilitating the public use of large particle physics databases. QuarkNet staff and teachers attend and present at meetings of the American Association of Physics Teachers and the American Physical Society. At International Particle Physics Outreach Group (IPPOG) meetings QuarkNet presentations have highlighted how QuarkNet works, e-Labs, the Data Activities Portfolio and scientific discovery for students. QuarkNet has developed and coordinated the CMS masterclass, led the global cosmic ray studies project, and provided a wealth of information for other IPPOG members to consider in their own education and outreach programs.

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

<u>The PTM</u>

The first two pages of the PTM are presented here (Exhibit A and B, next page); the full model is shown in Appendix C. These 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.

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 recently 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 "blue print" as to how change is expected to happen through the program's underlying components and strategies (DuBow & Litzler, 2019).



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.

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

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 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.

<u>Who is the Audience</u>? 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.

Program Structure of QuarkNet

The structure of the QuarkNet program includes specific and varied program events that are part of the national and center-level program. The key program structure includes:

Data Camp

Data Camp is a 1-week program offered annually in the summer at Fermilab. It 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 (Large Hadron Collider) data. The camp emphasizes an authentic data analysis experience, in which the teachers are expected to engage as students as active learners of a challenging topic they may initially have known very little about. In the beginning of the week, teachers receive an authentic CMS (Cosmic Muon Soleniod) dataset and work in small groups to analyze the dataset. Groups use these data 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 data. Then, teachers explore various instructional materials in the Data Activities Portfolio (to be explained shortly) that offer them help in incorporating particle physics concepts into their everyday lessons and propose an implementation plan for their classrooms. Throughout the week, teachers take tours (e.g., LINAC tunnel, MINOS experiment) and participate in seminars held by theoretical and experimental physics.

[It should be noted that because of the hands-on, in-person necessity of Data Camp during the 2020 and again in the 2021 program year, Data Camp was replaced with Coding Camp. This will be described in more detail shortly.]

e-Lab

e-Lab is 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 CMS experiment at CERN2's 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 [CERN, Conseil Européen pour la Recherche Nucléaire].

Masterclass: U.S. Model

In the U.S. Model, Masterclass is a one-day event in which students become "particle physicists for a day." Teachers and mentors participate in an orientation by QuarkNet staff or fellows. Teachers implement about 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 explain the measurements they will make using authentic particle physics data. Working in pairs, students are expected to analyze the data in visual event displays; to characterize the events; pool their data with peers; and draw conclusions, helped by one or more particle physicists and their teacher. At the end of the day, students may gather by videoconference with students at other sites to discuss results with moderators at Fermilab or CERN. Some masterclasses take place at schools with teachers providing the particle physics and measurement information. U.S. Masterclasses are part of a larger program, International Masterclasses.

Workshops

The primary vehicle through which participating QuarkNet teachers receive professional development are workshops conducted through the national program or at the center level.

Center-run Workshops**.** A center's second year involves new associate teachers in a multi-week experience that focuses on a research scenario prepared by their mentor(s) with support from lead teacher(s). The mentor models research, similar to Data Camp, -- teachers, as students and active learners, have an opportunity to engage in an experiment, receive and analyze data, and present results. Then teachers have time to create a plan to share their experiences with their students and often use instructional materials from the Data Activities Portfolio in this planning.

During a center's third year and after, lead teacher(s) and mentor(s) have flexibility to organize 4-to-5 day workshops to meet local needs and interests. These workshops vary in content and structure. Centers may meet only during the summer, only during the school year or both during the summer and school year. Some centers meet even more frequently depending upon interest and availability of teachers. These workshops may include a national workshop and offer a learning-community environment with opportunities for teachers to interact with scientists, and learn and share ideas related to content and pedagogy.

National Workshops. On request, QuarkNet staff and/or fellows conduct workshops held at local centers. These workshops typically occur during the summer and can vary in length from several days to a week period. Content includes, for example, cosmic ray studies, LHC or neutrino data, and related instructional materials from the Data Activities Portfolio. National workshops also support opportunities for teachers to work in a learning-community environment, learn and share ideas related to content and pedagogy, and develop classroom implementation plans (PTM, 2019).

COVID-19 Program Modifications. Most implemented 2020 QuarkNet programs were modified in structure and content due to the need to hold these in a virtual environment because of COVID-19. Only a very few workshops were held face-to-face during this program year. These occurred very early in the calendar year or later in the year when socially-distant teachers could meet outdoors in a very limited capacity.

Regarding modifications, for example, Data Camp which is typically a very hands-on program experience at Fermilab with on-site tours was revised as a "Coding Camp."
In 2020, this consisted of two, 1-week sessions on Zoom where two groups of 12 teachers concentrated on coding CMS data using Jupyter and Python platforms. This effort led to pilot testing a Coding Workshop implemented in 2021.

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 sills 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: Level 4 activities are in development.

An adaptation of the current CMS masterclass was created in 2020 (that is, BAMC Big Analysis of Muons in CMS) such that students could engage in a masterclass experience while working remotely. Measurement was simplified measuring only muons and online support was ramped up by the use screen casts and intensified communication with teachers. Workshops held in 2020, and some in 2021, occurred over Zoom were often modified as half-day events spread over 1 to 2 days (or more) to help reduce on-line instruction fatigue and to give teachers time to engage in off-line exercises either alone or in working groups on-line at designated times. Often, the scope of the instructional content was reduced as well to better support learning/sharing in a virtual environment.

Data Activities Portfolio

The Data Activities Portfolio is an online compendium of particle physics classroom instructional materials organized by data strand and expected level of student engagement (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, CMS, Cosmic Ray Studies, 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 (level 4 activities are in the works). 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.*

Table 3. QuarkNet: Aligning Program Anchors and Core Strategies

Program Anchors: Effective Professional Development and Best Practices	Core Strategies: What Happens in QuarkNet?
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.	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.
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)]	

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.

As will be seen in subsequent sections of this report, program outcomes directed toward teachers are measured by a Teacher Survey (or subsequently a short update) distributed on an annual basis. And program outcomes related to mentors and interactions between mentors and teachers are 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 by, for example, links to operations data such as implemented workshop agendas and implementation plans developed by participating teachers (when available). We will explore including select interviews with participating teachers and/or classroom observations if these options become feasible post COVID.

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. 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?

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. 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 datasets.
6. Scientists form and refine research questions, experiments and models using patterns in large data sets.
7. The Standard Model[1] 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[1].
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.
15. 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)

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 understanding*s 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)]

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 will be 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.

Implementation of QuarkNet Program

An overview of the roles and responsibilities of key QuarkNet stakeholders is shown in Figure 1. 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

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.

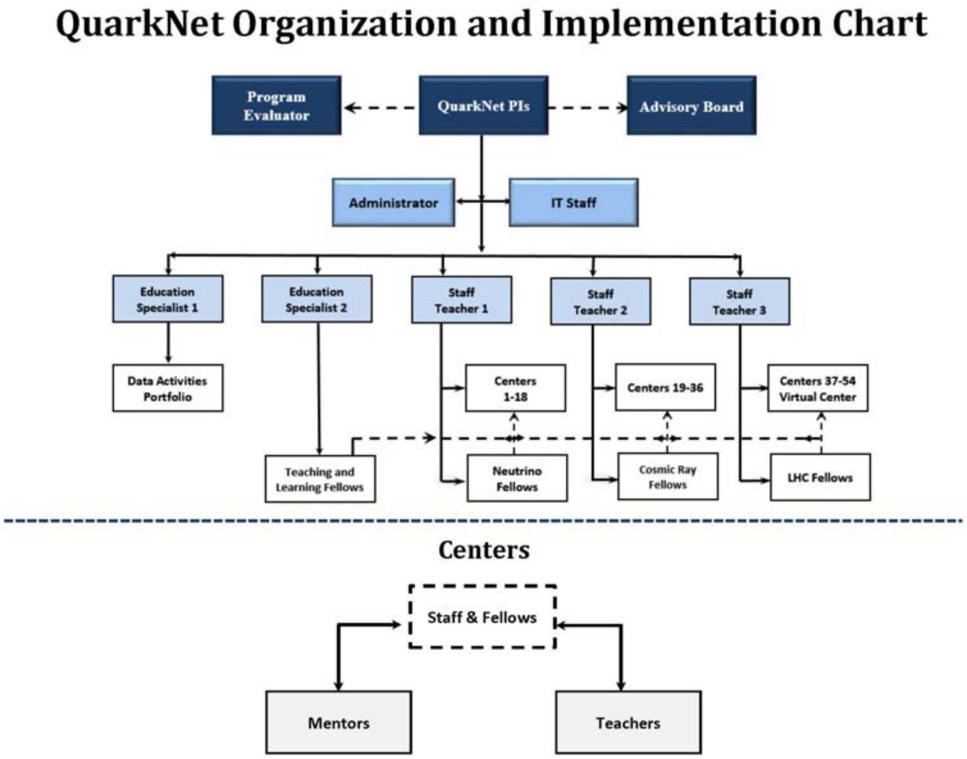


Figure 1. An overview of the organization and implementation of the QuarkNet Program.

the Data Activities Portfolio (personal communication, email M. Bardeen, April 17, 2019). Although a long-standing component of the program’s operational structure, these weekly meetings have been especially helpful in discussing and planning program content and delivery modifications as a result of coronavirus, COVID-19. This was particularly noteworthy during the early spring of 2020 when it became evident that the United States and the world at large were dealing with a virus that had grown into a pandemic with its full impact still unfolding.

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, 2019). Fellows may interact with any of the centers. As already stated the primary vehicle through which participating

Table 7

Active QuarkNet Centers: Workshop Held in Program Years 2019, 2020 and 2021[a]

Center	Status			Center	Status		
	2019	2020	2021		2019	2020	2021
Black Hills State University	Active	Active	Active	University of California at Riverside	--	--	Active
Boston Area (Brown & Northeastern Universities)	Active	Active	Active	University of California at Santa Cruz	--	Active	Active
Brookhaven National Laboratory/Stony Brook	Active	Active	Active	University of Cincinnati	Active	Active	Active
The Catholic University of America	Active	Active	Active	University of Florida	Active	Active	Active
Colorado State University	Active	Active	Active	University of Hawai'i	Active	Active	Active
Fermilab/University of Chicago	Active	Active	Active	University of Houston/ Rice University	Active	Active	Active
Florida Institute of Technology	--	Active	--	University of Illinois at Chicago	Active	Active	Active
Florida International University	--	Active	Active	University of Iowa/Iowa State	Active	Active	Active
Florida State University	Active	Active	Active	University of Kansas	Active	Active	Active
Idaho State University	Active	Active	Active	University of Minnesota	Active	Active	Active
Johns Hopkins University	Active	Active	Active	University of Mississippi	Active	Active	Active
Kansas State University	Active	Active	Active	University of New Mexico	Active	Active	Active
Lawrence Berkeley National Laboratory	Active	Active	Active	University of Notre Dame	Active	Active	Active
Northern Illinois University	Active	Active	Active	University of Oklahoma	Active	Active	Active
Oklahoma State University	Active	Active	Active	University of Oregon	Active	Active	Active
Purdue University	--	Active	Active	University of Puerto Rico at Mayaguez	Active	Active	Active
Purdue University Northwest	Active	Active	Active	University of Rochester	--	--	Active
Queensborough Community College	--	Active	Active	University of Washington	Active	Active	--
Rice University – (with University of Houston)	Active	Active	Active	University of Wisconsin – Madison	--	Active	--
Rutgers University	Active	Active	Active	Vanderbilt University	Active	Active	Active
Southern Methodist University	Active	Active	Active	Virginia Center (Hampton, George Mason, William & Mary Universities)	Active	Active	Active
Syracuse University	Active	Active	Active	Virginia Tech	Active	Active	Active
Texas Tech University	Active	Active	Active	Virtual Center	Active	Active	Active
University at Buffalo –SUNY	Active	Active	Active	Wayne State University	--	--	--

[a] Program Year 2019: June 2018 through May 2019; 2020: June 1, 2019 through May 31, 2020; 2021: June 1 2020 through May 31 2021 (as of August 2021)

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) 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.)

Data Activities Portfolio: Instructional Design and Review of Activities

Figure 2 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 past two years, 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 include the re-review of previously posted activities; filling in gaps for improved sequencing; developing neutrino materials; and creating activities at level 4. A brief history of the Data Activities Portfolio is highlighted in Appendix E.

Data Activities Portfolio: Activities, Masterclasses and e-Labs

Table 8 provides a list of the current activities in the Data Activities Portfolio (DAP); there are a total of 32 activities. This represents: 8 activities at Level 0; 12 activities at Level 1; 10 activities at Level 2; and 2 activities at Level 3. In comparison during the 2012-2017 program contract years where a focused effort to expand the number and quality of activities in the Data Activities Portfolio occurred, there were 10 activities at Levels 0-2 at the conclusion of that time period (not including masterclasses) (Beal & Young, 2017).

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 9.

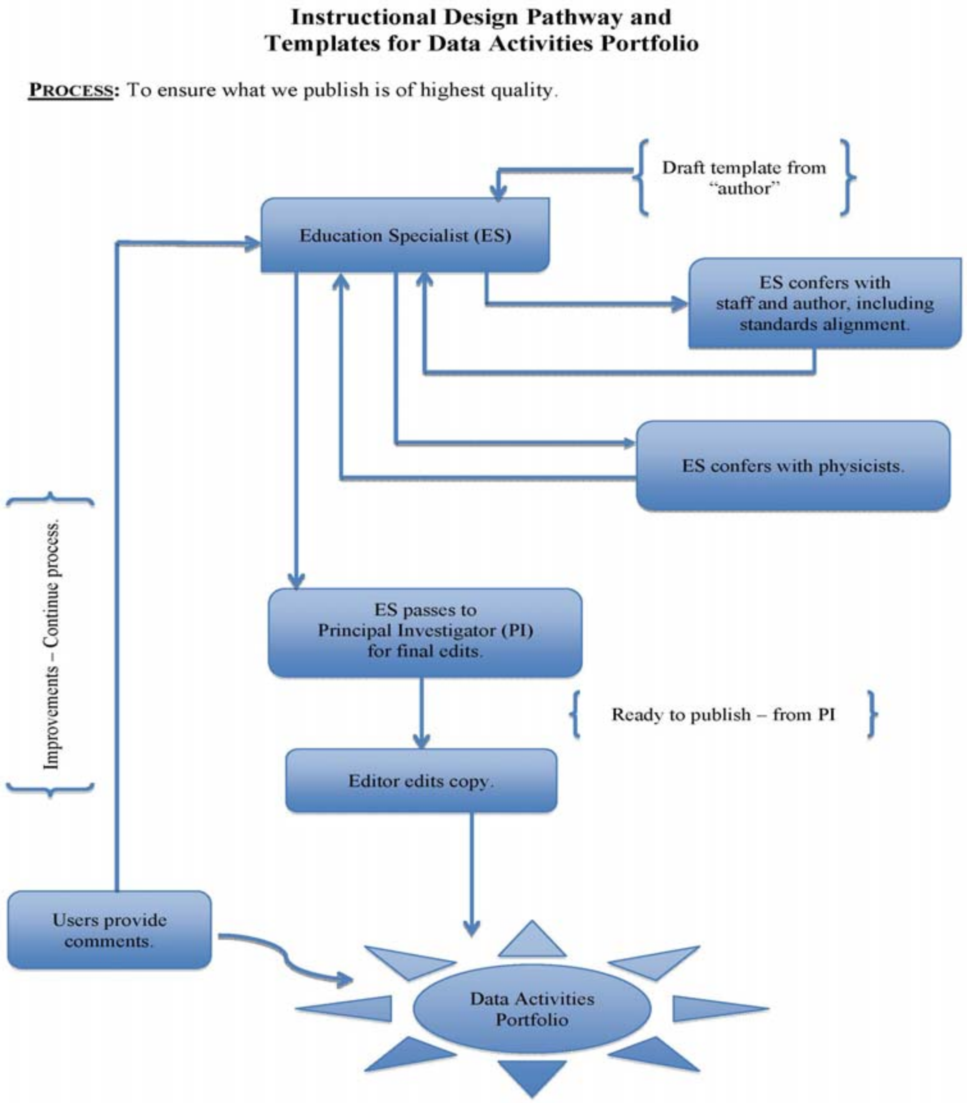


Figure 2. Instructional Design Pathway for Data Activities Portfolio (created by Young, Roudebush & Bardeen)

Table 8
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	1,2,4,6,7
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
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	1,2,3,4,5,7
1	Rolling with Rutherford	Cosmic Ray, LHC	1,3,4,5,7
1	Calculate the Z Mass	LHC	1,2,4,5,7,8
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 Transformation	Cosmic Ray, LHC, Neutrino	1,2,4,6,7
2	Making it ‘Round the Bend – Quantitative	LHC	1,2,3,4,5,6,7,8
2	CMS Data Express	LHC	2,4,5,7,8
2	TOTEM Data Express	LHC	2,4,5,6,7,8
2	ATLAS Z-path Masterclass	LHC	1,3,4,5,6,7,8
2	CMS Masterclass WZH-path	LHC	1,3,4,5,6,7,8
2	Mean Lifetime Part 2: Cosmic Muons	Cosmic Ray	2,3,4,5,7,8
2	Mean Lifetime Part 3: MINVERvA	Cosmic Ray, Neutrino	2,3,4,6,7,8
2	ATLAS Data Express	LHC	2,4,5,7,8
2	ATLAS W-path Masterclass	LHC	1,3,4,5,6,7,8
2	CMS Masterclass J/Psi	LHC	1,2,4,5,6,7,8
3	Cosmic Ray e-Lab	Cosmic Ray	1,2,3,4,6,7,8
3	CMS e-Lab	LHC	1,3,4,6,7

Note: List of activities taken from QuarkNet website https://quarknet.org/data-portfolio. (As of 2/25/2021). 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).

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/)

It should be noted that there are three activities that are not included in the above table that 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).

Table 9
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. Rosenbush and M. Bardeen August 18, 2020.

As noted, there are three activities that are not included in Table 8. 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).

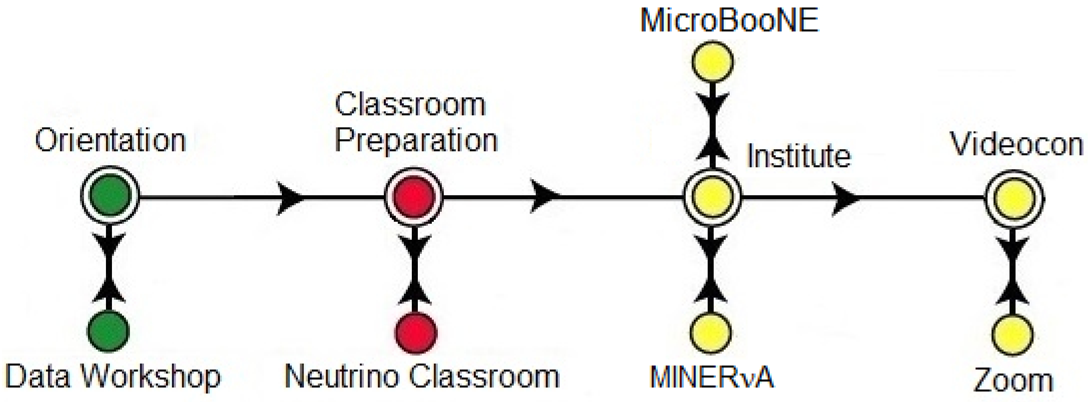


Figure 3. Neutrino Masterclass Project Map 2019 (developed by Cecire, Bilow and Wood; https://quarknet.org/content/neutrino-masterclass-project-map-2020).

Each of the current 32 activities 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 activities. Activities can be searched by 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 (0-3 and soon to be 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); information on technology requirements; and estimated class time to implement are 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 with 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 3. 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).

Aligning 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 in order 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 it a workshop; thus, an Enduring Understanding(s) is sequenced into a workshop as well. Of importance, DAP activities provide a means to suggest 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 4 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	2 2
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	0 0 2 1 2
4. 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
5. 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	0 0 0
6. Scientists form and refine research questions, experiments and models using observed patterns in large data sets.	• Cosmic e-Lab • CMS e-Lab	3 3
7. The Standard Model provides a framework for our understanding of matter at its most fundamental level.	• Quark Workbench 2D/3D • Particle Transformation • Cosmic e-Lab • CMS e-Lab	0 1 3 3
8. The fundamental particles are organized according to their characteristics in the Standard Model.	• Shuffling the Particle Deck	0
9. 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
10. Fundamental particles display both wave and particle properties, and both must be taken into account to fully understand them.	• TOTEM Data Express	2
11. Particle physicists continuously check the performance of their instruments by performing calibration runs using particles with well-known characteristics.	• CMS Data Express	2
12. Well-understood particle properties such as charge, mass, momentum and energy provide data to calibrate detectors.	• Calculate the Z Mass	1
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.	• Mean Lifetime Part 1: Dice • Mean Lifetime Part 3: MINERvA	1 2
14. 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
15. Scientists must account for uncertainty in measurements when reporting results.	• What Heisenberg Knew • Histograms: Uncertainty	1 1

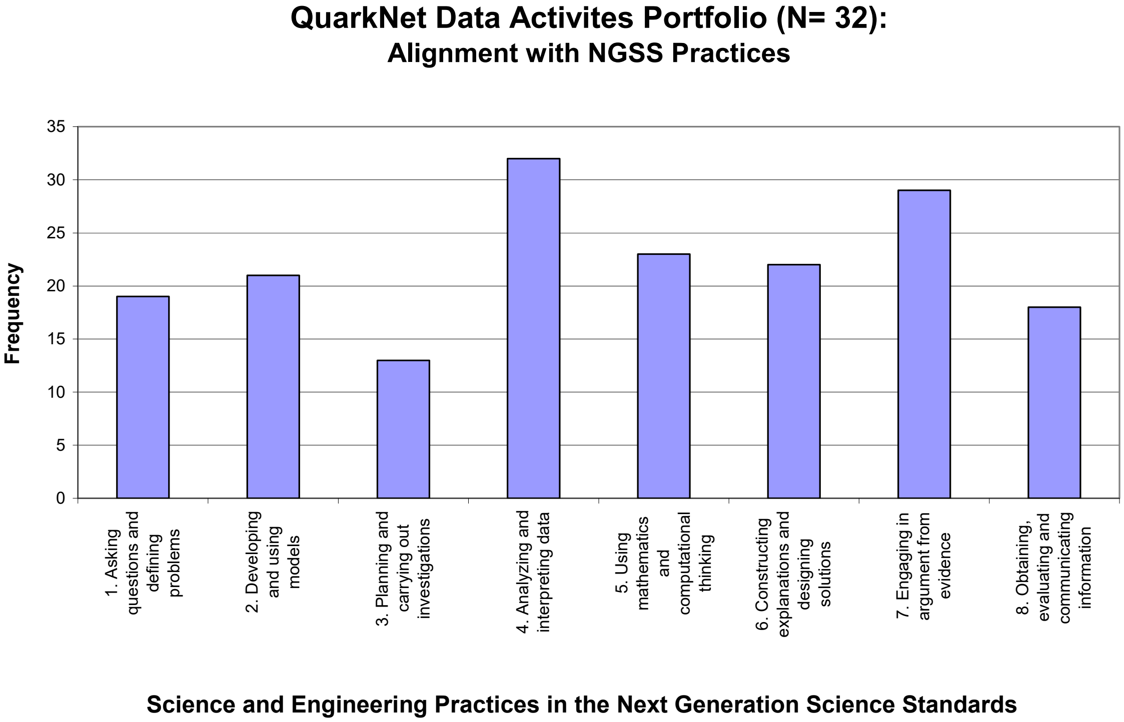


Figure 4. Alignment of Data Activities Portfolio activities with NGSS Science Practices.

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 Level 2 and 3 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.

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 with 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; 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: 2020-2021 Program Years

Throughout this current award period, each center is able to apply annually for a budgeted 30 teacher-days; for a merged 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 (in January 18, 2019; in February 3, 2020); 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 activity starting in the summer), centers were given a list of national workshop opportunities along with a sample agenda to aid in planning and implementation https://quarknet.org/page/ /summer-workshop-opportunities-quarknet-centers) as well as a staff-member representative list (https://quarknet.org/content/ quarknet-center-staff-assignments-january-2020).

Previous Program Years during this Award Period

Program Year 2018-2019. As usual in the planning of a given program year, centers were 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 (https://quarknet.org/content/summer-2019-rfp). Then, staff teachers 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).

Shown in Appendix F is a list of QuarkNet Workshops held during the 2018-2019 program year (that is, June 1, 2018 through May 31, 2019). Data Camp was implemented at Fermilab on July 16-20, 2018. Table F-1 shows the national workshops run by QuarkNet staff. Table F-2 lists the meetings and workshops held at QuarkNet

Centers and led by the individual centers. (See appendix for both tables.) 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). (As already mentioned, see Table 7 for a list of the centers and the status of each.)

This process was repeated for the 2019-2020 and 2020-2021 program years starting with an email blast distributed on February 3, 2020 with a link to support information (https://quarknet.org/content summer-2020-rfp); and again in March 1, 2021 (National Workshop opportunities for QuarkNet Centers | Quarknet).

Program Year 2019-2020 (June 1, 2019 through May 31, 2020)

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 be (and have been) modified for the workshops led by individual centers, if desired. During nationally-led workshops, these agendas are often modified in real time providing a straightforward way of documenting content/schedule changes. Once a workshop is completed, the updated agenda memorialized 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 likely make it easier for centers to 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 (pre-COVID and hopefully post-COVID); 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.)

Of particular importance, activities from the Data Activities Portfolio (DAP) included in the workshops were documented, too. It is evident from Table 11, especially for nationally-led workshops, that activities from the DAP are a frequent and integral part of a workshop. This focus – and its documentation – coincides with the improved quality and robust increase in the number of activities included in the DAP (since 2017). By design, the embedded DAP activities align with the content of the workshop, often at multiple student-skills levels (Level 0, 1, 2, and 3). Teachers engaged in these activities as active learners – as students -- and, at times, can select from examples of provided 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 how they may comprehend the content. This is compatible 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 classroom – a primary purpose of the DAP -- and incorporate these into their implementation plans.

As noted in Table 11, among the most frequently used DAP activities embedded within the 2019-2020 workshops were: *Shuffling the Particle Deck* (Level 0); *What Heisenberg Knew* (Level 1); *Rolling with Rutherford* (Level 1); and *Calculating the Z Mass* (Level 1); but other activities related to Mean Lifetime and MINERvA measurement were evident as well.

Program Year 2021 (June 1, 2020 through May 31, 2021)

QuarkNet staff responded in many ways to address the implications of coronavirus (COVID-19) starting in March 2020. An overview of these early efforts was submitted to NSF on May 1, 2020 and is shared in Appendix G. A variety of program modifications were made to help adapt QuarkNet to online teaching venues as shown in Table 12. The long-term implications of these modifications are discussed later in this report.

Additional teacher support for online resources were added including for example, remote online simulations and online lessons; how to use Cosmic Ray detectors remotely for data collection and analyses; shifting the content of the *Friday Flyer* (weekly) to remind teachers of available support and new online options; and from May 6 through June 10, 2020 holding QuarkNet Wednesday Webinars on particle physics-related topics. Additional Zoom channels were opened up (through the University of Notre Dame) as well as IT infrastructure support, which was already working remotely.

With these challenges and changes in mind, Table 13 summarizes the workshops held during the 2019-2020 QuarkNet program year. A planned workshop, but cancelled because of COVID-19, is shown as well.

As reflected in Table 13, the most frequently used DAP activities embedded with these workshops were: *Rolling with Rutherford*, (Level 1); *The Case of the Hidden Neutrino* (Level 1), *Calculate the Z Mass* (Level 1); *What Heisenberg Knew* (Level 1); Mean Lifetime Part 1: Dice (Level 1); and Mean Lifetime Part 3: MINVERvA (Level 2). As noted, the three STEP UP activities were implemented as well.

Table 11

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 11

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 11

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 11

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 11

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 11

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 12

QuarkNet Program Modifications as a Result of COVID-19 Program Year 2019-2020

Program modifications were made to help adapt these to online teaching venues:

Cosmic Ray Studies

- CMS e-lab (using CERN's LHC data from physics research projects remotely)
- A few detectors continue to upload data; and a staff member moved one of the Fermilab detectors to his home to provide an updated standard data set for e-Lab.

Masterclasses

- The current CMS masterclass was modified for remote learning – The Big Analysis of Muons in CMS (BAMC).
- One BAMC was held in April and another in May.

Staff also built a support infrastructure with student and teacher pages on the QuarkNet website; Zoom Q& A sessions for teachers; an April 15 webinar on the Standard Model and CMS (conducted by a Kansas State University particle physicist); tables for recording results online in the CMS Instrument for Masterclass Analysis; and an April 17 webinar to discuss the data with particle physicists.

Fellows Workshop

- A virtual workshop was held on May 15-17; its primary purpose for participating fellows was to develop online workshops to be offered during summer 2020.

Data Camp

- Two virtual data camp events are planned for summer 2020 that emphasize the use of coding skills as these pertain to physics in general and particle physics in particular.

STEP UP

- QuarkNet Ambassador Training (virtual) planned for June 19-20 focused on how to use STEP UP activities and training on workshop best practices.

Summer 2020 Workshops at Centers Options Included:

- Reschedule workshops for late summer or fall in hopes that face-to-face meetings would be possible at that time.
- Offer a virtual workshop – where at least a portion of their workshop time would be conducted remotely.
- Cancel a 2020 workshop with a plan to meet again in 2021.
- Other options.

Table 13

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 13 (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 13 (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 13 (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 13 (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 13 (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 13 (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 QuarkNet website by individual center.

Development of Evaluation Measures and Evaluation Plan

The first goal of the evaluation has been completed, that is, (1) Develop (and use) a Program Theory Model (PTM). Although the PTM will be reviewed and may be revised, as needed during this award period, the lion share of this model is completed.

To fulfill the remaining two evaluation goals: (2) Assessment of program outcomes at the national and center levels through teacher-level outcomes; and, (3) Assessment of the sustainability of program centers, based on center-level and sustainability outcomes, three evaluation measures were designed; that is, a Teacher Survey (in two versions full and abbreviated) and a Center Feedback Template. As a reminder, the new evaluation efforts began in September 2018 to coincide with the 2018-2019 program year. Most QuarkNet workshops and meetings at participating centers occur over the summer (as already noted in previous tables). The Teacher Survey (full version) was rolled out to coincide with these summer 2019 activities. (This aligns with Goal 2: assessment of teacher-level outcomes). A pilot test of the Center Feedback Template began in November 2019 and has been extended during the 2019-2020 and 2020-2021 program years. This coincides with assessment of center-level outcomes (Goal 3) and will serve to provide a context for teacher-level responses.

Program operations data, gathered from the Center Feedback Template, and other sources has been linked to teacher-level evaluation data when possible to assess outcomes relative to program engagement at the individual level (by teacher) and at the center level (teachers embedded or nested by center).

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. Rolling this out during the 2020-2021 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 was strongly recommended for center-run workshops. To complement this effort, an Update: Teacher Survey has been integrated into the process starting in spring of the 2019-2020 program year to help capture this planned classroom implementation by teachers. Finally, workshop observations (most recently done remotely) have been incorporated into this process. Teacher interviews and and in-person classroom observations may be added into the mix, based on specific sampling as feasible.

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

Table 14
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).	***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 Appendix H for a copy of the survey.) The unit of measure for this survey is the individual teacher; it is conducted via SurveyMonkey. The intent is for teachers to complete the survey during their on-site program engagement. This is 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.)
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.		

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

The 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 14, previous page). The full survey is shown in Appendix H (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 14 (segments 4-6). 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. 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 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 18 minutes to complete it.

The full survey is a planned annual event; however, a given teacher is asked to complete this survey only once during this grant period. Starting in spring 2020, if a teacher had completed the full Teacher Survey, he or she is asked to complete the short Update: Teacher Survey (see Appendix I). The update 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 has been rolled out to coincide with the 2019-2020 program year and to continue during subsequent program years. (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.

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 15); and, gather information on success factors as a means to assess sustainability outcomes (see Table 16).

The Center Feedback Template is a 4-page form divided into four sections (see Appendix J). Section I requests information about the Center (who is participating in this effort and who is completing this form). Section II asks about program events over the past two years. Section III gathers information about center-level outcomes (described in Table

Table 15
Center Feedback Template: Linking Core Strategies and Center-level 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). 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 (for science) and designing solutions (for engineering) 7. Engaging in argument from evidence 8. Obtaining, evaluating, and communicating information.	**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.	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 is and will be 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.
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.)		
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		

15); and Section IV is focused on the Success Factors listed in Table 16). Finally, there is an optional fifth page for Centers to note any additional comments, if desired.

Given that this template is more complicated than a survey per se, we have adopted the following protocol. First, relying on the help of QuarkNet staff teachers, centers were selected on a rolling basis (we have selected four centers initially starting in September 2019; six centers in spring 2020; and five centers in spring 2021.

Table 16

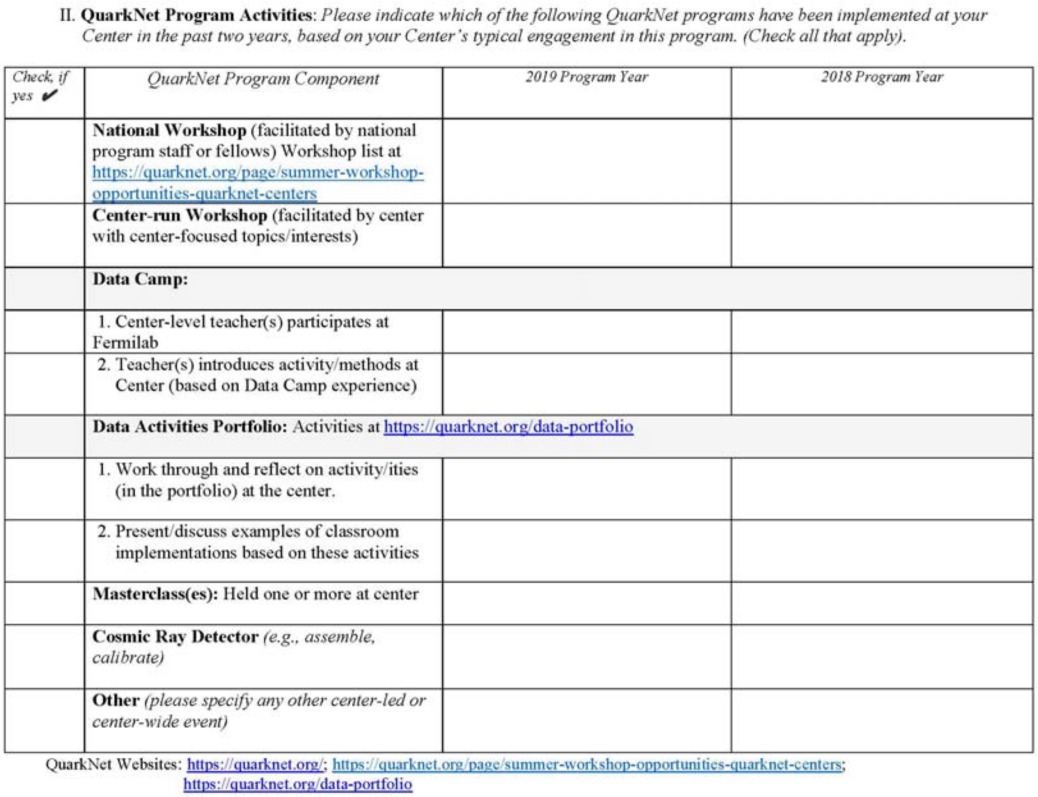
Center Feedback Template: Sustainability Outcomes and Success Factors[a]

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.



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*	*2019 Program Year*	*2018 Program Year*
	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)*		

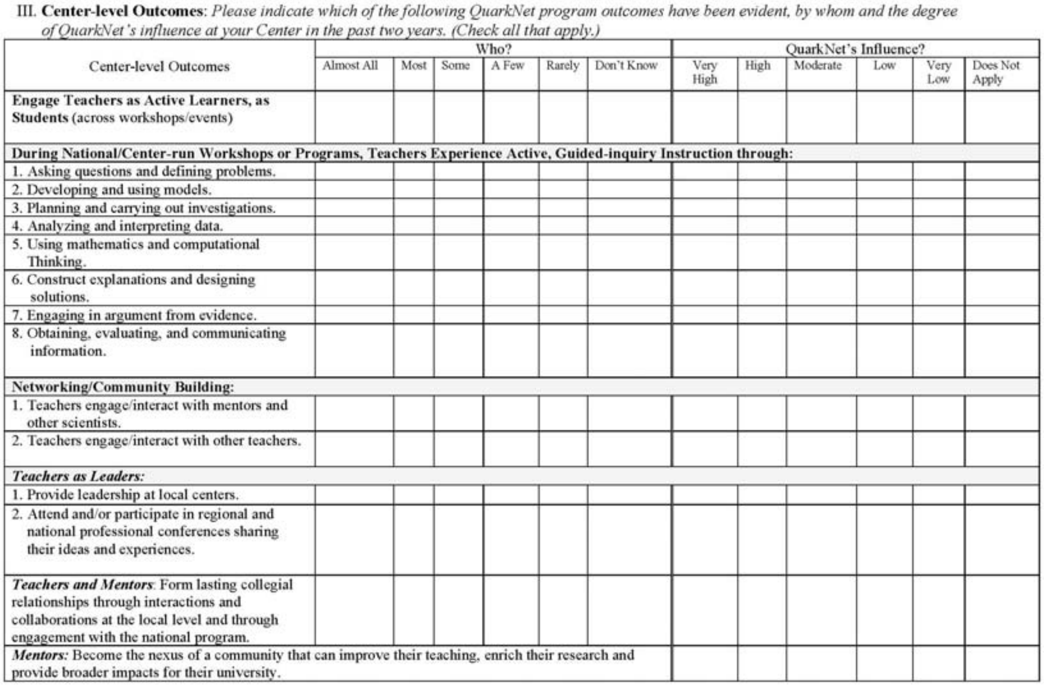
QuarkNet Websites: https://quarknet.org/; https://quarknet.org/page/summer-workshop-opportunities-quarknet-centers; https://quarknet.org/data-portfolio

Figure 5. Section II of the Center Feedback Template

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 a 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 move through this process, it is likely that selected centers will reflect 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). Overall, we see this process as helping the evaluation and through this process offering information that we hope is helpful to QuarkNet staff teachers and to the centers themselves.

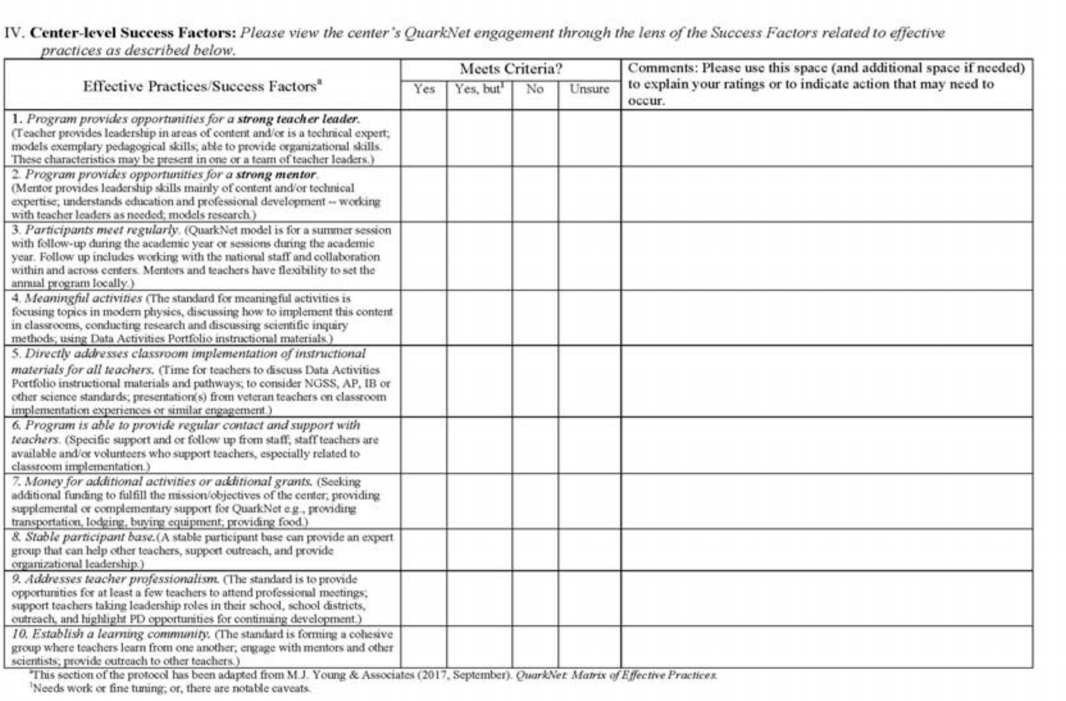
To help ease the task, a draft of Section II is completed by the evaluator based on information gathered from existing annual reports and agenda for a given center over the past two years, for example, 2019 and 2018 program years. This draft summary is reviewed by QuarkNet staff teachers who have direct knowledge about a given center and is revised as needed. (Figure 5 shows a blank Section II.) Then, the mentor is sent an email suggesting that an initial conference call is necessary to help the center fulfill this



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 6. 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.

Figure 7. Section IV of the Center Feedback Template.

request. In practice, this conference call has run about an hour and typically has included a staff teacher, the mentor and lead teachers and the evaluator. During discussion, Section II is reviewed but the focus of the call is on helping the center complete Sections III and IV after the call is complete (see Figures 6 and 7). (Not all centers have elected to participate in this conference call, completing the form on their own.) An agreed upon completion deadline is then set. Once the center completed the form a short summary of teacher survey responses (from their center) is emailed to them.

In addition to serving the evaluation needs that have been described, we hope that this information will be 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 hope that this process offers a summary of broader impacts of the program for centers to use for other purposes.

As mentioned, we plan on linking 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 Participant: Teacher Survey (2019 and 2020)

Based on enrollment numbers (as recorded for each year), 311 teachers participated in QuarkNet during 2019; and, 251 teachers participated during 2020 (representing a unique count for each program year).

The response rate for the 2019 Teacher Survey was 78% (based on a total of 242 surveys from teachers who participated in the 2019-2020 program year -- 242 out of 311). An additional 78 teachers (who participated in QuarkNet in 2018-2019 *but not* in 2019-2020) were contacted via email and asked to participate in the survey. A total of 22 of these teachers completed the survey for a response rate of 28%. Thus, a total of 264 teachers responded to the survey.

In the program year 2020, a total of 91 teachers completed the full survey and 90 teachers completed the shorter update survey; from a total of 251 participants. This represents a response rate of 72%. 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 was the administration of the survey -- face-to-face -- during 2019 workshops and programs. And even in a virtual environment in 2020, teachers were encouraged to complete the survey at the time of the workshop. The credit for this high response rate is due to QuarkNet staff's and facilitators' commitment to the survey and we are thankful for it.

Table 17
Full Teacher Survey: Gender of QuarkNet Teachers

	Program: Unique Count		
Gender	2019	*(new in)* 2020	Total
Men	161 (61%)	41 (45%)	202 (57%)
Women	103 (39%)	50 (55%)	153 (43%)
Total	264 (100%)	91 (100%)	355 (100%)

$\chi^2_{(1,\ 355)} = 7.00$, $p < .01$ (comparing gender across program years) Please note that this represents a unique count of teachers. The 91 teachers for 2020 do not represent the total number of teachers who participated in QuarkNet for the 2020 program (251 total) or who responded to the surveys in 2020 (total 181).

Raw Data

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

Data were reviewed, cleaned, and as necessary new variables were created to facilitate data analysis. These data manipulations are described in the analysis sections of this report, as needed. When a teacher self-identified and completed both surveys (full and update) 2019 and 2020 survey responses were linked so that year-to-year comparisons for these teachers could be made.

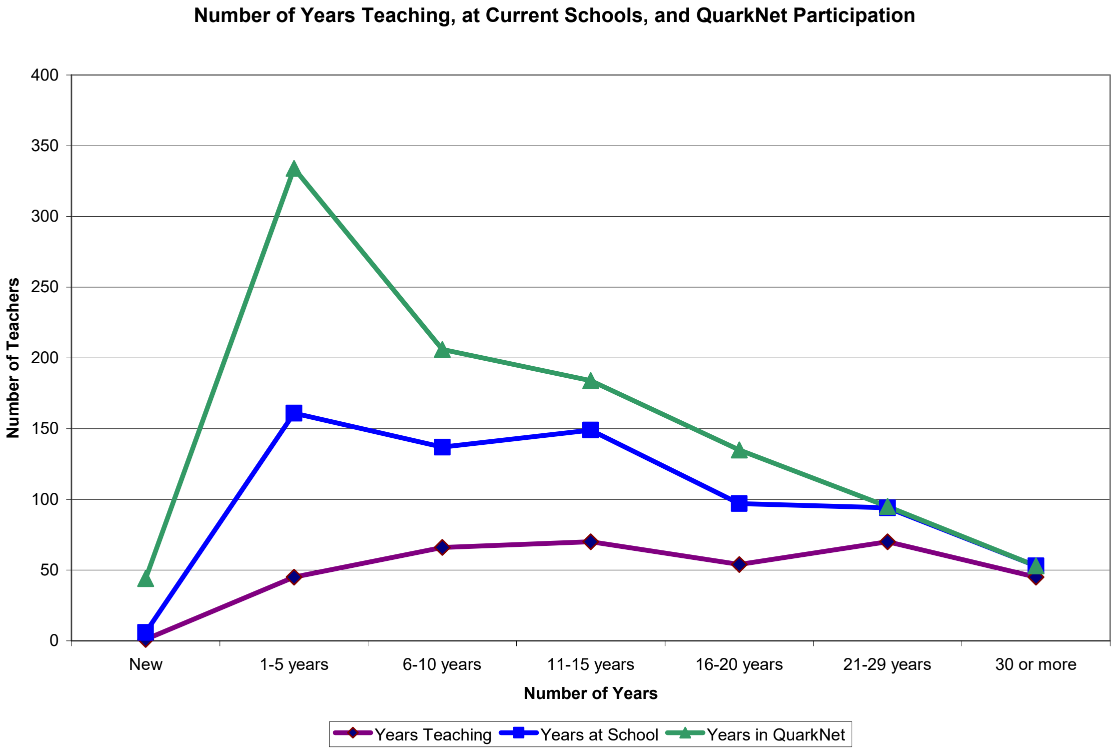
Survey responses labeled as 2020 reflect *new* teachers who did not participate in QuarkNet in 2019 (although they may likely not be new to the QuarkNet program). Thus these totals reflect a unique count of participating teachers; which at this point in time is 355 teachers. (Please keep in mind that 90 responses from teachers in 2020 were intended to be matched with their 2019 responses. Thus, these teachers are counted only once to arrive at this unique count.) Analyzes are broken down by program year when statistically significant differences were found or when programmatically relevant (these comparisons are based on the teachers who are marked as *new*).

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

Demographics

As already noted, a combined 355 teachers participated in the Full Teacher Survey; of these 202 are men and 153 are women (see Table 17).

There were no statistically significant differences by program year regarding teacher experience, number of years at the current school and participation in QuarkNet; thus these responses are combined. Teaching experience, number of years at their current



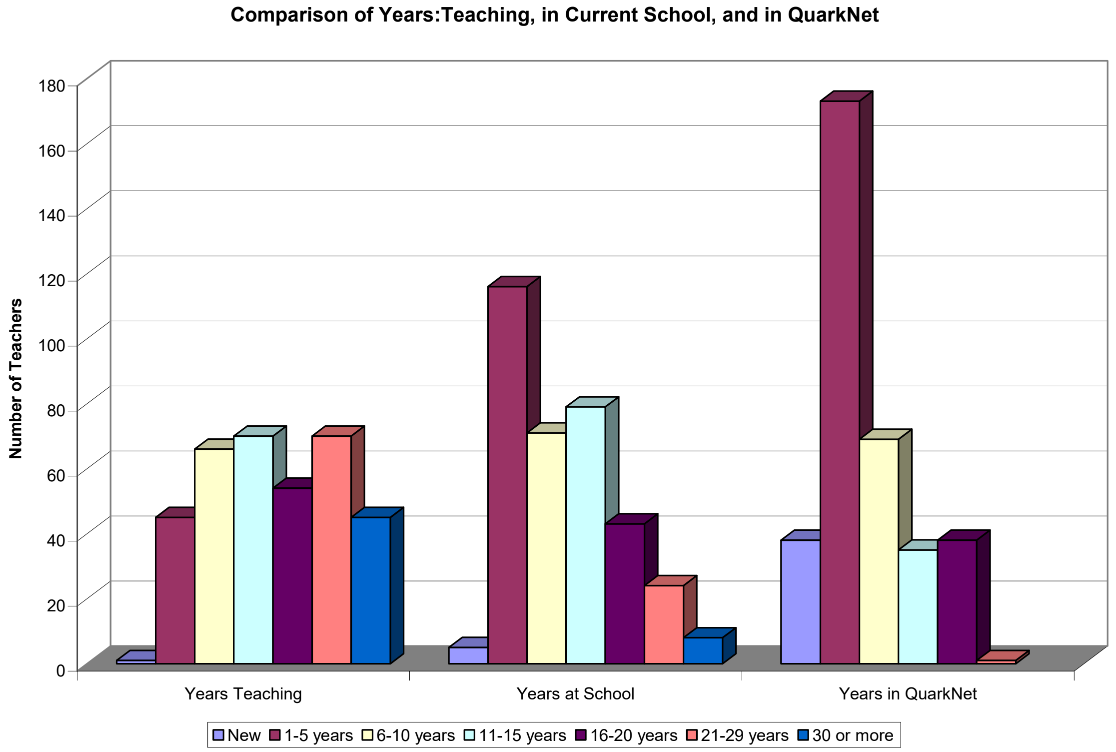


Figure Set 8. Comparison of the number of years: Teaching; at current School; and participating in QuarkNet.

Table 18
Description of School Location and Teaching Physics

	Number	Percent
Best Describe Location of School		
Rural	70	20
Suburban	170	48
Urban	67	19
Urban, Central City	42	12
Not Specified	7	1
Total	356	100
Teaching Physics?		
Yes	296	83
No*	56	16
Not Specified	4	1
Total	356	100

*Responses were explained as for example: Taught in the past; will teach soon by not this year; general science; physic tutor.

school and participation in QuarkNet remain well correlated. The correlation between years teaching and years at current school was high (r = .63); as well as years teaching and QuarkNet experience (r = .50); and, years at current school and QuarkNet experience (r = .53). The number of years that teachers participated in QuarkNet ranged from 0 (his/her first time) up to 21 years.

Shown in Figure Set 8 (on previous page), many participants were new to QuarkNet or had participated in the program for just a few years; however, the number of long-term participants is noteworthy as well that is, -- the mean number of years was 6.20 years, with a median of 4 years (50th percentile). Collectively, these teachers had a mean number of years teaching of 17 years (median 15 years); and, a mean of 10 years at his/her school (8.0 median years); with a few teachers who are retired.

There were noted statistically significant differences in this profile; however, when responses from male and female teachers were compared (no statistically significant differences were noted based on program year so data were collapsed for these analyses). Regarding number of years participating in QuarkNet, the mean number of years was 6.82 (Standard Deviation, SD = 5.89) for male teachers versus 5.36 (SD = 5.53) for female teachers [$t_{(351)} = 2.37$, $p < .02$]. The same held true for the reported number of years teaching; the mean number of years was 18.24 (SD = 10.78) for male teachers versus 15.29 (SD = 9.39) for female teachers [$t_{(348)} = 2.69$, $p < .01$]. And, this difference was statistically significant for number of years at their current school, a mean number of years was 11.09 (SD=8.02) for male teachers versus 8.65 (SD = 7.42) for female teachers [$t_{(348)} = 2.69$, $p < .01$].

As shown in Table 18, most often participating teachers represented schools in suburban areas (170 or 48%); followed by rural (70 or 20%) and urban locations (67 or 19%). The

Table 19
Which Workshop or Program?

Workshop/Program	Num. Teachers	Workshop/Program	Num. Teachers
Data Camp	146	Cosmic Ray e-Lab Ad.	32
ATLAS	33	Neutrino Data Workshop	79
CMS Data Workshop	87	ATLAS Masterclass	46
CMS e-Lab Workshop	71	CMS Masterclass	101
Cosmic Ray e-Lab Intro	154	Neutrino Masterclass	36

Note. Multiple responses were allowed.

type of "best descriptor" for location of school was not related to whether the teacher is male or female.

Most participating teachers indicated that he or she is teaching physics (296 or 83%). There was a statistical association by gender, however, as to whether or not a teacher taught (is teaching) physics based on program year. That is, for the 2019 program year slightly more female teachers reported that they were *not* teaching physics; and, slightly more male teachers reported that they were teaching physics [$\chi^2_{(1, 261)} = 6.13$, $p < .02$]. In the 2020 program year, this gender difference was not detected (that is, not statistically significant).

QuarkNet Participation

Teachers were asked to select the QuarkNet workshops or programs where they were participants. These responses are summarized in Table 19. (Multiple responses were allowed.) Most common, teachers indicated that they had participated in a Cosmic Ray e-Lab introduction (43%). A total of 146 (or 41%) of the teachers indicated that they had participated in Data Camp. Teachers also mentioned the CERN Summer Program (46); World Wide Data Day (17); International Cosmic Day (28); and International Muon Week (352).

These responses and answers to the following question Of *these which do you think have been most helpful to you in your teaching Physics?* will be explored in more detail later in the evaluation especially relative to use of activities from the Data Activities Portfolio in the classroom; when implementation plans are reviewed; and when center-level outcomes are analyzed in more detail.

Overview of Analyses: Teacher (and their Students) Outcomes

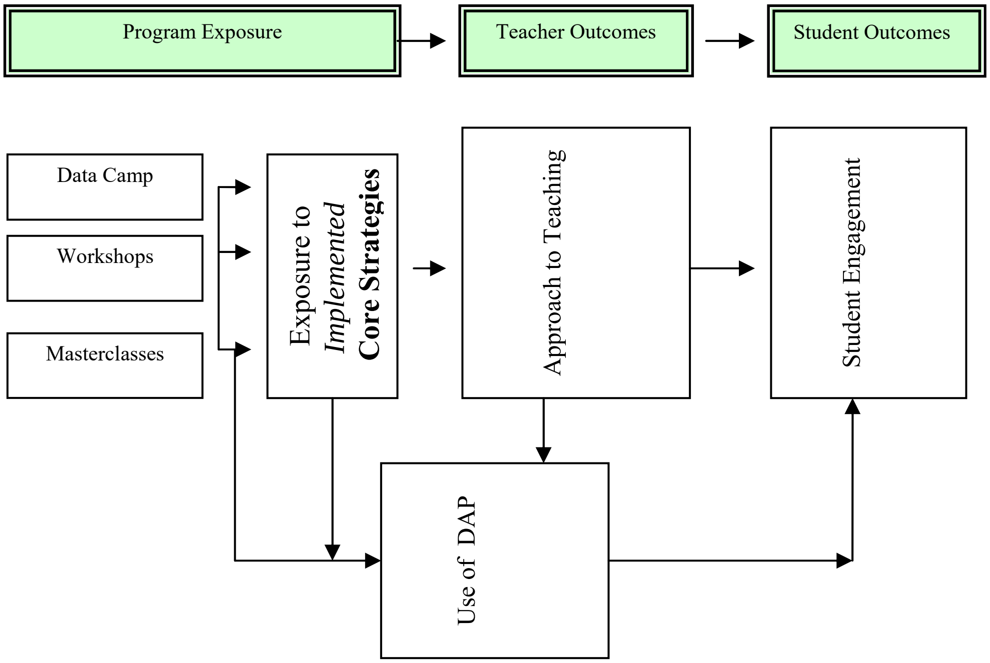


Figure 9. Teacher (and their Students) Outcomes: Overview of Analyses

To begin analyses related to outcomes, we explore the relationship between engagement in QuarkNet and exposure to core program strategies; and, subsequently the potential impact this involvement may have on teacher outcomes and student engagement outcomes. At this point in time, we have analyzed responses from the 2019 and 2020 Full Teacher Survey and we have begun a preliminary look at responses from the 2020 Update Teacher Survey. In the future, we will add new data into the mix from additional program years.

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 a model 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 9 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 analyzes and to use data with measured reliability (internal consistency) several scale scores were created (which will be explained shortly). (Statistical support and preliminary results relative to the reliability of these scale scores are shown in Appendix K.)

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; and, exposure to core strategies and expected outcomes as described below. We reserve judgment as to the best model to use at this time because these analyses are preliminary. Clarity on model selection is expected to increase as additional data are added into the mix. In the future, we hope to incorporate information on center-level engagement in QuarkNet into these models to provide a context to better understand the relationship between this engagement and subsequent outcomes. We also plan, in more detail, to analyze center-level engagement in its own right.

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

The following scale scores were developed in support of these analyses: Core Strategies; Approach to Teaching; QuarkNet's Influence on Teaching; Student Engagement; and, QuarkNet's Influence on Student Engagement. All are based on teacher self-reported responses to the Teacher Full Survey.

To get a better sense of the content of these scales, we list the individual survey items that are included in each of these scale scores as shown in Table 20. In all cases, the responses to a given item set 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 is shown in Table 21.

Exposure to QuarkNet Core Program Strategies Related to Type of Engagement and Use of DAP Activities

Using **Core Strategies** scores (as the dependent variable), we ask three initial questions, *Does perceived exposure to QuarkNet core program strategies differ for participating teachers, who:*

1. Did or did not participate in Data Camp?
2. Engaged in a variety of workshops (e.g., CMS Workshop, ATLAS Workshop, Neutrino Workshop)?
3. Did or did not participate in a Masterclass?

And, a fourth question (where use of DAP activities is the dependent variable),

4. Is perceived exposure to QuarkNet core program strategies related to reported use of activities from the Data Activity Portfolio in the classroom?

Table 20
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 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.*	**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 20 (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.

[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.

Table 21
Building Scales for Analysis of Program Engagement and Outcomes
(Higher the Score, the more Positive the Assessment)

Scale	What's Measured	# of Items	N	Mean	Standard Deviation	Cronbach's Alpha[a]
Core Strategies	Teachers' perceived exposure to program core strategies articulated in PTM	12	341	54.26	7.04	0.88
Approach to Teaching	Perceived assessment of QN teacher outcomes	12	329	43.02	8.45	0.90
QN's Influence on Teaching	Perceived assessment of how QN has influenced teaching practices and content	12	303	48.10	9.60	0.95
Student Engagement (SE)	Teachers' perceptions of student engagement in their classroom	5	321	18.69	3.52	0.83
QN's Influence on SE	How QN has influenced this student engagement	5	284	20.01	3.70	0.89

[a]Measure of reliability (internal consistency). (Factor analyses suggest one factor solutions for each.) This summary is based on 2019-2020 Teacher Survey responses.
Note. The smaller mean value for student engagement (SE) and QN"s Influence on SE is due to the smaller number of items that comprise this scale.

These data are summarized in Table 22 (and include responses from the 2019 and 2020 Teacher Full Survey). (As there were no statistically significant differences based on program year, responses by program year were collapsed for these analyses.) As can be seen, participating teachers reported higher scores on the Core Strategies scale based on degree of program engagement. This is evident for teachers who participated in Data Camp (as compared to teachers who did not); for teachers who engaged in a variety of workshops (the more varied the higher the score, on average); and, for those teachers who participated in one or more Masterclasses (compared to teachers who did not). It is important to note that these analyses are conducted, not to pit a type of QuarkNet engagement against each other but rather, to explore whether a Core Strategies measure supports a common sense idea that more engagement in the QuarkNet program (*as implemented*) is related to a higher likelihood of exposure to program strategies (as perceived by teachers); strategies deemed core to the program as identified by the PTM. Further, these analyses are not intended to imply causality but do suggest that program engagement and measurement of Core Strategies are related in a meaningful way and speaks to the fidelity of the *implemented* program as compared to the program as *designed* as perceived by participating teachers.

Finally and important as well, those teachers who used activities from the Data Activities Portfolio (DAP) tended to report higher Core Strategies scores than those teachers who have not used these instructional materials in their classrooms (although the R^2 value was modest, estimated at 0.14).

Table 22
Perceived Exposure to QuarkNet **Core Program Strategies** Compared to
Type and Variety of Program Engagement and Use of Data Activities Portfolio

Comparison	N	Mean	SD[a]	Analysis Results
Data Camp				
Yes	142	55.41	5.17	$t_{(330.10)}{}^{b} = 2.75, p < .01$
No	195	53.42	8.06	
Variety of Workshops[c]				
No workshops	115	52.57	8.81	$F_{(2,\ 334)} = 7.33, p < .001$
One workshop[c]	100	54.56	6.04	
Two or more[c]	122	55.79	5.42	
Masterclasses				
None	200	53.32	7.73	$t_{(334.43)}{}^{b} = 3.16, p < .01$
One or More	137	55.63	5.67	
Used DAP Activities				
Yes	173	56.38	4.69	$\chi^2_{(1,\,336)} = 28.39, p <.001$ [d]
No	163	51.98	8.37	

[a] Standard deviation

[b] Equal variance not assumed; independent t-test.

[c] This variable refers to the variety of workshops not the total number of events.

[d] Based on a binary, logistic regression analysis.

Program Outcomes: Approach to Teaching and QuarkNet's Perceived Influence

Using **Approach to Teaching** scores (as the dependent variable), we again ask the same questions; the first three are, *Do Approach to Teaching scores differ for participating teachers, who:*

1. Did or did not participate in Data Camp?
2. Engaged in a variety of workshops (e.g., CMS Workshop, ATLAS Workshop, Neutrino Workshop)?
3. Did or did not participate in a Masterclass?

And, a fourth question (where use of DAP activities is the dependent variable),

4. Are Approach to Teaching scores related to reported use of activities from the Data Activity Portfolio in the classroom?

These data are summarized in Table 23. (Again, as there were no statistically significant differences based on program year, responses by program year were collapsed for these analyses.) As can be seen, participating teachers reported higher scores on the **Approach**

Table 23

Approach to Teaching Outcome Related to

Type and Variety of Program Engagement and Use of Data Activities Portfolio

Comparison	N	Mean	SD[a]	Analysis Results
Data Camp				
Yes	140	44.84	7.78	$t_{(325)} = 3.39, p < .001$
No	187	41.68	8.74	
Variety of Workshops[b]				
No workshops	112	41.36	8.42	$F_{(2,\ 324)} = 7.99, p < .001$
One workshop[b]	97	42.03	9.14	
Two or more[b]	118	45.45	7.63	
Masterclasses				
None	193	41.69	8.49	$t_{(325)} = 3.49, p < .001$
One or More	134	44.96	8.10	
Used DAP Activities				
Yes	167	45.79	7.53	$\chi^2_{(2, 244)} = 41.52, p <.001$ [c]
No	157	39.99	8.39	

[a] Standard deviation

[b] This variable refers to the variety of workshops not the total number of events.

[c] Based on binary, logistic regression analysis.

to Teaching scale based on type of program engagement. This is evident for teachers who participated in Data Camp (as compared to teachers who did not); for teachers who engaged in a variety of workshops (the more varied the workshop experience, the higher the score, on average); and, for those teachers who participated in one or more Masterclasses (compared to teachers who did not). Approach-to-Teaching scores were also related to use of activities in the Data Activities Portfolio.

Although single-variable analyses are helpful; for example, in suggesting that these measures are “behaving” in expected and meaningful ways, more variables need to be added into the mix. And with this, more complicated analyses are warranted and may be more illustrative of these relationships.

Before describing these models, it is important to note that there were no statistically significant differences based on teacher’s gender for type of QuarkNet engagement (Data Camp, Variety of Workshop or Masterclass participation); and there were no differences by gender based on Core Strategies, Approach to Teaching, and QuarkNet’s Influence on Teaching. (This was also the case for Student Engagement scores, and QuarkNet’s Influence on Student Engagement scores.)

Table 24
Approach to Teaching: Summary Statistics and Related Variables
Model Summary[a]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Final	.598[b]	.358	.351	6.69

Coefficients[b]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	16.193	3.61		4.679	<.001
QN's Influence on Teaching	.355	.041	.468	8.588	<.001
Used DAP	2.133	.840	.128	2.540	<.001
Core Strategies	.170	.072	.130	2.369	<.02

[a] Predictors: (Constant), QuarkNet Influence on Teaching, Used DAP, Core Strategies
[b] Dependent Variable: Approach to Teaching

How is QuarkNet Engagement Related to Approach to Teaching?

In a combined analysis -- Engagement in: Data Camp, Variety of Workshops, Masterclasses; and, perceived exposure to Core Strategies, perceived QuarkNet's Influence on Teaching, and Use of Activities in the Data Activities Portfolio – were investigated simultaneously in a stepwise, multiple regression analysis with Approach to Teaching as the dependent variable. This analysis suggests that perceived QuarkNet's Influence (entered first); Used DAP activities (added second); and exposure to Core Strategies (added third) are related to **Approach to Teaching scores** [$F_{(3,\ 293)} = 53.93$, $p < .001$, with an $R^2 = .35$]. The summary statistics from this analysis are shown in Table 24. Additional variables did not improve the model (that is, were not statistically significant).

So, What's Related to ***Used DAP*** *Activities in the Classroom?*

To understand what's related to **Used DAP** activities in the classroom, a binary logistic regression analysis was conducted with Used DAP as the dependent variable and the following variables seen as "predictors," these are: perceived exposure to Core Strategies; Approach to Teaching; QuarkNet's Influence on Teaching; and engagement in Data Camp; Variety of Workshops; Masterclasses; and Program Year. Based on this analysis, all variables were statistically related to **Used DAP** except QuarkNet's Influence and Program Year. Participation in Data Camp was added first, followed by Core Strategies and Approach to Teaching, followed by workshop and masterclass engagement [$\chi^2_{(6,\,294)} = 111.3$, $p <.001$, estimated $R^2 = .423$].

To summarize, Used DAP activities was shown to be related to exposure to Core Strategies, Approach to Teaching, and all of the types of QuarkNet program events (Data Camp, Variety of Workshops, and Masterclass engagement). Approach to Teaching was shown to be related to *perceived* QuarkNet's Influence on Teaching, Use of DAP activities and reported exposure to Core Strategies.

At this stage of preliminary analyses, we have not pursued an exploration of which among these models are the best or the most parsimonious. However, these preliminary analyses suggest that Used DAP activities can serve as an indicator (predictor) or surrogate measure to represent type of QuarkNet engagement. And, the Core Strategies measure can be used as an indicator (predictor) in subsequent analyses to represent the degree of program "dosage," that is the fidelity of the implemented program in subsequent analyses to help us understand the relationship between the QuarkNet program and the outcome of Approach to Teaching.

To help test the stability of this model, we selected teachers from the 15 Centers who completed the Feedback Process (which will be described shortly). This roughly represented half of the teachers who responded to the Teacher Full Survey. Comparing the results from this split-half approach suggested that the findings shown in Table 24 were very stable (there were slight variations in parameter estimates which are not shown) with a consistent solution of QuarkNet Influence on Teaching, Used DAP activities and Core Strategies serving as indicators (predictors) of the Approach to Teaching outcome.

The weight of these analyses (thus far) suggests that there is a positive relationship between engagement in QuarkNet and exposure to core program strategies; and, that the type and degree of program engagement is related to teacher outcomes (Approach to Teaching) and, also of importance, the use of activities from the Data Activities Portfolio in the classroom.

Student Engagement

How is QuarkNet related to Perceived Student Engagement?

Based on what we have learned from the Approach to Teaching outcome analysis, the following variables were placed in a stepwise, multiple regression analysis: Used DAP Activities (as a surrogate measure for type of QuarkNet engagement: Data Camp, Variety of Workshops, and Masterclasses), Core Strategies, Approach to Teaching, QuarkNet's Influence on Student Engagement, and QuarkNet's Influence on explore the relationship to **Student Engagement** (dependent measure). The following emerged as statistically related: Approach to Teaching (entered first), QuarkNet's Influence on Student Engagement (as perceived by teachers), QuarkNet's Influence on Teaching (as perceived by teachers); and Used DAP Activities [$F_{(4,\ 273)} = 52.67$, $p < .001$, with an $R^2 = .43$]. Additional variables did not improve this model. (See Table 25 for the summary statistics of this analysis.)

Table 25
Student Engagement: Summary Statistics and Related Variables

Model Summary[a]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Final	.663	.439	.431	2.5909

[a]Predictors: (Constant), Approach to Teaching, QuarkNet's Influence on Student Engagement, QuarkNet's Influence on Teaching, Used DAP

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	7.081	.913		7.757	<.001
Approach to Teaching	.216	.025	.506	8.767	<.001
QuarkNet's Influence on Student Engagement	.250	.039	.380	6.390	<.001
QuarkNet's Influence on Teaching	-.060	.021	.192	2.843	<.01
Use of DAP Activities	.720	.338	.103	2.127	<.04

[a]Dependent Variable: Student Engagement

However, this model proved to be less consistent when we tested its stability based on the split-half process we just described (that is, selected teachers from the 15 Centers who completed the Feedback Process). In this analysis, only Approach to Teaching and QuarkNet's Influence on Student Engagement emerged as statistically related to Student Engagement (R^2 = .46). Thus, these results should be interpreted cautiously. We hope that this model will stabilize as the evaluation moves forward. That said, at a minimum, Student Engagement is statistically related to Approach to Teaching and QuarkNet's Influence on Student Engagement (as perceived by teachers) but we hold these results in reserve.

Incorporating QuarkNet Experiences in the Classroom (Early Results from the Update: Teacher Survey)

The Update: Teacher Survey was introduced during the 2020 program year (as already described). Its focus is on exploring implementation of QuarkNet content and materials in the classroom, specifically how teachers have used (or will use) content from a QuarkNet experience(s); and, use (or planned use) of DAP activities in their classrooms.

To link implementation to program exposure, we have matched Update Surveys with the responses form the 2019 Teacher Full Survey. This match was accomplished for 69 teachers (out of 91 responses when a teacher self-identified on both surveys). This number is expected to climb over the next several program years as we gather more evaluation data. Thus, the following presents a very early look at how teachers have described what this classroom implementation looks like.

Regarding QuarkNet content, we asked the following open-ended question:

> *Briefly describe how you intend to incorporate (or have incorporated) your QuarkNet experiences into your classroom (e.g., Cosmic Ray, LHC, neutrinos, e-labs; masterclasses) when teaching, for example, conservation, uncertainty, the standard model or something else.*

And to gather information about the use of DAP activities, we asked this question:

> *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.)*

Perceived teacher-level outcomes were measured again by repeating questions 27 and 29 from the Teacher Full Survey (Approach to Teaching scores); and perceived student-level outcomes were re-measured by repeating question 32 from the Teacher Full Survey (Student Engagement scores).

Who are these Teachers?

A number of analyses were conducted to get a sense of who these teachers are as a group in this sample. These teachers tended to be very frequent participants in QuarkNet, more likely to have participated in Data Camp [$\chi^2_{(2,\ 338)} = 10.07$, $p <.01$]; more likely to have participated in a variety of workshops [$\chi^2_{(4,\ 338)} = 18.50$, $p <.001$]; more likely to have participated in a masterclass [$\chi^2_{(2,\ 338)} = 7.28$, $p <.03$]; and more likely to report using DAP activities in their classrooms [$\chi^2_{(2,\ 333)} = 14.30$ $p <.001$].

Incorporating QuarkNet Content and Experiences in the Classroom

As just indicated, teachers were asked an open-ended question in the Update: Teacher Survey to describe how (and if) they have implemented QuarkNet content and materials into their classroom. We have summarized the responses to this open-ended question in Table 26. The responses in this table, in some cases lightly edited, reflect teachers' thoughts on implementation (or plans to implement) in their classroom.

As is evident, many teachers reported "how," or "why" they have implemented QuarkNet content and materials. Because teachers often listed multiple implementation opportunities, it was challenging to organize these responses into general themes or categories, since this would require determining which implementation was most important or repeating the same response in more than one category. However, as the number of teachers responding to this follow-up survey increases and as we add into the mix centers that have completed the Center Feedback Template, we anticipate that we will be able to include these reported implementation efforts within the context of the QuarkNet center. In this way, we should be able to parse these responses in many ways and organize these by common themes. We hope this context will help us better understand the relationship between program engagement and teacher- and center-level outcomes.

Use of DAP Activities in the Classroom

In addition, for this sample of teachers, we looked at how teachers responded to the "use of DAP activities" question asked in 2019 and then again in 2020 by putting these responses into yes/no categories. These responses are summarized in Table 27. In this sample, most teachers reported using DAP activities, (a total of 48 out of 69 teachers). Of these, 46 teachers reported having used DAP activities in 2019 and reported their use (or planned use) again in 2020. A total of 21 teachers indicated in 2019 that they had not used DAP activities; in 2020, 12 of these teachers indicated that they had used (or planned to use) DAP activities in 2020. Based on a chi-square analysis, these responses were statistically related. That is, teachers who reported using DAP activities in 2019 were more likely to report using these in 2020. And, of importance more than expected teachers who reported not using DAP activities in 2019 -- reported using (or planning to use) these activities in 2020 [$\chi^2_{(1,\ 69)} = 16.32$, $p < .001$].

Figure 10 shows which DAP activities were mentioned as used in 2019 classrooms and those activities that were used (or planned to be used) in 2020. The following activities were among the most frequently mentioned: *Rolling with Rutherford; Quark Workbench; Mass of U.S. Pennies; Calculate Z Mass;* and, *Dice, Histograms & Probability.*

Teacher-level Outcomes and Student-level Outcomes

For this same sample of teachers, we compared **Approach to Teaching** scores based on their 2019 responses and their 2020 responses. These teachers, on average, reported higher Approach to Teaching scores in 2020 compared to 2019 and this increase was statistically significant [2019 mean = 45.45, SD= 7.39; vs. 2020 mean = 47.55, SD = 7.67; $t_{(65)} = 2.47$, $p < .02$].

As to **Student Engagement** scores there was not a statistically significant difference for 2019 responses and 2020 responses [2019 mean = 19.81, SD= 2.90; vs. 2020 mean = 20.14, SD = 2.88, *ns*].

Table 26
Responses to How QuarkNet Content has (or will be) Used in the Classroom

Introduction content - Use Rolling with Rutherford. Planning to use Careers in Physics and Changing the Culture this coming year as well. At the end of an intro kinematics/constant velocity unit, I do a Cosmic Ray Speed experiment with my students. Near end of momentum conservation, we do the Top Quark activity to showcase conservation and 2D vectors. I'm planning to use Making it ‘Round the Bend during the magnetism unit.
I use the Cosmic Ray muon lifetime lab using the detectors in my classroom; attend masterclasses, several data activities including dice, quark puzzle, Rolling with Rutherford, top quark, z-mass. After experiences in particular this summer I plan to begin incorporating more Jupyter Notebooks into my curriculum to give students experience using programming languages to analyze large data sets.
I've already incorporated the Cosmic Ray and e-lab activities as well as Masterclasses, and will add in what I've learned and developed from Data Camp. These included lessons on CERN, conservation laws, and kinematics as well as Special Relativity and statistics.
I've used CRMD for learning, also for Science Fair and Illinois Junior Science and Humanities Symposium presentations. I have had students participate in International Physics Masterclass; I have had QuarkNet personnel visit my classroom in person and virtually to help with Masterclass: one of the mentors, Antonio Delgado, did a virtual visit with Hispanic students at a school with 47% Hispanic students to discuss his career with them in Spanish. Because of my QuarkNet connection, I have been able to take students to Fermilab's Open House to do activities with younger children and then stayed a day for a tour.
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 bench to introduce 10th graders to quarks as part of atomic structure. Use Rolling with Rutherford to introduce students to indirect measurement.
I have used them for ideas for demos, and based some labs on these (half life and momentum labs, and cosmic ray demos).
I’ve already incorporated the Cosmic Ray and e-lab activities as well as Masterclasses, and will add in what I’ve learned and developed from Data Camp. These included lessons on CERN, conservation aws, and kinematics as well as Special Relativity and statistics.
My Physics II class will be collecting data with the Classroom Cosmic Ray Detector and uploading the data. They may also be doing an e-lab or analyzing some LHC data.
I incorporated QuarkNet-related exercises in my Advanced Physics Topics and brought students in that class and my Honors Physics course to Particle Physics Masterclasses.
This year we worked on Juypter Notebooks. I will use this as springboard to introduce Python in the engineering course I teach. Additionally, I created an activity that can be done in the classroom or assigned virtual based on forces and a large data set from NASA.
I plan on using some of the great ideas for coding implementation from the other teacher participants.
I intend to use coding in the Jupyter notebooks for both my engineering classes as well as my physics classes as a way to deal with large data sets as well as some basic coding skills.
Teaching freshman biology how to use Python to make simple graphs.
I plan to use PhyPhot with my physics students.
Analyzing J/Psi data with students.
Unit on programming or particle physics unit.
Activities for my AP Physics and Honors Physics classes. Discussions about the standard model!
I use the activities to assist lower level ability students in graphing, data analysis and other low level written work.
Use CMS & Cosmic Ray e-Labs, Masterclass, W2D2, Data Activities Portfolio, and neutrinos extensively in Particle Physics Research Hybrid course. Use these resources to a small degree in AP Physics 1 and Advanced Physical Science.

Table 26 (con’t.)
Responses to How QuarkNet Content has (or will be) Used in the Classroom

I have used many of the "beginning level" activities like the Quark Workbench and Mass of U. S. Pennies to start my physics year with an intro to particle physics as well as histograms. I also used Making it ‘Round the Bend to teach centripetal force with AP physics. They enjoyed it! This year, in Data Camp, I have been learning to incorporate Python coding into my physics classes. I think this will be a fantastic addition especially with the new challenges brought on by this year. Programming seems like a good way to do data analysis while still being engaging in a world where we are limited in our typical hands-on approach.
Data activities, CMRD detector, Cosmic Ray e-lab, use in Physics and Chemistry classes, as well as club extracurricular, informal settings.
Using a CRMD in my classroom to do research, We have used the data on the Cosmic Ray site to do research without our detector. I do Quark Workbench, Rolling with Rutherford, and Top Quark Mass. I plan to do the case of the missing neutrino this year and the MINERvA activity.
I used the Cosmic Ray detector as an extension two years ago and have implemented Rolling with Rutherford and ideas of collecting whole-class data, histogram use, and sprinkling Standard Model facts throughout the other Regents topics.
I have had a group of students work with my cosmic ray detector. I have also taken those students to do a masterclass. I have done the Rolling with Rutherford activity with my students and use the particle cards each year. I would like to try to do at least part of the cloud chamber lab this year and may try to incorporate the conservation of momentum activity.
I plan to use the cosmic ray and first lab in my class.
AP Physics 1- conservation of momentum 2D, Electricity/circuits AP Physics 2 - standard model and atomic physics, Elect./Magnetism Engineering -scintillators, Geiger tubes, circuits.
I will be implementing Rolling with Rutherford and the Standard Model activity in my classes, as well as the Case of the Hidden Neutrino.
Google Science Journal for labs and science fair. Rolling with Rutherford virtual simulator is very convenient. Great way to do the activity if you are pressed for time or going virtual.
I will use several QuarkNet e-labs for distant learning during the COVID pandemic. Modeling conservation of energy and momentum, demonstrating principles of physics and the development of mathematical equations from experiment.
I have used some of the e-Labs and data from the LHC in my particle physics unit in my high school physics class.
Using the e-lab the deal with conservation momentum and vector analysis; along with using the Cosmic Ray detector with students to analyze data and have then choose what they want to explore.
This year, we did more online learning because of the circumstances related to the pandemic. Having content that can be used virtually, like the QuarkNet e-labs, will be super useful.
I will be using Z Mass, Top Quark, Rolling with Rutherford, Standard Model, and Quark Workbench as part of the curriculum.
Conservation of Momentum, Vector Addition

Table 26 (con't.)
Responses to How QuarkNet Content has (or will be) Used in the Classroom

I began by incorporating individual lessons into my regular and advanced physics classes (data activities mainly). I also have had student interest in a "particle physics group" in which students met on their own once a month after school in my room. These students have participated in masterclasses and done some work with the cosmic ray detector I am able to have in my room. I have also had the opportunity to bring multiple groups to the University of Minnesota to participate in masterclass sessions during their spring break. Finally currently have been able to develop a course called "Introduction to Particle Physics" this spring and it was a hit! A student told me that he and some others were talking wondering "Are we just going to be doing the same activities (top quark, etc) that we've already done?" and then they realized it was so much more. Thanks to all the work done by QuarkNet staff, I was able to present them with a tremendous number of activities and ideas to whet their appetite and encourage further study. The breadth and depth of what they could learn was amazing.
I teach the conservation laws as part of the required state curriculum. I give my students a Standard Model lecture during the 4th quarter each year and I have them explore the Particle Adventure online. I assign individual projects during the 4th quarter and CERN: LHC and CMS is one of the topics. Students then share what they learned by giving a presentation to their class. I have also done a lesson on gravitational waves and LIGO. In the future I would like to include neutrinos and cosmic rays by using the e-labs. It all really depends upon the time available once I have taught the required course work.
Vectors, conservation, energy, atomic models…
Conservation laws, the standard model.
I will use Time of Flight from the Cosmic Ray Lab for kinematics. I use an introduction to the Standard Model with mass and the scientific method.
I will continue to use many QuarkNet resources.
Modify SequimScience.com
I'd like to use the Calculate the Top Quark Mass particle activity to show applications of vectors and vector addition
I plan to teach a unit on particle physics using activities from the Data Activities Portfolio and the cosmic ray detector in my classroom.
I am going to consider new physics principles, such as pulsars and microwave telescopes.
E-labs especially for remote students.
1. Use of the materials in classroom is great. The sub-particle puzzle to start modern physics. 2. Masterclass involvement and implementation. 3. Standard model discussions.
I plan to use the idea of probability in radioactive decay. I am going to implement the Muon detector more in the class curriculum.
I want to use the muon decay lesson with histogram analysis to help students understand error analysis.
Big ideas in Physics – include various QuarkNet activities to review of conversation laws, measurement probability (and others) at the beginning of the year.
The overall plan is to use the Mass of U.S. Pennies to show small quantities before talking about atoms and subatomic particles. Understanding histograms is the other point I need to make with students.
Shown the Fermi Lab introduction video and pictures of my summer workshop at Fermi lab. The students love that. Also have used some of the experiments in class.

Table 26 (con’t.)
Responses to How QuarkNet Content has (or will be) Used in the Classroom

In the 2019-2020 school year, I had a student work independently on CRMD research. This student graduated, but I have another student scheduled to do an independent study during the 2020-2021 school year. I used the Rolling with Rutherford activity in AP boot camp in summer 2019. I attended the masterclass teacher orientation in spring 2019 and was planning to bring a group to masterclass but was unable to make that work due to changes with Covid-19. For this fall, I plan to add some histogram activities (dice rolling, Rolling with Rutherford) to a measurement unit at the beginning of the year with a discussion about modern physics and classical physic to the general physics class. I also plan to incorporate some of the Step Up diversity activities at the beginning of the year.
QuarkNet materials were implemented into my General Physics classes in two areas: 1) study of forces, and 2) applications of Conservation of Energy/Momentum. The LHC was the primary tool that was introduced to students. Unfortunately, shelter-in-place prevented me from revisiting particle physics at the end of the year.
We look at cosmic rays and do a study from e-lab, we talk about detectors and use information from QN, we go to Masterclass and Fermilab, and we do activities like Rolling With Rutherford to talk about indirect measurements.
I am planning on using the STEP UP information on careers and diversity in the classroom. I am going to have students use the cosmic ray detector for gathering data and analysis.
I try to sprinkle in as many activities as I can in my various classes. I also lead the Particle Physics Club at our school. I do plan on adding the Careers in Physics activity this year as well as trying to implement some of the Women in Physics activities.
I use many QuarkNet activities already in my classroom. I will certainly use the Step Up activities this coming year.
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.
I have done Masterclasses (2 different ones) after school for interested students, had an Advanced Research class student work with me over the summer doing QN research at Notre Dame, done a STEP UP program during class, and totally used a bunch of lab ideas like Rolling for Rutherford.
Will use the programming from today.
I use QuarkNet resources in class whenever I can. Our class has a "Physics Fun Friday" every few weeks, in which we explore a topic in modern physics. I often use QuarkNet data activities for these lessons, including Rolling with Rutherford, the Quark puzzle, and the particle card deck. We used Cosmic Ray e-labs a couple times, and I've participated in Masterclass every year for the last couple years. I frequently refer to particle physics examples when discussing conservation laws. The students used the top quark mass activity to practice vector decomposition.
I'm not going to have enough time this year to cover all the topics that I usually do so I'm going to take that as an opportunity to try more of the activities in the QuarkNet experience.
I will incorporate materials periodically through the year when time permits.
I mostly use these tools in my school club Theoretical Physics Club. Students present topics and activities on different subjects each week.
In my middle school "Super Science" elective class, I did use several of the introductory particle physics lessons from summer 2019. Mostly introduction to the standard model, how particle physics is done, DUNE, Rutherford experiment, and more. With my 2020 summer work, I expect to integrate the Colab Python notebooks within other content areas. I'll use data sets to explore the periodic table, simple Python coding, analyzing CO2 data sets, and hopefully more.
(As a retired teacher), I am a private tutor in physics. I do incorporate ideas which I glean form the workshop. With one on one interaction with each student, I find this helps.
I would like to support and assist teachers during the school year.
While I am not teaching in 2020-2021 school year, I’ll be back after 1 year. I did the masterclass with some students and used the Making it ‘Round the Bend Data Portfolio Activities. Some students joined in the QuarkNet Wednesday Webinars and we loved it.

Table 27
Reported Use of DAP Activities by QuarkNet Teachers in their Classrooms

Reported Use of DAP Activities in 2019	Reported Use of DAP Activities in 2020		
	Yes	No	Total
Yes	46	2	48
No	12	9	21
Total	58	11	69

[$\chi^2_{(1,\ 69)} = 16.32$, $p < .001$]

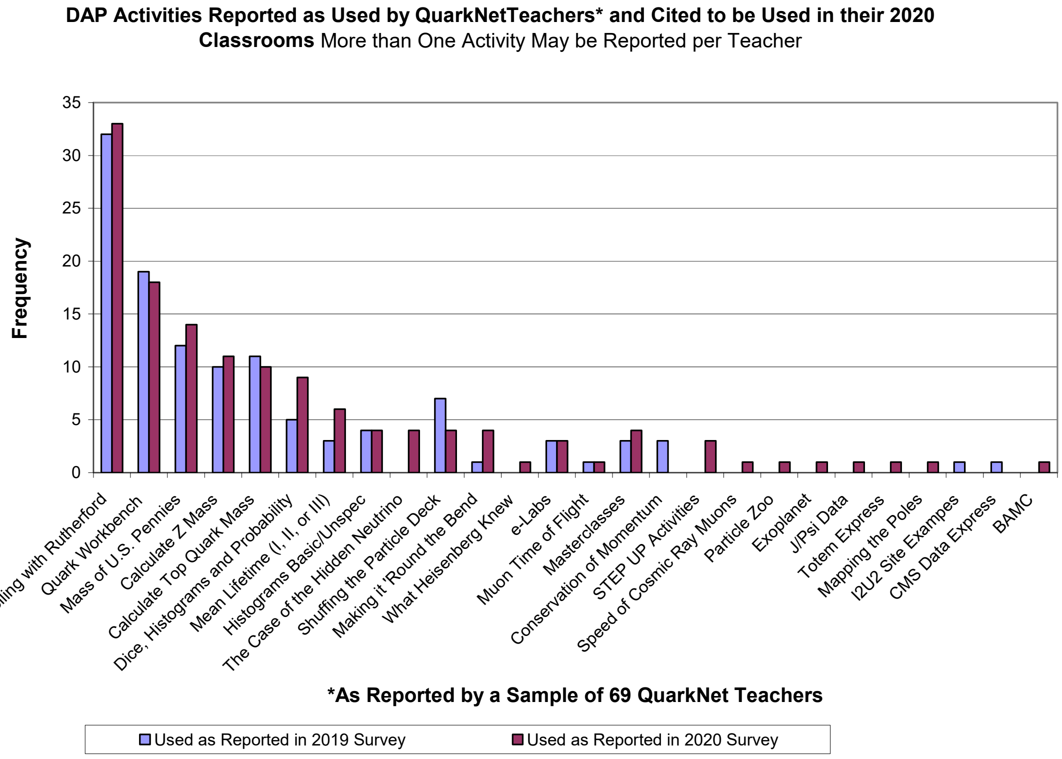


Figure 10. Frequency of reported use of DAP activities in the classrooms.

Table 28
QuarkNet Centers with Completed Feedback Templates

Center	Completion Date	Center	Completion Date
Pilot Test		**Added in December 2020/January 2021**	
Catholic University	December 7, 2020	Florida State University	January 24, 2021
Fermilab/University of Chicago	February 17, 2020	Southern Methodist University	January 24, 2021
Rice University/ University of Houston	March 31, 2020	Virginia Tech University	February 15, 2021
Colorado State University	July 21, 2020	Vanderbilt University	February 23, 2021
Added in Spring 2020		University of Iowa/Iowa State	February 15, 2021
University of Cincinnati	April 6, 2020	**Added in Spring 2021**	
Boston Area/Brown University	May 19, 2020	Syracuse University	May 25, 2021
University of Kansas	May 21, 2020	Black Hills State University	In Progress
Virginia Center	May 21, 2020	University of Puerto Rico- Mayaguez	June 10, 2021
Kansas State University	June 24, 2020	Virtual Center	April 22, 2021
University of Minnesota	June 29, 2020	University of Wisconsin - Madison	Semi-active will revisit

Implementing the Center Feedback Template an Early Look: Informing These and Other Analyses

As we have mentioned, the involvement of Center-level engagement in QuarkNet, as measured through the Center Feedback Template, has been added to the mix of the individual-teacher analyses to provide the context in which teachers participate in QuarkNet. Through this center-level nesting, we hope to offer a more complete picture of the relationships between program engagement and teacher (and their students) program outcomes. And, we will use this information to gauge center-level outcomes in their own right.

We began obtaining feedback from participating QuarkNet centers with a pilot test of the process starting in November 2019 for four centers; six additional centers were rolled out in Spring 2020; and five centers were added in December 2020/January 2021. All 15 centers have completed this process (see Table 28). An additional four centers have completed this template (or are in the process); these centers will be added into future analyses.

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 a 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 nationally or center-led), e-labs, and/or masterclasses. As we move through this process, it is likely that selected centers will reflect 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). Overall, we see this process as helping the evaluation and through this process offering information that we hope is helpful to QuarkNet staff teachers and to the centers themselves.

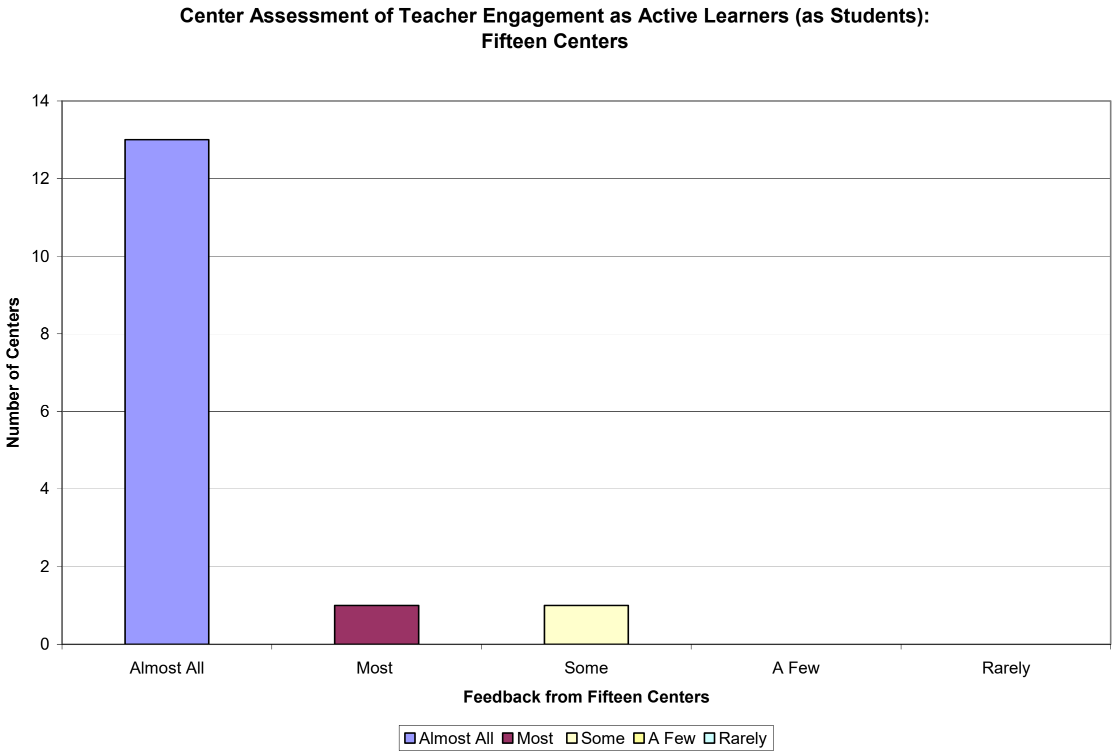
As already noted, these centers were selected based on conversations with staff teachers and the evaluator. For each of these centers, Section II was completed by the evaluator (and reviewed by the Staff Teachers) before it was distributed. One lesson gleaned from this process is that Section II offers a succinct summary of programs and events at a particular center (an easy reference of two years of agenda and annual reports). Early feedback from centers suggests that pre-filling Section II is a helpful and staff teachers have noted that it is of value as well.

Results: Center-Level Outcomes

As the number of centers who participate and complete their Center Feedback Template increases, we will conduct more complicated analyses. At this early stage, we have explored descriptive analyses to give a sense of how center-level outcomes and teacher-level outcomes will be compared in the future.

To begin, Figure Set 11 presents responses to the question about the opportunity for QuarkNet teachers to engage as active learners (as students). The first graph, in this set, shows the responses from the 15 centers who participated in the Center Feedback Template process so far. As indicated, 13 out of the 15 centers indicated that *"Almost All"* of their teachers were engaged as active learners (as students) during the workshops held at their center. This same question was asked of individual teachers, that is, the degree to which QuarkNet provided them with an opportunity to engage as an active learner (as a student). These responses are shown in the second graph of this set. As shown, most teachers rated the opportunity to engage as active learners, as students as "*Excellent"* for participating teachers from these centers (who completed the Feedback Process); for teachers from other centers (who have not completed the Feedback Process as year); and for all teachers who responded to the Teacher Survey. This figure set supports the program strategy of engaging participating as active participants (as active learners) in *implemented* workshops as gauged by individual teachers and the sample of 15 centers.

In Figure Set 12, we look at the degree to which QuarkNet activities and engagement in workshops expose participating teachers to NGSS practices at the program level. This is



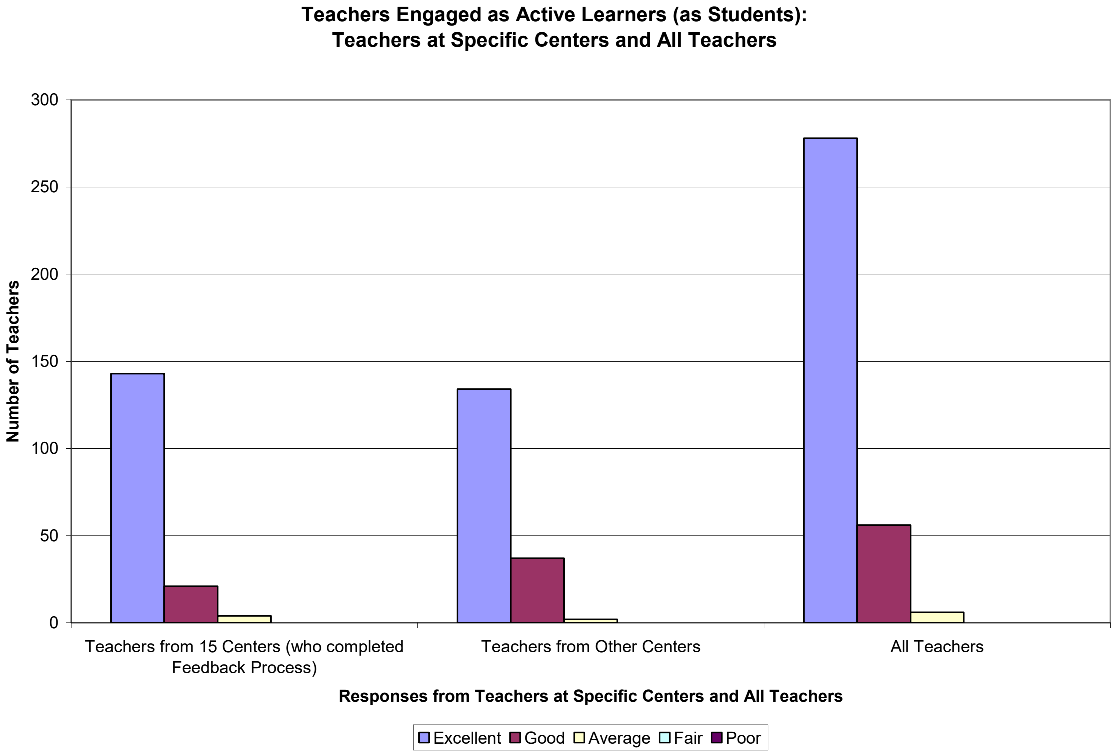
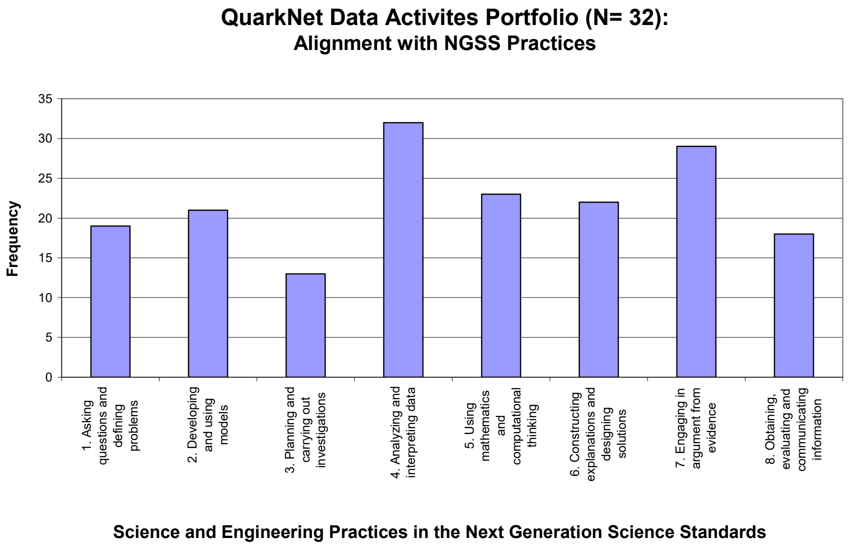
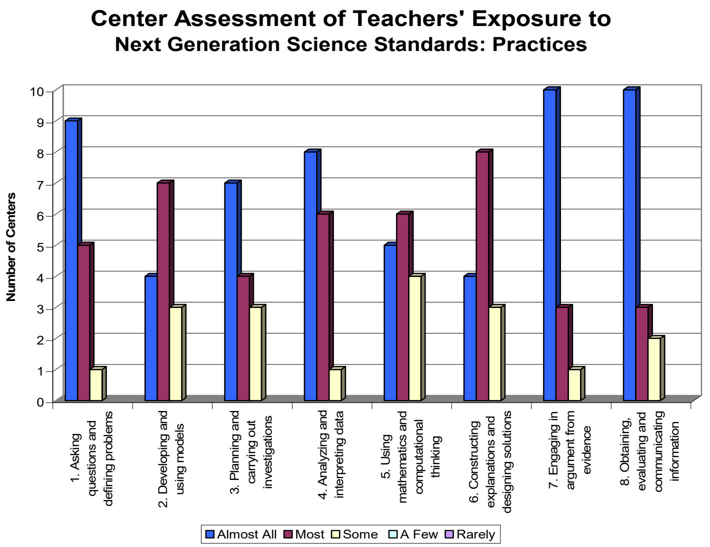


Figure Set 11. Centers' Assessment of Teachers Engagement as Active Learners compared to teacher perspectives of this opportunity.





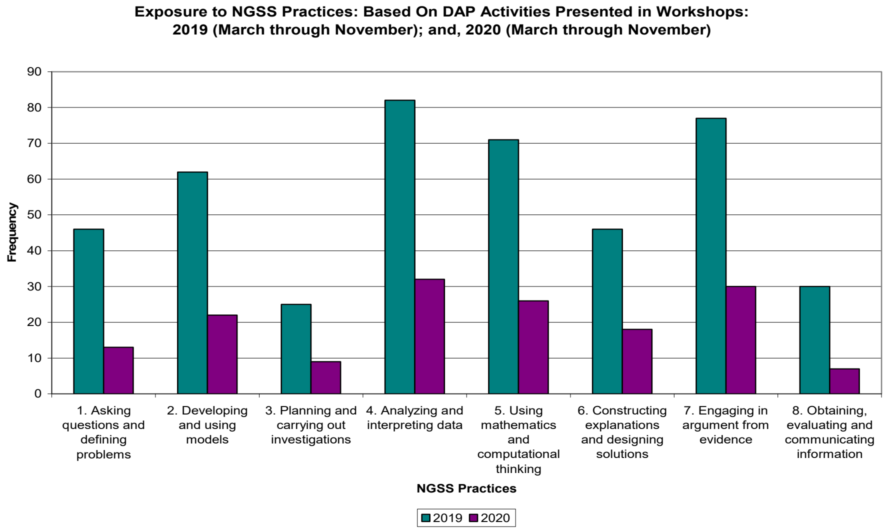


Figure Set 12. Alignment of Next Generation Science Standards (NSS) practices and activities from the Data Activities Portfolio as *designed;* and, as *implemented* based on center-level assessment of individual teacher engagement; and, based on *implemented* 2019 and 2020 QuarkNet workshops.

assessed by activities from the Data Activities Portfolio *as designed* and then for the *implemented* program. The graph in the upper right-hand corner (a graph that was presented earlier in this report) is the teachers' exposure to NGSS practices as *designed* based on the activities in total. The remaining two graphs show the exposure of teachers to NGSS practices based on the *implemented* program. In the upper right hand corner, the perceived engagement in NGSS practices by teachers based on center-level assessment of their *implemented* program is shown. This graph suggests these centers judge the individual-teacher engagement at the center to align well with these NGSS practices, with "*Most*" or *Almost All*" teachers engaged in scientific endeavors that align with these practices. (For this center-level graph, teacher engagement in scientific endeavors is based on two years of workshops at these centers, engagement in DAP activities as well as other endeavors that are part of QuarkNet workshops and programs.)

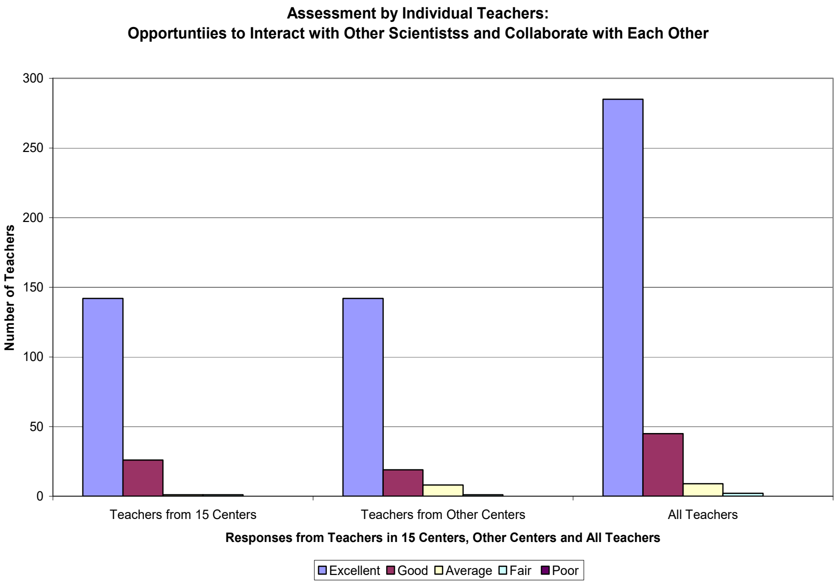
The graph in the bottom of this figure set shows the exposure to NGSS practices based on *implemented* QuarkNet workshops held during the 2019 and 2020 program years (based on review of workshop agendas). Together, these three graphs suggest that at the overall program level, participating QuarkNet teachers are engaged in scientific endeavors that align with NGSS practices *as designed and as implemented*, especially analyzing and interpreting data (practice 4); use mathematics and computational thinking (practice 5); engaging in argument from evidence (practice 7); and obtaining, evaluating and communicating information (practice 8).

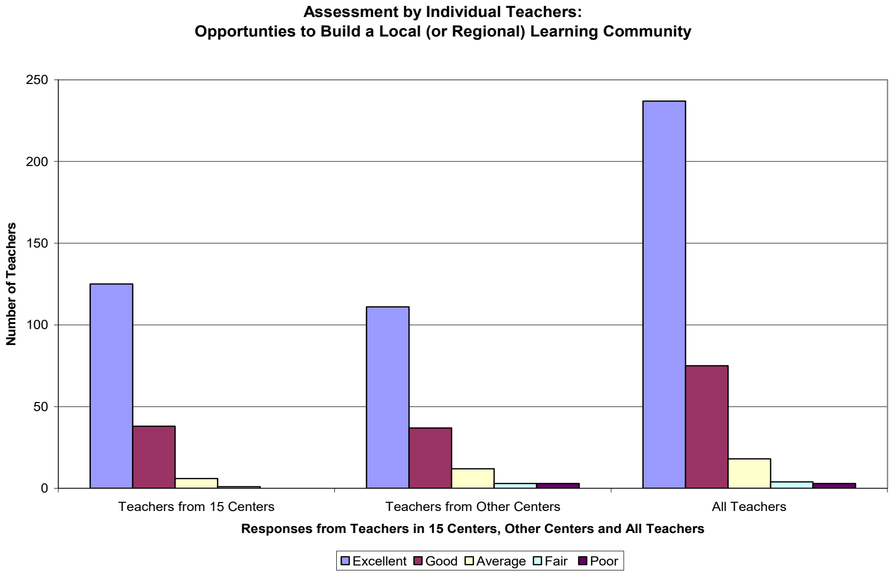
Building Networks and Forming Lasting Collegial Relationships

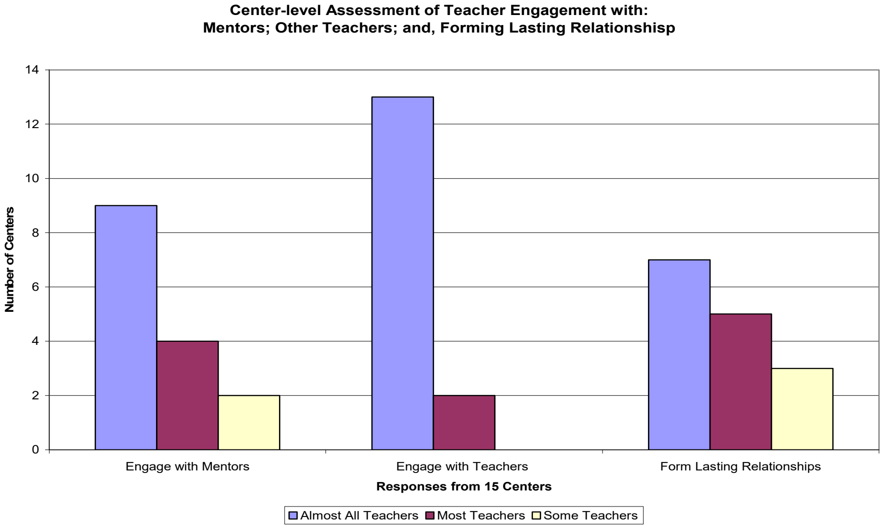
Individual teachers were asked to indicate QuarkNet opportunities for teachers and mentors to: (a) interact with other scientists and collaborate with each other; and (b) build a local (or regional) learning community. Both of these questions were based on an "Excellent" to "Poor" rating scale.

In a similar fashion, centers – as part of the Center Feedback Template process – were asked to assess (based on a scale from "Almost All" Teachers to "Rarely") who among their center-level teachers: (a) engage/interact with mentors and other scientists; (b) engage/interact with other teachers; and, (c) teachers and mentors form lasting collegial relationships through interactions and collaborations at the local level and through engagement in the national program. (As a reminder, there are 15 QuarkNet Centers, so far, where such data are available.)

These responses are shown in Figure Set 12. Together these graphs suggest good agreement based on individual-teacher assessment as to the opportunity to engage with others and center-level assessment of teacher participation in this engagement. That is, the graph in the upper left-hand corner suggests that individual teachers most often rated the opportunity to interact with other scientists and collaborate with each other as *Excellent*; this was also the case as to the opportunity to build lasting collegial relationships (graph in the upper right-hand corner). This pattern of responses was similar when teachers from these 15 centers were separated out; from teachers from other centers; and, when teacher responses were combined for all who responded to the


Assessment by Individual Teachers:
Opportuntiies to Interact with Other Scientistss and Collaborate with Each Other
Number of Teachers
300
250
200
150
100
50
0
Teachers from 15 Centers
Teachers from Other Centers
All Teachers
Responses from Teachers in 15 Centers, Other Centers and All Teachers
Excellent
Good
Average
Fair
Poor


Assessment by Individual Teachers:
Opportunities to Build a Local (or Regional) Learning Community
Number of Teachers
250
200
150
100
50
0
Teachers from 15 Centers
Teachers from Other Centers
All Teachers
Responses from Teachers in 15 Centers, Other Centers and All Teachers
Excellent
Good
Average
Fair
Poor


Center-level Assessment of Teacher Engagement with:
Mentors; Other Teachers; and, Forming Lasting Relationshisp
Number of Centers
14
12
10
8
6
4
2
0
Engage with Mentors
Engage with Teachers
Form Lasting Relationships
Responses from 15 Centers
Almost All Teachers
Most Teachers
Some Teachers

Teacher Surveys. Center-level assessment support these conclusions (the graph on the bottom center) relative to the perceived number of teachers engaged with mentors, engaged with teachers and others; and forming a lasting collegial relationship.

Long-term Implications of Program Options because of COVID Program Modifications

It is important to note that nearly all of the 2020 workshops and masterclasses, with few exceptions, were conducted in a virtual environment – and all occurred during a turbulent time of considerable uncertainty as to the severity and longevity of the COVID-19 pandemic. Major modifications to the QuarkNet implemented programs during the 2020 program year have already been noted. These changes have many implications for long-term benefits or options for the program.

With direct feedback from members of the QuarkNet development team (Cecire, Wood, Roudebush, & Bardeen), the following is proffered:

1. Teachers may now have an increased comfort level with virtual environments; with this, centers have the option of meeting more frequently during the program year. For example, remote sessions during the school year can support in-person workshops held during the summer or at other times. And, centers might opt to hold their program remotely even when in-person events are possible, bringing in teachers that are more distal to the center's location.

2. Virtual workshops open up possibilities for centers to work collaboratively; for example, teachers could attend virtual workshops and physics talks held at other centers and explore topics that cut across centers.

3. Staff members can implement the following remote learning sessions beyond the immediate COVID need (if interest by teachers persists): (a) Coding Camp, which is being pilot-tested as a Coding Workshop held remotely (in program year 2021); (b) BAMC (Big Analysis of Muons in CMS) which offers a masterclass experience with simplified analyses while working remotely; and. (c) shorter half-day workshops (over a few days) conducted virtually. And, given their original design, Cosmic and CMS e-labs can be offered in person or remotely.

4. The QuarkNet STEP UP workshops were modified to support virtual presentation; these can be implemented remotely in future program years.

5. More than half of the DAP activities can be adapted for implementation in remote classrooms (see Table 29). These modifications enable teachers to use these activities not only in remote classrooms but also outside the classroom as homework assignments or in informal settings such as physics club meetings.

Table 29
QuarkNet DAP Activities for Use in Remote, Online Teaching

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.

Additional on-line opportunities such as: QuarkNet Weekly Webinars (QW2); Summer Session for Teachers (SST); QuarkNet Educational Discussions (QED); and QuarkNet collected resources for teaching physics (https://quarknet.org/ content/resources-teaching-physics-online) may be implemented or used in the future.

With all this said, the value of in-person workshops, masterclasses and e-labs cannot be overstated. Striking a balance in the future may be key. Although we have noted that more exposure to remote learning as evident during the 2020 program year may have increased teachers' comfort level with this option, it is also possible that this could lead to considerable burn-out to engage in remote environments once in-person events become an option. Further, an important outcome of QuarkNet is to form and build long-lasting collegial relationships between teachers, mentors and other scientists; an outcome that fundamentally may require face-to-face engagement. As one member of the development team noted, "For all we gained in opening up new pathways, we also lost valuable personal interaction with and between our teachers and mentors" (Cecire, email May 6, 2021). And, onsite tours at laboratories and research institutions offer teachers the rare opportunity to observe world-renowned physicists conducting research in real time.

Preliminary Summary and Recommendations

As has been stated, 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).

This report is a prototype of the final evaluation report of this program to be submitted at the end of this award period; as such, it presents a draft of the final evaluation report (although as an interim report it is final). In serving as a prototype, the present report and its review demonstrate the shift in evaluation efforts from formative (and summative) assessment to an outcomes-based evaluation. One intent of this early look is that it has provided opportunities for QuarkNet program staff members to better understand this shift. And, it has offered opportunities for staff to identify principal needs and concerns that the evaluation may be able to be responsive to; and to give the evaluator time to adjust to these needs and suggestions proposed by staff to help aid in the usefulness of evaluation findings and recommendations.

The evaluation focused on the following, the: (1) Develop (and use) a Program Theory Model (PTM); (2) Assess program outcomes at the national and center levels through teacher-level outcomes; and, (3) Assess the sustainability of program centers, based on center-level and sustainability outcomes.

The fully-articulated PTM is complete. The process used to create the PTM has been described in this report and the model has been described in detail. Ideally, a program theory model offers a cohesive and representative picture of the program, "an approximate fit" of the program as *designed*. We have sought consensus on the representativeness of this model with key stakeholders and will revisit the PTM over the course of the award period, as this is needed.

To a large extent the PTM elaborates on how change is expected to occur, based on the 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).

We have used the PTM to direct the development of evaluation measures and methods designed to address the remaining two goals. A Teacher Survey (full) and a Center Feedback template have been designed to measure the teacher-level and center-level outcomes articulated in the PTM, respectively. Each of these has been developed, the first administration of the Teacher Survey coincided with the start of summer workshops that occurred in 2019; and the roll-out of the Center Feedback template began in September 2019. To coincide with the 2020-2021 program year, we have added an Update: Teacher Survey to continue to capture information from participating teachers and to focus on classroom implementation of QuarkNet content and instructional materials.

Based on 2019/2020 survey efforts, 355 teachers have completed the full Teacher Survey (this represents a unique count). A total of 90 teachers completed the Update Survey with 69 of these responses matched with responses from the original full survey. Our approach to analysis has been to explore, preliminarily, teacher perspectives as to their exposure to core program strategies, perceived approach to teaching, student engagement, the potential influence QuarkNet has had on teachers' approach to teaching and student engagement (based on scale scores generated from like items on the full Teacher Survey); as well as self-reported use of activities from the Data Activity Portfolio. The Update Survey focuses on reported classroom implementation of these activities. These results are supplemented with information gathered from the QuarkNet Center Feedback process (15 Centers presently included in the analysis mix) to help provide the program content in which the teachers engage in the program and to assess center-level outcomes in their own right. We have focused on exploring consistent patterns in the data and to use multiple sources whenever possible (e.g., teacher responses, center responses, and information from workshop agendas and annual reports of active centers).

In preliminary analyses ….

Regarding **Core Strategies**, program engagement and exposure to core program strategies (as perceived by teachers) were shown to be related in a meaningful way. That is, more engagement by type of QuarkNet event was related to perceived higher exposure to core strategies; and more reported use of activities from the Data Activities Portfolio in the classroom. This speaks to the fidelity of the *implemented* program as compared to the program as *designed* as perceived by participating teachers; and, to the usefulness of this measure in subsequent outcomes analyses.

Regarding, **Approach to Teaching,** teaching outcomes were shown to be related to *perceived* QuarkNet's Influence on Teaching, Use of DAP activities in the classroom, and exposure to Core Strategies (based on results from multiple regression analyses). Of importance, Use of DAP activities and Core Strategies scores can serve as surrogate measures for degree of engagement in a variety of QuarkNet programs (e.g., Data Camp, Variety of Workshops, and Masterclass engagement) and degree of exposure to strategies seen as core to the program; this helps to simplify the model. A split-half analysis (based on teachers from 15 centers) suggests that this model is stable; and, thus Use of DAP activities and Core Strategies can be used as measures shown to be statistically related to teachers' Approach to Teaching. We continue to explore the use of center-level measures to help improve this model and to better understand the impact of offering teachers QuarkNet programs nested within partner-centers.

Regarding, **Student Engagement,** Approach to Teaching and QuarkNet's Influence on Student Engagement (at least) were shown to be related to perceived student engagement in inquiry-based science. This model, however, was less stable, based on a split-half analysis; thus, we continue to work to build a representative model of the impact of the program on student engagement as perceived by QuarkNet teachers.

Although preliminary, the weight of these analyses suggests that there is a positive relationship between engagement in QuarkNet (the type and degree of program engagement and use of activities from the Data Activity Portfolio); exposure to core program strategies; and perceived influence of QuarkNet on Teaching and teacher outcomes (Approach to Teaching). Regarding the engagement of their students in inquiry-based science (that aligns with the NGSS Science and Engineering practices), teachers' perceived Approach to Teaching and QuarkNet Influence on Student Engagement (at least) were shown to be related to Student Engagement. We continue to explore ways in which these statistical models can be improved including integrating center-level assessments into this process.

In assessment of the process of conducting center-level information through the Center Feedback Template, results from the pilot test and two additional rounds of outreach suggest that this process has been helpful for QuarkNet staff teachers, the centers themselves (mentors and lead teachers), and the evaluation (based on 15 centers to date). Using information from this process, along with information obtained from workshop agendas, and annual reports from active centers we have explored responses based on individual teacher perceptions and center-level assessments. In the main, there has been consistent agreement across information sources. For example, results from the teacher survey and feedback from centers suggest that teachers typically engage in activities as active learners. Similarly, both individual teachers and centers report opportunities for teachers to interact with other teachers, mentors and other scientists and to help foster collegial, long lasting, relationships. Moreover, activities from the Data Activities Portfolio, *as designed,* align well with the Next Generation Science Standards science practices, and *as implemented* through QuarkNet workshops (based on workshop agendas) and as evidenced by center-level assessment of these practices by participating teachers at their center.

Finally, responses from the Update Survey have provided a preliminary look on what (and how) activities from the Data Activity Portfolio are used (or planned to be used) by QuarkNet teachers in their classrooms. Although currently presented at the raw response level, we seek to integrate this information – either qualitatively or quantitatively – to help inform the outcomes analyses described in this report.

Program Summary and Recommendations

It is important to note that nearly all of the 2020 workshops and masterclasses, with few exceptions, were conducted in a virtual environment – and all occurred during a turbulent time of considerable uncertainty as to the severity and longevity of the COVID-19 pandemic. We have described how COVID-19 (coronavirus) has impacted the implementation of the 2020 QuarkNet program year; and how this has continued into the 2021 program year. Virtual workshops held in 2020 were reduced in scope focused on core concepts; and converted, for example, to half-day sessions with small-group breakout sessions, separate off-line time to work on specific tasks, and breaks built into the agenda. Programs in 2021 were held (or planned to be held) in in-person and/or virtual environments. With important input from QuarkNet staff, we have outlined the long-term possible implications of many of these program modifications.

The following program summary and recommendations are proffered:

1. 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 been invited to attend these weekly meetings, and she has regularly attended the staff-wide meeting. Of importance, these weekly meetings have been especially helpful in discussing and planning program content and delivery modifications as a result of coronavirus, COVID-19 during the 2020 and 2021 program years. The staff-wide meeting has provided 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. Continue to hold these meetings as feasible by everyone’s schedule as these are of value to both the program and the evaluation.
2. Starting in the 2019-2020 program year, 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. This is 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.
3. Documenting workshop agendas and center annual reports – and posting these on-line -- have been extremely helpful in gathering information useful to the evaluation. Specifically, the workshop agendas improved our ability to identify which (and how) activities from the Data Activities Portfolio (DAP) have been incorporated into workshops, especially nationally-led workshops and to a lesser extent but still notable for 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 *as designed* and *as implemented* comparisons; and in comparing individual teacher- and center-level response similarities/differences. For these reasons (plus benefits noted in 2) continue to encourage centers to use the agenda template options to create their own.
4. DAP activities, collectively, have been shown to align well with Next Generation Science Standards Science and Engineering Practices. QuarkNet staff has provided operational definitions to support how this alignment is determined and has also shown the alignment of these activities with Enduring Understandings of Particle

Physics. Of importance, these activities are a bridge for teachers to implement QuarkNet content and materials into their classrooms. As a result of COVID-needed modifications, many of these activities can now be implemented in on-line environments expanding implementation options for teachers. Continue 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 either in-person, on-line (or both).

5. Starting with the 2020-2021 program year, staff created a guide 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 its use in center-run workshops. Based on early results, this structured approach has helped teachers reflect on classroom plans in meaningful ways. This information along with responses gathered from the Update Teacher Survey is very valuable to the outcomes evaluation. Continue to support this effort.
6. The number (and the quality) of activities in the DAP has increased dramatically from 2017 (the end of the past grant period) to the new program-award period. 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 work-load for their development and eventual use. Consider adding a Project Coordinator position to QuarkNet staff in the future renewal funding. This person could help the education specialist with DAP activity development as well as have other responsibilities related to gathering and updating program-operations data such as helping to track participation related to registration, updating teacher profiles on the QuarkNet website; and subsequent stipend payment.
7. When feasible, 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 remote meetings via Zoom during the 2020 and 2021 program years may help centers move in this direction.
8. 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 program. The brief one-page summary of the PTM and preliminary evaluation results might help in this effort.
9. Kudos 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 planned to be continued in subsequent program years). Given that all QuarkNet centers are mature, staff realized that there was need to clarify the roles and responsibilities of lead teachers and to give these teachers a platform to exchange ideas on these possibilities.
10. Continue to support the evaluation and its efforts as reasonable; and continue to work with the evaluator, as planned, to help embed evaluation efforts and requirements within the structure and delivery of the program.

Evaluation Summary and Recommendations

The following evaluation summary and recommendations are proffered:

1. The response rates for the full Teacher Survey and the Update Survey remain high over the 2019 and 2020 program years (78% and 72%, respectively). 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.
2. Working with QuarkNet staff, the Update Teacher Survey dovetails well with the guidelines for teachers in the development of classroom implementation plans. As the number of teachers who complete the Update Teacher Survey grows, we anticipate using this information to help illuminate how and in what ways teachers have planned or have used QuarkNet program content and practices in their classrooms. And, to the degree possible we will link this implementation to the type and degree of engagement by teachers in QuarkNet, either qualitatively or quantitatively.
3. Continued efforts to distribute and collect center-level information through the Center Feedback Template suggest that this process has been helpful for QuarkNet staff, Center level mentors and lead teachers, and the evaluation. To date, we have information from 15 Centers that have been incorporated into analyses. Additional centers will be added into the mix and incorporated into future analyses.
4. Preliminary analyses from the Teacher Survey suggest that there is a meaningful link between exposure to program strategies and program engagement; and that this engagement along with use of activities from the Data Activities Portfolio and teachers' perceptions of QuarkNet's Influence on Teaching are related to teacher outcomes. Perceived student engagement was shown to be related to teachers' Approach to Teaching and QuarkNet's Influence on Student Engagement.
5. Data analyses suggest agreement between center-level perceptions and teacher-level perceptions. This is evident when looking at information about teachers experiencing activities as active learners (as students); and, exposure to opportunities to develop and maintain collegial relationships with other teachers, mentors and other scientists. We have also shown that activities from the Data Activities Portfolio, *as designed*, align well with the Next Generation Science Standards Engineering Practices and *as implemented* based on workshop agendas as well as the perceptions of participating teachers and feedback from QuarkNet centers.
6. Continue to incorporate center-level outcomes data (from the Center Feedback Template process), in analyses of teacher-level outcomes (and in particular the regression models). Add sustainability outcomes into the mix as the number of participating centers grows.
7. 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. The one-page summary of the PTM and evaluation results may help in this process.
8. Continue to be mindful of the many responsibilities that program staff, mentors and teachers have. 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.

9. Work to ferret out the benefits and challenges of implementing QuarkNet programs (workshops, masterclasses) in a virtual environment and work with QuarkNet staff to highlight positive long-term implications of this over time.
10. 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, participating teachers, NSF and others who may be interested in QuarkNet.

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Briefly 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

In sync with the start of the current award period, 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. Thus at this stage of the program, 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.

Accordingly, we drew on 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. And as discussed in the full narrative of the report, we have included a framework that adds program sustainability strategies and outcomes into the mix.

The narrative of the evaluation report describes in detail the three program anchors:

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

of the PTM and will not be repeated in this appendix.

Initial Interviews with Key Program Stakeholders

An important part of the information-gathering step in creating the PTM was the conduct of a structured interview 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 and the list of stakeholders and evaluators who participated in this interview process are shown 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. Moreover, 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.

Diversity – Women and Minorities: QuarkNet partners with other STEM organizations to reach more students underrepresented in STEM, either through their teachers or directly. Recent partners are *Step Up 4 Women,* an American Physical Society program to increase the representation of women amongst physics bachelor's degrees and *STEAM Workshop at NACA,* a program of the Native American Community Academy, Albuquerque, in which students create visual stories using projection art about ideas in Western science and indigenous culture. An example of being nimble to respond to opportunities is the *i.am. Angel Foundation,* transforming lives through education inspiration and thinking. Also, some centers partner with other organizations to reach beyond QuarkNet schools to students traditionally underrepresented in STEM.

Advisory Board: Seven or eight 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+.

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.

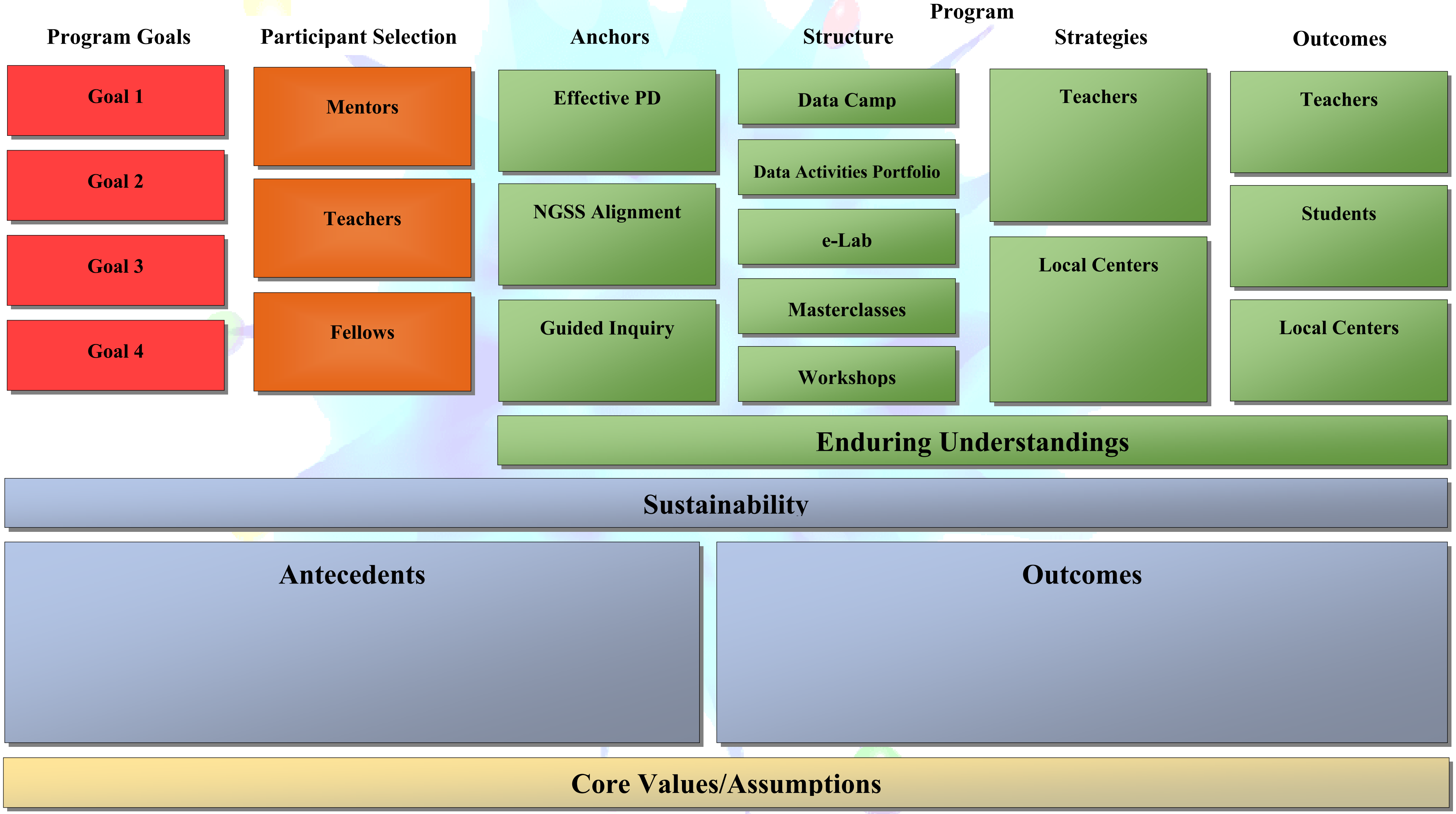
Broader Impacts and Community Outreach: QuarkNet efforts extend beyond the program. Often, centers integrate QuarkNet in other community outreach and broader impact efforts. QuarkNet has led in facilitating the public use of large particle physics databases. QuarkNet staff and teachers attend and present at meetings of the American Association of Physics Teachers and the American Physical Society. At International Particle Physics Outreach Group (IPPOG) meetings QuarkNet presentations have highlighted how QuarkNet works, e-Labs, the Data Activities Portfolio and scientific discovery for students. QuarkNet has developed and coordinated the CMS masterclass, led the global cosmic ray studies project, and provided a wealth of information for other IPPOG members to consider in their own education and outreach programs.

QuarkNet

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.



Program Goals

- Goal 1
- Goal 2
- Goal 3
- Goal 4

Participant Selection

- Mentors
- Teachers
- Fellows

Anchors

- Effective PD
- NGSS Alignment
- Guided Inquiry

Program Structure

- Data Camp
- Data Activities Portfolio
- e-Lab
- Masterclasses
- Workshops

Strategies

- Teachers
- Local Centers

Outcomes

- Teachers
- Students
- Local Centers

Enduring Understandings

Sustainability

Antecedents

Outcomes

Core Values/Assumptions

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.
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)

Program Structure

Data Camp: A 1-week program offered annually in the summer at Fermilab. It 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 the teachers are expected to engage as students as active learners of a challenging topic they may initially have known very little about. In the beginning of the week, teachers receive an authentic CMS dataset and work in small groups to analyze the dataset. Groups use these data 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 data. Then, teachers explore various instructional materials in the Data Activities Portfolio that offer them help in incorporating particle physics concepts into their everyday lessons and propose an implementation plan for their classrooms. Throughout the week, teachers take tours (e.g., LINAC tunnel, MINOS experiment) and participate in seminars held by theoretical and experimental physics.

Data Activities Portfolio: An online compendium of particle physics classroom instructional materials organized by data strand and expected level of student engagement. These materials are based on authentic experimental data used by teachers to give students an opportunity to learn how scientists make discoveries. Strands include LHC, CMS, Cosmic Ray Studies, and neutrino data. Activities increase in complexity, sophistication and expected student engagement from Levels 0 to 4. Curriculum topics provide guidance for teachers to develop a sequence of lessons or activities appropriate for their students. Draft instructional materials are reviewed 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 opportunity such that:
Level 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.
Level 1 – Students use the 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 the 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.
Level 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. The level and complexity of the Level 3 investigations is generally higher than in Level 2.
Level 4 – Students use the skills from Level 3. They identify datasets and develop code for computational analysis tools for the investigation of their own research plan.

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

Masterclass, U.S. Model: A one-day event in which students become "particle physicists for a day." Teachers and mentors participate in an orientation by QuarkNet staff or fellows. Teachers implement about 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 explain the measurements they will make using authentic particle physics data. Working in pairs, students are expected to analyze the data in visual event displays; to characterize the events; pool their data with peers; and draw conclusions, helped by one or more particle physicists and their teacher. 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 or CERN. Some masterclasses take place at school with teachers providing the particle physics and measurement information. U.S. Masterclasses are part of a larger program, International Masterclasses.

Workshops: The primary vehicle through which participating QuarkNet teachers receive professional development.

Center-run Workshop: A center's second year involves new associate teachers in a multi-week experience that focuses on a research scenario prepared by their mentor(s) with support from lead teacher(s). The mentor models research, similar to Data Camp, where teachers, as students and active learners, have an opportunity to engage in an experiment, receive and analyze data, and present results. Then teachers have time to create a plan to share their experiences with their students and often use instructional materials from the Data Activities Portfolio in this planning.

During a center's third year and after, lead teacher(s) and mentor(s) have flexibility to organize 4-to-5 day workshops to meet local needs and interests. These workshops vary in content and structure. Centers may meet only during the summer, only during the school year or both during the summer and school year. Some centers meet even more frequently depending upon interest and availability of teachers. These workshops may include a national workshop[3] and offer a learning-community environment with opportunities for teachers to interact with scientists, and learn and share ideas related to content and pedagogy.

[3] **National Workshop:** On request, QuarkNet staff and/or fellows conduct workshops held at local centers. These workshops typically occur during the summer and can vary in length from several days to a week period. Content includes, for example, cosmic ray studies, LHC or neutrino data, and related instructional materials from the Data Activities Portfolio. National workshops support opportunities for teachers to work in a learning-community environment, learn and share ideas related to content and pedagogy, and develop classroom implementation plans.

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.[4, 5] *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.

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[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.

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[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. 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 datasets.
6. Scientists form and refine research questions, experiments and models using observed patterns in large data sets.
7. The Standard Model[6] 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.
15. Scientists must account for uncertainty in measurements when reporting results.

Developed by Young, Roudebush, Smith & Wayne, 2019

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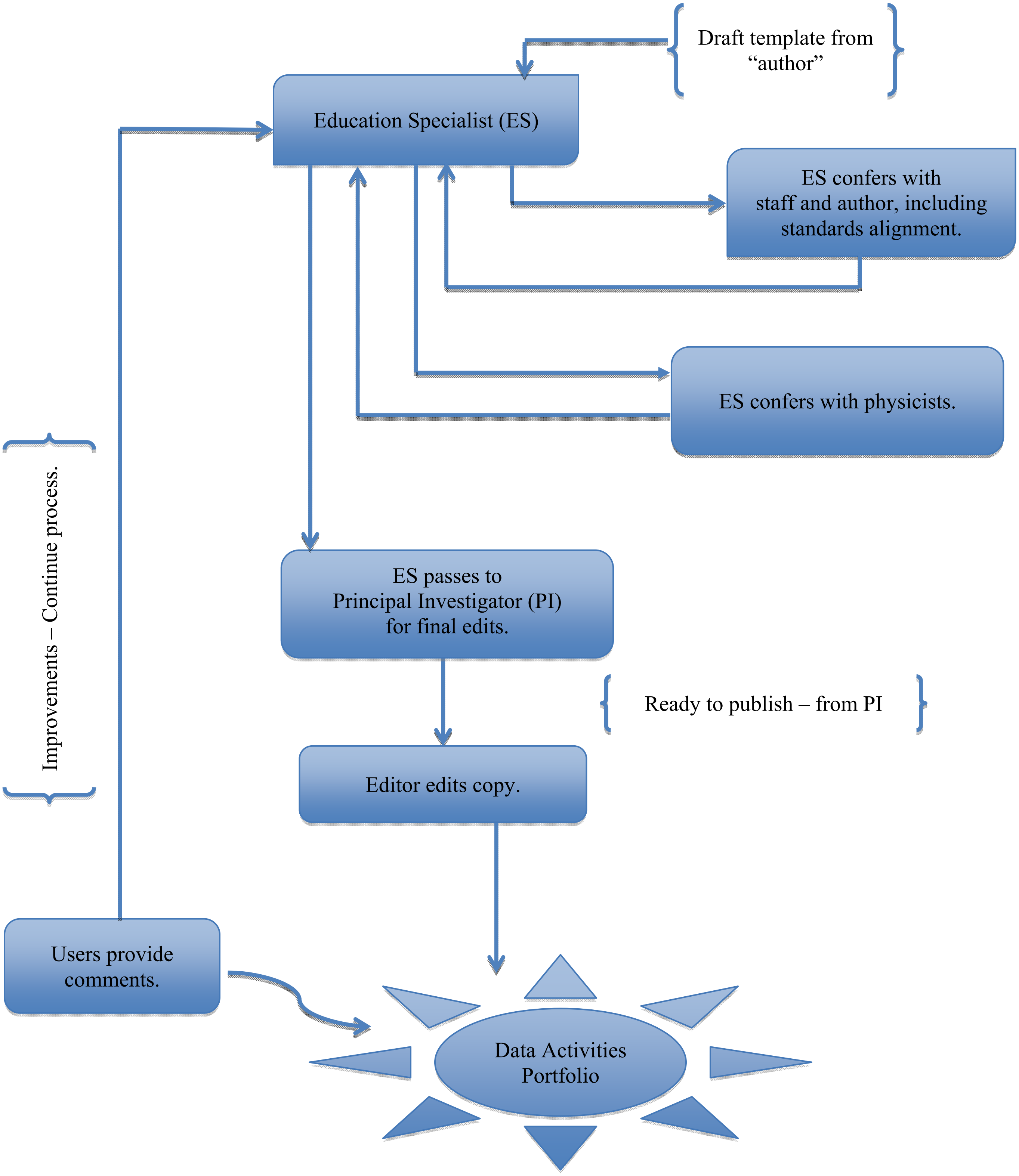
[6] The Standard Model of Particle Physics: the current theoretical framework that describes elementary particles and their forces (six leptons, six quarks and four force carriers). Physicists (and other scientists) can understand every phenomenon observed in nature by the interplay of the elementary 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)

Instructional Design Pathway and Templates for Data Activities Portfolio

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



CRITERIA USED AT INSTRUCTIONAL DESIGN STAGE – ANNOTATED

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:

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

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

Practical Applications:

What is the value of what you learned?

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

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-staff Held 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 QuarkNet Workshops held 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.

F-2 lists the meetings and workshops held at QuarkNet Centers and 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). (As already mentioned, see Table 7 for a list of the centers and the status of each.)

A breakdown of annual participants (2018-2019 and 2019-2020 program years) is provided in the annual NSF report submitted by the PIs and program staff, respectively

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	

QuarkNet and COVID-19
May 1, 2020

Introduction: The COVID-19 crisis has profoundly affected QuarkNet and our teachers. Summer workshops at centers and other opportunities have been cast in doubt, re-imagined, or postponed. Almost all of our teachers have had to cope with a shift to online remote teaching. Quickly, staff realized that it would be important to maintain contact and support our teachers. Working from home, as the teachers and their students are, staff adjusted and created offerings to help teachers engage students with meaningful learning in physics. This report shows what we have done and how.

Before addressing the issues and initiatives related to the crisis, we note that the staff has maintained contact with one another and continued routine aspects of QuarkNet. Tuesday staff conferences and Wednesday technical conferences which are conducted remotely continue unabated. The weekly newsletter, the *Friday Flyer*, continues and has, if anything, taken on a stronger role to connect QuarkNet members. Staff continue to field questions from and check in with mentors and teachers. Next week, staff will contact all mentors to get updates on summer plans in light of the crisis and offer support. Staff still meet remotely with fellows—perhaps more than ever. For example, the monthly LHC and Neutrino Fellows monthly videoconference has become weekly so that Ken Cecire and Shane Wood can consult with them on the initiatives below. With the whole group mostly limited to home, it has become their virtual “night out.”

Support for Teachers: As schools moved to remote online learning in March, staff realized that teachers were entering a new world and needed support. Staff built and continue to support online resources to assist teachers in remote teaching and maintaining their access to QuarkNet content and practices:

- Resources for Physics Teaching Online. This page has resources on remote online learning, physics simulations and online lessons, and more. We have propagated it outside QuarkNet; as of May 1, teachers have accessed it over 900 times.
- QuarkNet Zoom Channels for Videoconferencing. We opened six Zoom channels on the Notre Dame Zoom account for QuarkNet teachers who might not otherwise have a robust way to communicate with students or colleagues.
- Resources for Cosmic Ray Analyses Online. Using the Cosmic Ray e-Lab, teachers can engage students remotely in physics research projects with data from QuarkNet cosmic ray detectors. This “how to” guide includes instructions and pre-selected useful data files.
- Using the CMS e-Lab. Using the CMS e-Lab, teachers can engage students remotely in physics research projects with data from CERN’s Large Hadron Collider. This “how to” guide includes instructions and suggestions for meaningful studies.
- Comments on Adapting Data Activities to Teaching Online. Staff and LHC fellow Jeremy Wegner added comments to the Data Activities Portfolio to explain how students can engage in 16 different data activities at home in collaboration with teachers and often peers. To see such comments, one must log into the QuarkNet website. This page was added to make these comments available to all teachers, logged in or not. Mr. Wegner also contributed a Visual Python simulation online so the popular Rolling with Rutherford activity could be included.

Staff adapted the weekly QuarkNet newsletter, the *Friday Flyer (FF)*, for the current crisis. While the sections are familiar, much of the content shifted to making teachers aware of the support and new activities that have become available. *FF* has kept up with particle physics news, opportunities for teachers, and even a little humor throughout the crisis while being a conveyor of information QuarkNet teachers need. (Read the May 1 issue.)

Staff announced another project for teachers and students on May 1: the QuarkNet Wednesday Webinars (QW2). Experts will give webinars on particle physics-related topics between May 6 and June 10. Teachers and students will connect from home to learn new things about particle and contemporary physics. Like all of the Zoom webinars mentioned above, these will be recorded to widen their usefulness.

Cosmic Ray Studies: With many cosmic ray detectors inaccessible while teachers and students work from home, the total number of cosmic ray data file uploads is down. The number of cosmic ray analyses on the e-Lab, however, has increased as several teachers have challenged their students to perform measurements with existing data. Staff created a page containing resources for cosmic ray analyses online (see section above) to support teachers and students during this time of distance learning. Additionally, a few detectors continue to upload data. A staff member moved one of the detectors at Fermilab to his home in order to provide an updated standard data set for the e-Lab.

Masterclasses: International Masterclasses (IMC) run each year in and around March; they were just starting as the COVID-19 crisis set in. Masterclasses began to shut down and by March 18, further IMC videoconferences were canceled, effectively ending IMC 2020. One of the last masterclasses in the U.S. was done remotely by LHC fellow Jeremy Wegner and his students in rural Indiana. A few other groups also attempted remote masterclasses with varying success.

QuarkNet took the next step modifying the current CMS masterclass for remote learning. The simplified measurement focuses on muon tracks, and new online support enabled students to learn what to do via four screencasts and to complete the measurement with some coaching from their teachers. The result was a new remote learning masterclass, the Big Analysis of Muons in CMS (BAMC). Staff built a support infrastructure with student and teacher pages on the QuarkNet website, Zoom Q&A sessions for teachers, an April 15 webinar talk on the Standard Model and CMS by a Kansas State University particle physicist, ample tables for recording results online in the CMS Instrument for Masterclass Analysis (CIMA), and an April 17 webinar to discuss the data with three particle physicists. About 180 teachers and students attended each of the webinars and an estimated 240 students analyzed over 11,000 CMS events, one-by-one in the iSpy event display. BAMC provided a robust stress test for CIMA (which it passed), an opportunity for teachers to do a meaningful remote project with their students, and the chance for hundreds of students to be "particle physicists for a day" at home. Along the way, Staff developed capacities with webinars and designing remote learning experiences. And it all worked very well, with ample compliments from teachers and students.

With the success of BAMC in April, staff has started another session for May, opening this session up to more international participation. There are still details to sort, but the masterclass talk will take place on May 19 with the videoconference to follow later that same week.

Fellows Workshop: Meetings of QuarkNet fellows are vital to their development and foster communication among the groups. These meetings have maintained the coherence of their work. Staff had planned an in-person workshop for fellows who present our national workshops for May 15-17 at Fermilab. Now, staff is planning a virtual workshop. The primary goal is to enable select fellows to create remote online workshops that will be offered to teachers through our centers in Summer 2020. The fellows virtual meeting will also provide the opportunity to share ideas among groups of fellows and continue the focus on research-based best practices in offering professional development.

Data Camp: Each year, Data Camp brings 24 teachers from around the country to Fermilab for a week-long, multi-faceted workshop that includes tours, talks, particle physics data analyses, and the exploration of data activities to bring back to the classroom. This "classic" Data Camp will not be offered in 2020; instead, the Teaching and Learning Fellows will conduct a virtual/remote workshop that emphasizes the use of coding skills as they pertain to physics in general and particle physics in particular. Another goal of this virtual workshop, still under development, is to give teachers some comfort and confidence that, if remote learning is continued in the fall, they will have the skills and resources to implement something interesting, challenging, and useful with their students.

Summer 2020 Workshops at Centers: Summer workshops at many centers are among the QuarkNet highlights for teachers, mentors and staff. These meetings are the primary pathway to offer teachers at QuarkNet centers opportunities to develop professionally, build community, learn new physics, and improve their teaching. At this point, there is much uncertainty regarding these workshops. Staff, mentors, and lead teachers are discussing possibilities, which so far include:

- Rescheduling the workshop for late summer and/or fall in hopes that face-to-face meetings will be possible then.
- Offering a virtual workshop, in which centers would meet for at least a portion of their workshop time remotely.
- Cancelling the 2020 workshop, with a plan to meet again in 2021.
- Other creative solutions.

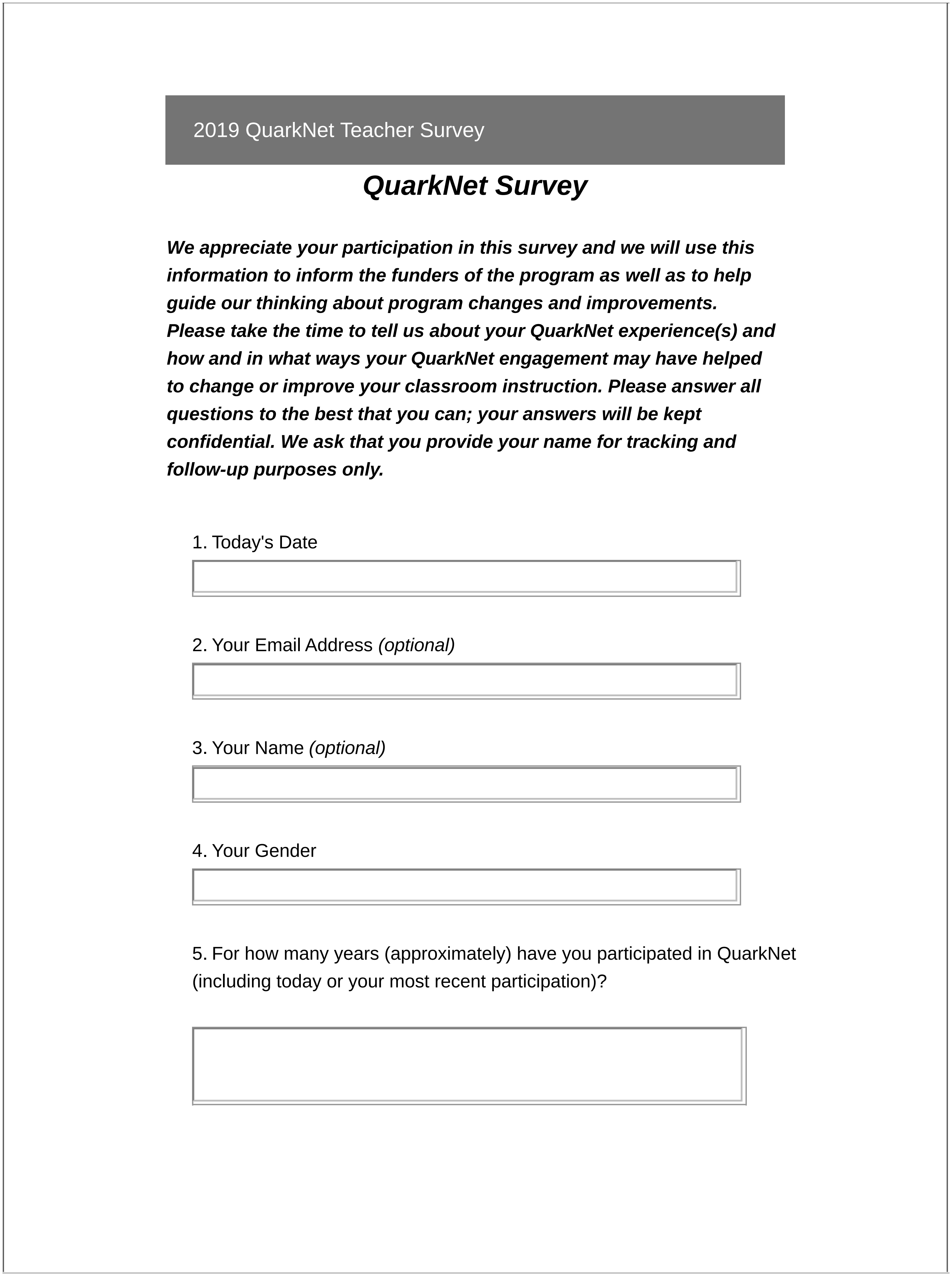
Staff is working with fellows to re-tool some of our national workshops in order to offer them remotely. Virtual summer meetings could also allow teachers to share successful strategies and tools with each other for teaching in a virtual setting, as the possibility of teaching this way may extend into the next academic year for at least some teachers.

STEP UP: In 2019, QuarkNet began a partnership with STEP UP, a program that supports teachers to encourage more women and minorities to pursue physics as a career. As part of this partnership, nine QuarkNet leaders, including staff, educational specialists, fellows and teachers, attended the 2019 STEP UP Summer Institute to become ambassadors for the program. Deborah Roudebush, QuarkNet Educational Specialist and STEP UP ambassador, has taken the lead in coordinating work that is beneficial to both organizations. As part of this work, several STEP UP classroom activities have been edited to fit our format. Soon, we will post these activities in the Data Activities Portfolio. The 2020 STEP UP Summer Institute will be virtual, and Deborah is helping STEP UP leaders plan for this event. Several QuarkNet STEP UP ambassadors from 2019 plan to attend the 2020 institute as well. In addition, Deborah and the staff are coordinating QuarkNet STEP UP ambassador efforts to arrange virtual STEP UP workshops open to all QuarkNet teachers.

IT Infrastructure: Support for remote teaching and learning and carrying out new initiatives online only work if the IT infrastructure is strong. Fortunately, QuarkNet has been in a very good position in this regard. The QuarkNet servers at Notre Dame were not significantly affected by the COVID-19 crisis. IT staff was already working remotely, and Notre Dame has provided ongoing support. ND Studios assisted the staff in setting up webinars and exploring the capabilities of Zoom. The IT staff continues to work on development and maintenance of QuarkNet resources such as e-Labs and masterclass tools. One area of concern in International Masterclasses was the response of the CMS Instrument for Masterclass Analysis (CIMA) to large numbers of students; this eased when IMC 2020 was canceled and gave IT staff time to fix problems. The first BAMC masterclass in April served as a stress test for CIMA: it passed and the few non-critical issues that remained were identified. The current situation did delay the installation of new QuarkNet servers to improve capacity and performance. As the old servers are still working well, this has not been a problem.

Evaluation: Given that many centers do not have plans for the summer yet, we were able to reach out to more than the planned centers to obtain information about center-level outcomes and sustainability factors. We contacted a total of ten centers, with all but two either completing or in the process of completing this. The unexpected effect of these conversations, especially for the six centers we have recently contacted, have been reflections on how each center might incorporate virtual workshops or other outreach to their teachers as necessary now and in the future

Going forward, evaluation plans will include possibly “observing” virtual workshops, attending some in person events if this becomes possible; and urging workshop participants to complete the new abbreviated (short ten questions) Teacher Survey. The external evaluator also plans on incorporating implementation plans as part of the evaluation effort as well as the new information we glean from the short Teacher Survey. If we are forced to engage in virtual workshops as the usual means of implementing workshops, then she would like to work with staff to glean how and what formative evaluation efforts would be helpful for them.



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)

2019 QuarkNet Teacher Survey

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.*

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)

☐

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?

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.												

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

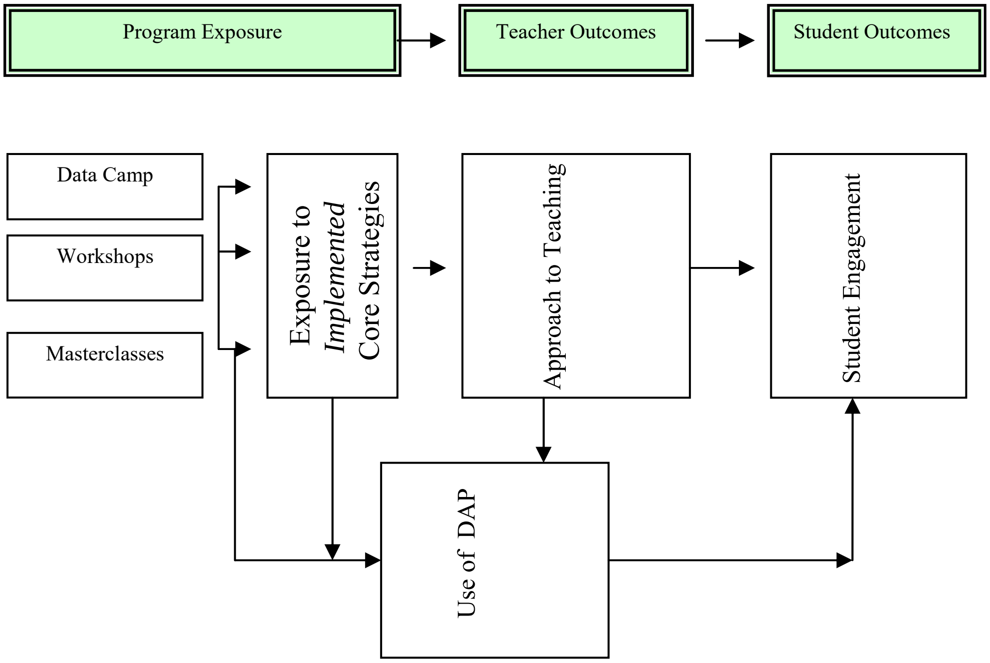


Figure 9. Overview of analyses related to Teacher (and their Students) Outcomes.

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 and student engagement outcomes. And as stated, 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, Figure 9 (noted here and in the narrative of the report) 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. All are based on teacher self-reported responses 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 does not intend 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. As previously described, 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=341, ranged from 12 to 60, with a Mean = 54.26 (Standard Deviation, SD = 7.04); and an alpha = 0.88 (reliability coefficient, Cronbach's alpha).

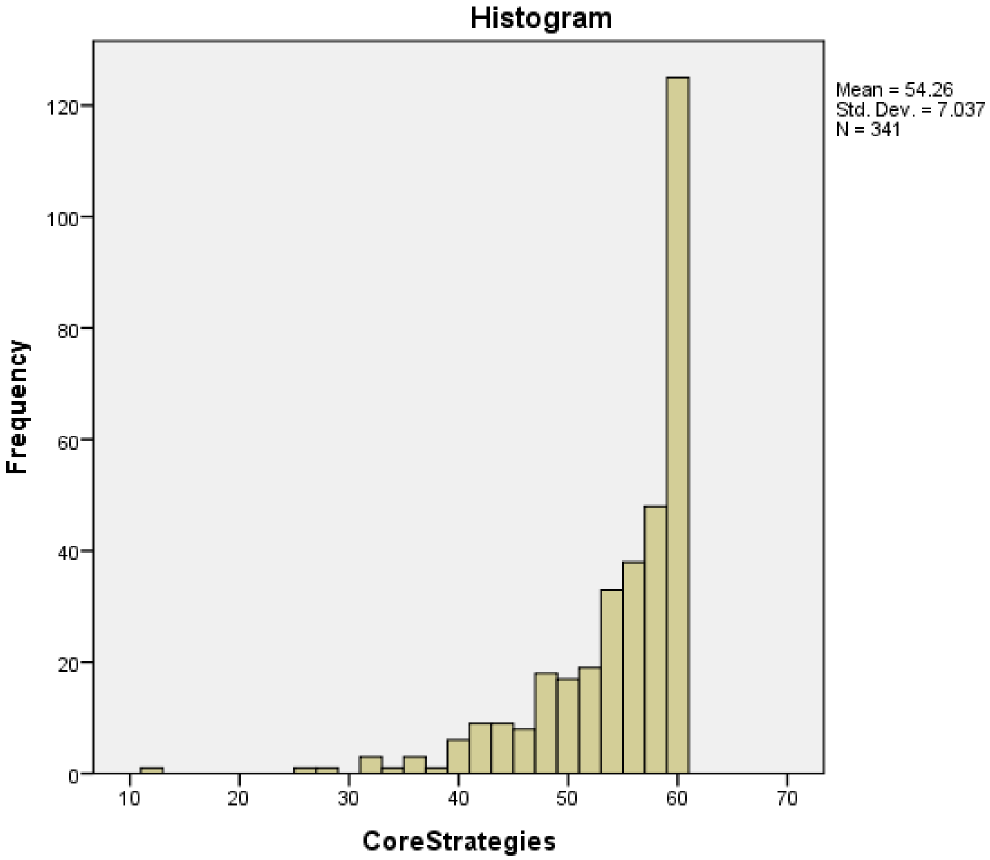


Figure K-1. Distribution of Core Program Strategies scale scores.

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 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
Items Used to Form an **Approach to Teaching**
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 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=329, ranged from 14 to 60, with a Mean of 43.02 (SD = 8.45); and an alpha of 0.90 (reliability coefficient). Figure K-2 shows the distribution of these scores, suggesting an approximate normal distribution. We conclude 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-2 (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 done for 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

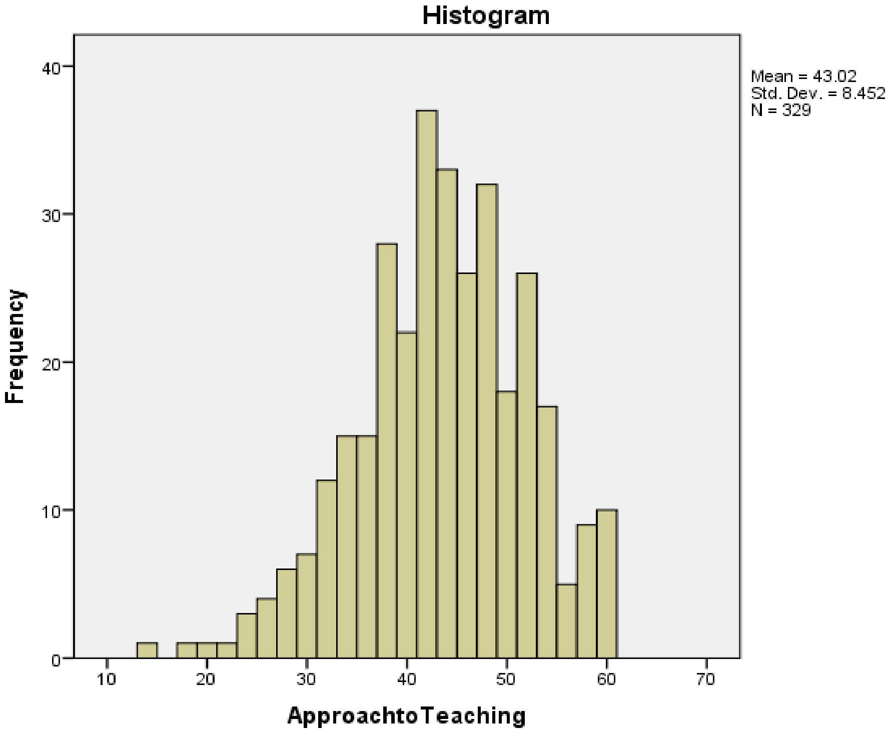


Figure K-2. Distribution of Approach to Teaching scale scores.

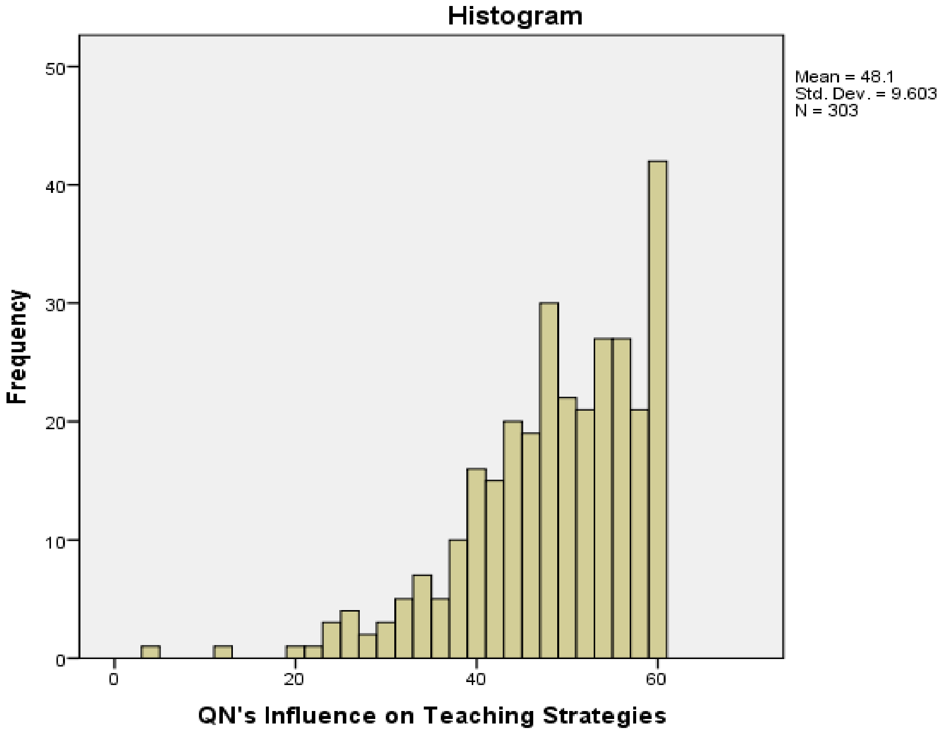


Figure K-3. Distribution of QuarkNet's Influence of Teaching scale scores.

scores from this 12-item scale, based on an N= 303, ranged from 4 to 60, with a Mean of 48.10 (SD = 9.60); and an alpha of 0.95 (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-3
Items Used to Form a **Student Engagement**
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-3 (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=321, ranged from 2 to 25, with a Mean of 18.69 (SD = 3.52); 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-3 (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 done for 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= 284, ranged from 5 to 25, with a Mean of 20.01 (SD = 3.70); and an alpha of 0.89 (reliability coefficient). (See Figure K-5.)

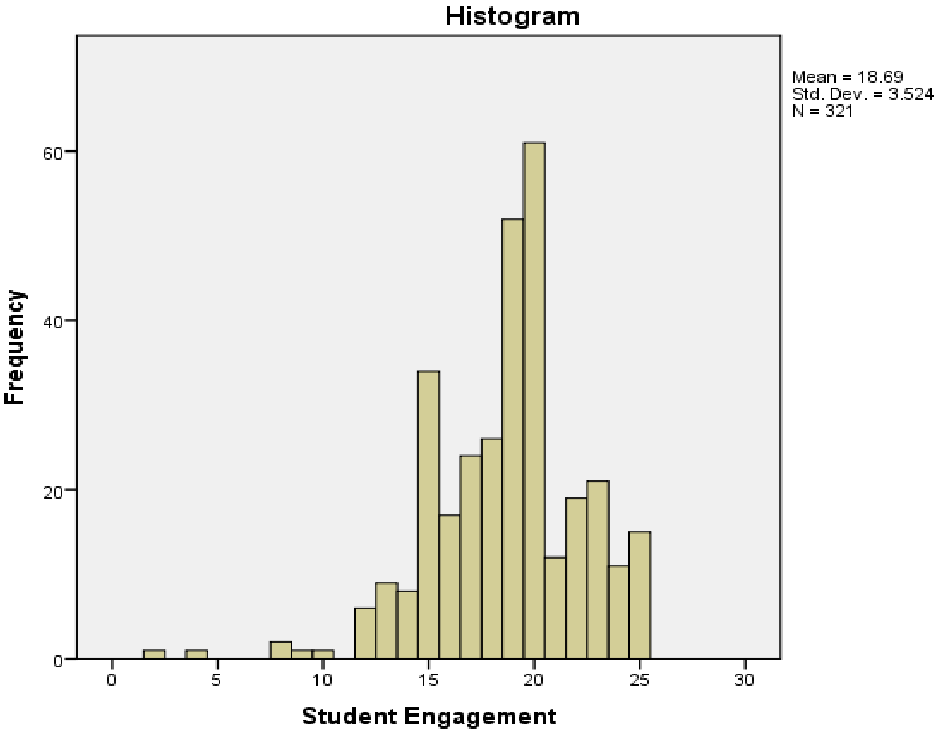


Figure K-4. Distribution of Student Engagement scale scores.

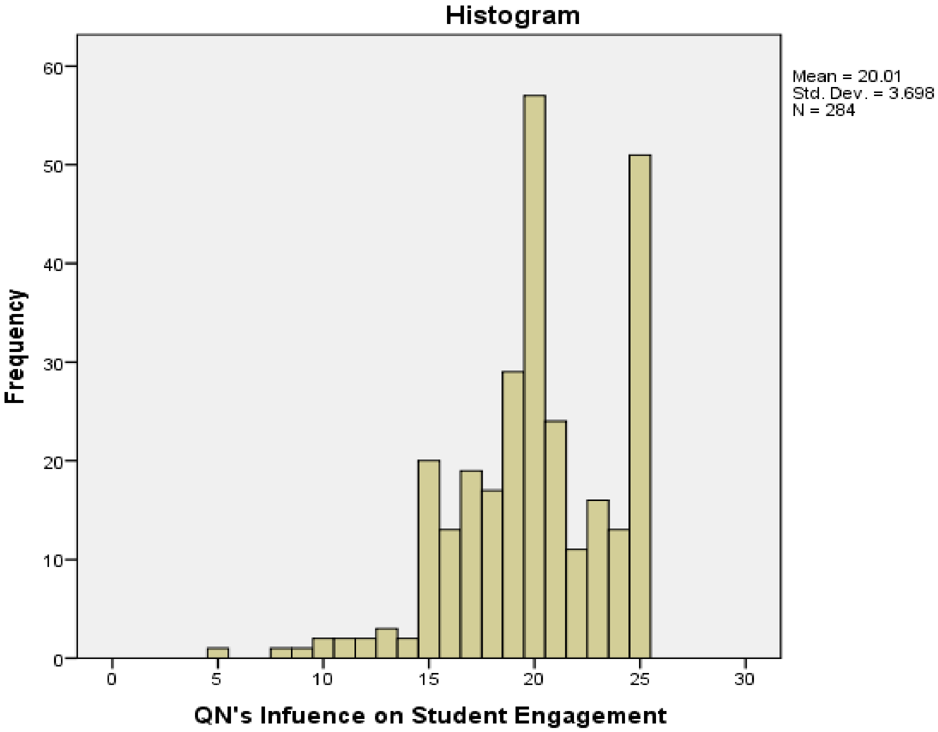


Figure K-5. Distribution of QuarkNet’s Influence on Student Engagement scale scores.