**DOE TITLE PAGE**

**Quantum Learning Lab (QuLL) User Facility**

Sandia National Laboratories

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**TITLE PAGE SUPPLEMENT FOR COLLABORATIVE APPLICATIONS**

**Collaborating Institutions, Abbreviations, and PIs**

|  |  |  |
| --- | --- | --- |
| **Institution** | **Abbreviation** | **PI** |
| **Sandia National Laboratories** | **SNL** | **Megan Ivory (Lead)** |
| Central New Mexico Community College | CNM | Phil Lister |
| Navajo Technical University | NTU | Abraham Meles |
| New Mexico Institute of Mining and Technology | NMT | Nikolai Kalugin |
| New Mexico State University | NMSU | Abdel-Hameed Badawy |
| University of New Mexico | UNM | Marek Osinski |
| Growth Sector | GS | Gabe Hanzel-Sello |

**Collaboration Leadership Structure, Facilities/Equipment/Resources, Training/Mentoring**

The collaboration will be led and coordinated by PI Megan Ivory at Sandia National Laboratories. Work will be divided into seven main activities: 1) QuLL experiments setup, 2) Create curriculum/lab manuals, 3) Summer SQOL, 4) BootQamp, 5) Augmented Research, 6) Lab maintenance, 7) Evaluations. The leadership structure, facilities/equipment/resources, and training/mentoring associated with each of these activities is described below, with as much activity as possible being performed by students and early-stage researchers (ESRs) with guidance from senior researchers (SRs):

1. **QuLL experiments setup**: SNL will organize meetings amongst all collaborators (CNM, CNM-I, NTU, NMT, NMSU, UNM, GS) in Months 1-3 to agree upon the experimental demonstrations that will be initially included in QuLL. SNL will order all necessary materials and work with our facilities provider at CNM-I to ensure readiness of the facility. Experiments will be setup by **student/ESR interns** with guidance/support from SRs at SNL in time for Task 3 (Summer SQOL) in Month 9. Additional experiments may be set up during Years 2 and 3 of the project to cover additional skillsets and emerging technologies.
2. **Create curriculum/lab manuals**: During the SNL-organized meetings amongst all collaborators (CNM, CNM-I, NTU, NMT, NMSU, UNM, GS) in Months 1-3, each of our university Co-PIs (NTU, NMT, NMSU, UNM) will choose an experimental demonstration for which they will develop the curriculum/lab manual over the course of Months 3-9 along with 1-2 **student/ESR interns** at their institution. Co-PIs and **student/ESR interns** will meet regularly with SNL for any additional needed SR support and to ensure material is culturally inclusive. CNM, CNM-I, and GS will provide guidance on accessibility of material at the conceptual level.
3. **Summer SQOL**: Each summer, SNL will coordinate with partner institutions (CNM, CNM-I, NTU, NMT, NMSU, UNM, GS) to facilitate visits of **student/ESR cohorts** from each institution (CNM, CNM-I, NTU, NMT, NMSU, UNM) and from additional institutions (GS). The lab demonstrations will be guided by SNL **student/ESR interns** with support from SNL SRs.
4. **BootQamp**: During Months 12-15 and 24-27, SNL will coordinate with CNM and CNM-I to facilitate visits of cohorts composed of veterans, career changers, and professionals seeking upskilling opportunities. During Months 1-9, SNL, CNM, and CNM-I will develop the structure of the BootQamp and partner with industry, economic development organizations, and workforce development groups to identify desirable skills and outcomes and create pathways to jobs in QIST and STEM. BootQamp activities will be carried out by SNL/CNM-I **student/ESR interns** whenever possible, with support from SNL, CNM, and CNM-I SRs.
5. **Augmented Research:** During Months 16-19 and Months 28-31, QuLL will be open to Summer SQOL and BootQamp **student/ESR** “graduates” for senior, graduate, and faculty research projects. These projects will be initiated and led by the students/faculty.
6. **Lab Maintenance**: SNL will oversee the maintenance of the laboratory experiments, with maintenance being performed by SNL **student/ESR interns** with guidance from SNL SRs whenever possible. SNL and CNM-I will be responsible for facilities maintenance.
7. **Evaluations**: NMSU SOAR Lab personnel, with guidance from all partner institutions, will perform evaluations to determine the effectiveness of the lab experiments across participants with different education levels and backgrounds.

**Facilities/Equipment/Resources**

The lab space will be approximately 1000 sqft and co-located with FUSE Makerspace in downtown Albuquerque, NM. FUSE Makerspace is a hands-on makerspace and engineering lab featuring a large collection of industrial fabrication tools, manufacturing equipment, engineering software, and numerous workforce training opportunities spanning workshops to immersive bootcamps. The equipment, expertise, and training opportunities at FUSE Makerspace are an excellent complement to QuLL. Additional details about the facilities at FUSE Makerspace can be found under Appendices 2 and 3.

**Summary Budget**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Collaborative Application Information | | | | | | |
|  | **Names** | **Institution** | **Year 1 Budget** | **Year 2 Budget** | **Year 3 Budget** | **Total Budget** |
| Lead PI | Megan Ivory | Sandia National Laboratories | $993,605 | $626,686 | $609,742 | $2,230,033 |
| Co-PI | Phil Lister, Brian Rashap | Central New Mexico Community College | $312,329 | $314,307 | $319,156 | $945,792 |
| Co-PI | Gabe Hanzel-Sello | Growth Sector | $100,000 | $100,000 | $100,000 | $300,000 |
| Co-PI | Abraham Meles,  Thiagarajan Soundappan | Navajo Technical University | $139,350 | $134,215 | $135,430 | $408,995 |
| Co-PI | Sanchari Chowdhury, Wenyang Gao, Nikolai Kalugin | New Mexico Institute of Mining and Technology | $106,933 | $108,736 | $110,627 | $326,296 |
| Co-PI | Hameed Badawy, Boris Kiefer | New Mexico State University | $158,170 | $161,308 | $164,539 | $484,017 |
| Co-PI | Marek Osinski | University of New Mexico | $133,396 | $138,920 | $144,914 | $417,230 |
| **Total Budget:** | | | **$1,943,783** | **$1,584,172** | **$1,584,408** | **$5,112,363** |

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**PROJECT NARRATIVE**

1. **Background/Introduction:**

Quantum Information Science and Technology (QIST) is a nascent field that has been recognized by the US government as a key strategic investment area due to its promising applications in sensing, timekeeping, computing, and communications, and it is set to see significant growth in the years to come [1].  This has fueled a critical need for skilled workers which doubled in the first half of 2018 alone [2].  To meet this demand, a number of courses and training programs have been developed over the past few years. These programs include QIST certification programs for professionals from quantum-adjacent fields such as computer science and engineering [3], certification programs for PhD students in quantum-adjacent fields [4], advanced undergraduate courses in QIST [5-6], modules for inserting QIST concepts into existing courses [7], developing courses for quantum technician training programs at community colleges [8], programs for introducing QIST concepts at the high school level [9-11], and additional resources allowing the quantum-curious to do self-guided learning [12].

Despite these tremendous efforts, there are still gaps which need to be addressed. A 2021 study of QIST courses offered at US institutions found that 88% were offered at PhD granting institutions and that only 21% of the Hispanic Serving Institutes (HSIs) surveyed offered QIST courses [6]. This indicates that students at Predominantly Undergraduate Institutions (PUIs) and HSIs have less opportunity to engage in this field.

Another challenge lies in access to hands-on training opportunities on QIST hardware. Hands-on training is one of the most important skillsets for a quantum-ready workforce [1] and one of the most difficult to obtain due to the sparsity, expense, and complexity of quantum research labs.  Oftentimes, the only way to obtain hands-on opportunities is through funded internships in industry, national labs, and research universities, which require buy-in from researchers and professionals at those institutions who are willing to let students learn on their equipment and set aside the time to mentor and train these students. Generally, demand for internships outweighs the supply, and prior hands-on experience is preferred, significantly limiting opportunities for many communities that are already underrepresented in Science, Technology, Engineering, and Mathematics (STEM).

Here, we propose an alternative way to provide hands-on training to a broad, diverse audience by establishing a facility specifically designated as quantum learning lab. **The Quantum Learning Lab (QuLL) User Facility will give participants access to and experience with actual hardware and experiments related to quantum computing**, through curriculum or “lab manuals” developed by QIST researchers and educators for audiences with multi-disciplinary backgrounds and at varying education levels. This will allow participants without an advanced math/physics background to gain conceptual understanding of QIST concepts and experiments while Early-Stage Researchers (ESRs) can enhance their advanced theoretical knowledge of math/physics with the same experimental hardware demonstrations.

Programming for QuLL will have three focus areas. First, the Summer Student Quantum Opportunities for Learning (Summer SQOL) will bring cohorts of up to 12 students to QuLL for 2-week visits where they are guided through the experiments. During the fall semesters, BootQamp will bring professionals, veterans, and career changers to QuLL for upskilling in QIST and other STEM-relevant hardware skills. During the spring semesters, the lab will be available to “graduates” of Summer SQOL to carry out research projects on QuLL equipment that might not be otherwise available at their home institutions.

At the heart of this effort is increasing access to quantum skill sets to new and underrepresented communities. Therefore, this project brings together 11 QIST researchers and educators across the state of New Mexico from 5 MSIs spanning a community college to an R1 university, 2 educational non-profits, and led by a DOE national lab. All of our collaborating IHEs are HSIs. Our collaborating nonprofit CNM Ingenuity has existing upskilling programs geared toward professionals, veterans, and career-changers, and our collaborating nonprofit Growth Sector has nationwide connections with HSIs and Historically Black Colleges and Universities. This team will allow us to engage with communities across the state of New Mexico including numerous underrepresented communities with dimensions of diversity including cultural, racial, geographic and socioeconomic diversity, all within an EPSCoR state with majority minority population, above average poverty levels, and significant physical and digital infrastructure challenges [13]. We believe this team and approach will allow us to provide hands-on opportunities in QIST to hundreds of participants from the New Mexico community throughout the period of performance, preparing a quantum-ready workforce that can help meet the needs of other core DOE-SC programs such as the Quantum Systems Accelerator, the Center for Integrated NanoTechnology, the Quantum Scientific Computing Open User Testbed, and other programs within our state’s DOE Laboratories.

1. **Project Objectives:**

The overall objectives and associated tasks of the QuLL project are to:

1. **Make crucial hands-on learning with** **quantum technology accessible** to participants who do not have such opportunities due to regional, educational, and socio-economic barriers/constraints.
   1. Summer Student Quantum Opportunities for Learning (Summer SQOL) will bring cohorts of students to QuLL for two-week visits throughout the summer, providing them with hands-on learning with quantum hardware that wouldn’t otherwise be available to them.
   2. BootQamp will provide upskilling with quantum hardware to veterans, professionals, and career-changers.
   3. Augmented Research will allow students who have attended Summer SQOL with additional opportunities to utilize lab equipment for research projects on QuLL equipment that they do not have access to through their home institutions.
2. **Introduce participants to a** **variety of qubit technologies** through hands-on experiments that are paired with multi-tiered learning modules suitable for different participant backgrounds and education levels.
   1. QuLL will host 10 initial experiments that expose participants to technology relevant to neutral atom qubits, trapped ion qubits, defect qubits, spin qubits, and photonic qubits.
   2. Each experiment will be accompanied by multiple lab manuals to make learning content accessible to participants of different backgrounds and education levels.
3. **Inspire new and diverse communities** of participants to pursue quantum information science and technology (QIST) and to better prepare them for educational and career opportunities in QIST.
   1. QuLL participants will be recruited through our collaborating MSIs and educational non-profits with emphasis on many facets of diversity, including gender, racial, socio-economic diversity as well as veteran-status, first-generation college students, etc.
   2. QuLL participants will interact with QIST SRs to learn about follow-on opportunities, pathways to continue their QIST education/careers, and how to capture QuLL skills in their resumes.
   3. QuLL programming will be formally evaluated to gauge content learning and attitudes for our variety of participants.

**III. Proposed Methods and Activities:**

To achieve these objectives, a team of educators and researchers from institutions throughout the state of New Mexico will collaborate to form a first-of-its kind lab space, lab manuals, and training programs dedicated to QIST.

1. **QuLL Experiments**

QuLL facilities will be centrally located in Albuquerque, NM near Sandia’s Albuquerque site and utilizing space provided by CNM and CNM-Ingenuity, allowing for accessibility by collaborating MSIs throughout the state and broader accessibility nationwide via the Sunport International Airport. Our partnership with CNM and CNM-I will provide facilities for the lab space and bypasses common accessibility issues at SNL due to necessary security measures. The lab space will be approximately 1000 sqft and co-located with FUSE Makerspace in downtown Albuquerque, NM. FUSE Makerspace is a hands-on makerspace and engineering lab featuring a large collection of industrial fabrication tools, manufacturing equipment, engineering software, and numerous workforce training opportunities spanning workshops to immersive bootcamps. The equipment, expertise, and training opportunities at FUSE Makerspace are an excellent complement to QuLL. Additional details about how we plan to model our upskilling BootQamp after an existing Internet of Things bootcamp at FUSE Makerspace can be found under the “B. QuLL Programming → Bootcamp” section below. Additional details about the facilities at FUSE Makerspace can be found under Appendices 2 and 3.

The collaboration has already identified 10 different experiments with relevance to QIST that will be set up in QuLL spanning multiple qubit technologies, including neutral atom qubits, trapped ion qubits, photonic qubits, defect qubits, and spin qubits.

***Neutral Atom and Trapped Ion Qubits*:**  We plan to incorporate experiments covering absorption spectroscopy, laser cooling, optical tweezers, magneto-optical traps, and quadrupole traps. These experiments will introduce students to crucial hardware tools utilized in quantum computing with atomic qubits (lasers, electronics, optics, vacuum systems), as well as concepts such as isolation of qubits, atomic structure, measurement, etc.

***Photonic Qubits*:** Interferometry, double-slit experiment, quantum cryptography analogy, and entanglement experiments will introduce students to hardware tools for quantum computing with photons (lasers, optics, detectors, electronics) and concepts including wave vs particle nature of light, polarization, superposition, interference, measurement, and entanglement.

***Defect Qubits*:** We plan to include a quNV system to introduce basic principles of defect qubits – in this case using nitrogen vacancies in diamond. This experiment introduces students to NV- defect quantum states for quantum computing and non-invasive quantum sensing, including energy levels, laser addressing, and measurement.

***Spin Qubits*:** Spin qubits will be introduced through an experiment with quantum dots that allows students to study the absorption and emission properties of quantum dots, introducing them to yet another two level system and reiterating concepts such as absorption and emission spectra.

A list of these experiments, the related qubit technology, and anticipated skills and outcomes are shown in TABLE 1:

**TABLE 1**

|  |  |  |
| --- | --- | --- |
| **Experiment** | **Qubit Technology** | **Skills/Outcomes** |
| Absorption Spectroscopy | Neutral Atoms & Trapped Ions | Observing atomic levels, diode laser operation and alignment, oscilloscopes, optics |
| Magneto Optical Trap | Neutral Atoms & Trapped Ions | Laser cooling, magnetic trapping, vacuum systems, laser locking and alignment, optics |
| Optical Tweezers | Neutral Atoms & Trapped Ions | Optical trapping, laser alignment and optics, vectors, refraction |
| Quadrupole Trap | Trapped Ions | Paul traps, micromotion, electronics |
| Interferometry | Photons | Wave interference, laser alignment, detectors |
| Double Slit Experiment | Photons | Wave interference, laser alignment, detection, wave-particle duality, superposition |
| Quantum Cryptography Analogy | Photons | Polarization, detection |
| Entanglement | Photons | Single-photon detection, entanglement, polarization |
| Quantum Dots | Spin Qubits | Absorption and emission spectra, spectrometers |
| NV Diamond | Defect Qubits | Energy states, fluorescence, sensing |

With the experiments in TABLE 1, we introduce participants to 5 different qubit technologies and associated hardware, as well as several critical quantum concepts including interference, superposition, and entanglement.

Where possible, we have chosen to utilize educational kits rather than build our own experiment. The reasons for this are two-fold. First, this saves time, avoiding any recreation of the proverbial wheel, and allowing us to build off of existing curriculum and lab manuals. Second, as these kits are widely accessible and lower the barrier to such experiments, our associated curriculum and lab manuals can then be made readily available to others who seek to implement similar experiments. These could be groups outside of the QuLL collaboration who have a similar interest in QIST educational labs, or our collaborators may wish to implement similar lab experiments as part of new or existing courses at their home institutions.

Half of these experiments, including the quadrupole trap for microbeads, optical tweezers, interferometry, double slit, and quantum cryptography analogy experiments are priced at ≤ $20k each. While this price may be affordable for some undergraduate laboratories, many smaller institutions would still find this cost to be prohibitively expensive. Therefore, we feel it is important to incorporate these lower cost experiments into QuLL. In addition, if institutions can afford such experiments, QuLL can serve as an introduction to the hardware and learning outcomes for students and faculty. Faculty can then be better prepared to bring these experiments into their undergraduate labs and utilize QuLL lab manuals at the appropriate level for their students.

The other half of these experiments would likely be prohibitively expensive for implementation in a typical classroom laboratory, especially at PUIs. These experiments include absorption spectroscopy, magneto-optical traps, NV diamonds, quantum dots, and photon entanglement. The accessibility of these experiments to our student cohorts and collaborators via QuLL will have the most value-add, by exposing participants to hardware and systems they would not otherwise have the opportunity to handle.

The QuLL experiments will be built and maintained by year-round **student/ESR interns** with guidance from SNL researchers, with the goal of having a fully operational learning lab in time for summer 2024 participants. By relying on interns rather than QIST researchers, we provide yet another learning and leadership opportunity for students/ESRs. Year-round **student/ESR interns** will also play a critical role in maintaining the experiments and developing add-on experiments in later years, allowing QuLL to keep up with emerging trends in QIST.

1. **QuLL Programming**

Programming will fall along three tracks: 1) Summer SQOL (Student Quantum Opportunities for Learning), 2) BootQamp, and 3) Augmented Research. Summer SQOLs will aim to bring cohorts of 12 students to QuLL for 2 weeks at a time to cycle through the experimental setups. BootQamp will aim to bring professionals, veterans, and career changers to QuLL during the school year for upskilling in QIST. For the latter, we will collaborate with CNM Ingenuity, a nonprofit institution in New Mexico with a successful track record of developing upskilling bootcamps in emerging technology fields that feed into national labs and other employers in NM. In addition, we will work to establish industry partnerships to better understand how QuLL might meet their workforce needs and to develop follow-on sustainability for QuLL through sponsorship by industry, workforce training organizations, and economic development groups, as well as identifying pathways for QuLL participants to gain additional experience.

***Summer SQOL*** will be a two-week long immersion in QuLL during the summers, with cohorts of up to 12 students from each of our collaborating IHEs (CNM, UNM, NTU, NMT, NMSU) and an additional cohort from GS partner institutions. The goals of Summer SQOL are to expose students to QIST concepts and experiments and to give them basic QIST-relevant skills (for example, optics alignment, spectroscopy, interferometry, etc) that will better prepare them for internships, careers, and additional educational opportunities in QIST.

Summer SQOL will build off related summer camps for introducing students to QIST concepts without any prerequisite STEM backgrounds [10]. These prior camps developed by SNL, UNM, and NMSU are focused on concepts more so than hardware but demonstrate the team’s ability to effectively communicate complex concepts to high school students with no prerequisite math or science classes and provide a starting point for conceptual material for lab manuals.

Summer SQOL will also highlight pathways to additional opportunities, as well as incorporate a resume workshop at the end of each two-week cohort to ensure that student resumes capture the skills they have learned throughout their visit. Resume workshops will be led by the faculty collaborators at the coordinating institutions, with input from career counselors and SNL SRs.

Summer SQOL will be led by SNL **student/ESR interns** with guidance from SNL SRs and the collaborating teams who developed the lab manuals.

***BootQamp*** will be a semester-long immersion in QuLL during the fall semesters, with cohorts of up to 12 persons seeking upskilling opportunities in QIST. BootQamp will be modeled off similar deep dive immersive training programs at CNM-I focused on developing high technology workers in New Mexico. To ensure a low barrier to entry to the bootcamp education, there will be minimal prerequisites (ie basic pre-algebra and rudimentary computer skills). Any additional skills will be taught during BootQamp using the method of just-in-time math – teaching a mathematical concept and then immediately applying it in the lab to accomplish a task, enabling students to develop algebra, geometry, trigonometry, linear algebra, and numerical computation skills. Each mathematical teach-and-apply concept will be repeated several times throughout the course, with increased complexity, helping drive proficiency and retention.

Similar programs at CNM-I have been wildly successful in taking individuals with little/no technology background and preparing them for technology careers in less than 3 months. For example, the CNM-I Internet of Things bootcamp [14] students have a 92% graduation rate and have gone on to work at large tech corporations, the National Labs and other research facilities, and a variety of technology start-up companies. Approximately 60% of IoT graduates successfully secure jobs within a few months of graduating, on average more than doubling their pre-bootcamp salary. About 25% of the graduates take advantage of Credit for Prior Learning and their new confidence around STEM to continue their education towards a CNM associate degree. Many then continue on to a 4-year STEM degree. The remaining 15% of graduates start their own companies with the help of other CNM-I programs.

We will follow a similar model of engaging with QIST employers to understand the technical, hands-on, and process (problem solving, documentation, etc) skills that would most benefit their businesses and developing curriculum to meet those needs. We will also provide opportunities for QIST employers to regularly engage with BootQamp students through weekly career seminars and plan to directly connect students to open QIST job opportunities.

The CNM-I Internet of Things Bootcamp course designer and lead instructor, Brian Rashap, is a former Intel Corporation executive who managed large teams of engineers and technicians both in manufacturing and in facilities. We are excited to partner with Dr. Rashap to develop a first-of-its kind QIST BootQamp. Dr. Rashap will work with QIST SRs at SNL to develop the BootQamp curriculum, with additional input from our collaborating IHEs and support from GS on math implementation. BootQamp will also be supported by two year-round **student/ESR interns**, as well as operational technicians at FUSE Makerspace.

***Augmented Research*** will provide graduates of Summer SQOL and BootQamp with the opportunity to perform additional research projects during the spring semesters using QuLL equipment and experiments to fulfill senior research and/or graduate research requirements at their home institutions. This research will be led by their faculty advisors with additional guidance from SNL SRs and year-round **student/ESR interns**. Co-locating QuLL in the FUSE Makerspace also provides additional industrial manufacturing and fabrication equipment and expertise to researchers. Access to specific QuLL experimental equipment will be coordinated by SNL PMs and SRs if necessary, though collaboration will be encouraged whenever possible (for example if multiple researchers seek to use the same hardware for their experiments).

With these three programming thrusts, we expect to introduce up to 84 students per year to the variety of QuLL experiments and qubit technologies, providing them with valuable skill sets for advancing their education and careers in QIST.

1. **QuLL Curriculum and Lab Manuals**

The curricula/lab manuals will provide background information, detailed instructions for performing the chosen experiments, and the interpretation of the results for diverse educational levels and backgrounds. To ensure there is learning content suitable for community college students up to university faculty seeking to improve their understanding of QIST, the lab manuals will have three tiers. The first tier will be completely conceptual, allowing students to learn with no prerequisite STEM courses. The second tier will assume a math background including basic trigonometry, probability, linear algebra. The third tier will incorporate advanced math to provide deeper background and understanding of the learning outcomes. Each lab manual will also include a summary of skills that participants will gain from the experiment.

Because QuLL will introduce participants from a variety of education levels and disciplines to QIST, it is important that our collaborators span QIST experts and non-experts. QIST expert collaborators will guide non-experts in developing the experiments and provide the advanced math/subject matter expertise for the third-tier lab manuals. Our faculty collaborators from QIST-adjacent backgrounds will ensure the second-tier lab manuals are understandable to a diverse set of undergraduate learners. Our faculty collaborators at CNM and Growth Sector will ensure the first-tier lab manuals are accessible to first-year college students.

In addition to ensuring the material is academically accessible to our participants, we will also work to ensure that it is inclusive of and culturally relevant to the underserved communities within our state – particularly, Hispanic and indigenous communities. To this end, we will work with Diné scholars at NTU to connect QIST with the indigenous understanding of the natural world, natural elements, and energies and to create an awareness of how QIST might be used to study/solve problems relevant to these communities. We believe this work is crucial to engaging with these underrepresented communities.

In addition to the Summer SQOL lab manuals/curriculum, we will also develop a BootQamp curriculum. This effort will be led by CNM, CNM-I and Growth Sector to ensure it has low barrier to entry and meets the unique needs of students most likely to enroll in such upskilling programs. In particular, a just-in-time math approach will be utilized to introduce students to the necessary math concepts and skills and then immediately apply them in the lab for understanding and retention. We anticipate much of the QuLL experimentation can be supported with high school math, including algebra, geometry, trigonometry, and linear algebra, that can be taught in this applied manner. Our collaborators at CNM-I have extensive experience using this method for introducing the relevant math in other tech fields. Our collaborators at GS have additional experience providing intensive math readiness bridge programs for incoming college freshmen. With both CNM-I and Growth Sector working together, we will establish a BootQamp that addresses gaps in math background by quickly applying math concepts in experimental demonstrations. While the BootQamp curriculum requirements will differ in some ways from Summer SQOL, these two efforts will also have significant overlap, so each program’s resources can benefit the other.

In addition, the collaboration will have access to subject matter expertise in all of the above qubit technologies through SNL, where we have established research groups in neutral atoms, trapped ions, spin qubits, defect qubits, and photonics. SNL experts can provide additional guidance on the math and physics background and accuracy of the developed curriculum for both the Summer SQOL and BootQamp curriculum.

1. **Evaluations**

In addition to the programmatic evaluations provided by DOE SC through ORISE, we plan to implement additional evaluation of the lab manuals and programming for 1) gauging learning outcomes and effectiveness across our diverse participants, 2) fast turnaround of feedback for our specific programming, 3) improving materials and programming for future participants, and 4) ensuring program participants are receiving the support they need beyond the program activities to be successful in QIST pathways. This additional evaluation will be managed by Dr. Rachel Boren, Director of the New Mexico State University Southwest Outreach Academic Research (SOAR) Evaluation and Policy Center, and supported by her staff and doctoral students. SOAR serves as evaluators for grants across NMSU and the state, and Dr. Boren has over 10 years of experience as an evaluator in K-12 and higher education. She will make sure that all centralized evaluation data is collected for the current effort and that participants are tracked accordingly to report career paths, among other areas that may be requested.

The project team will collect multiple sources of data to determine QuLL impact on recruiting and retaining diverse students and populations in STEM and will be guided by our three overall objectives that seek to address these core areas. Our approach also includes evaluating more specific and relevant outcomes of interest within the overall goals of increasing recruitment and retention of diverse individuals in STEM. Our key outcomes and data sources are presented in the table below.

|  |  |
| --- | --- |
| **Key Outcomes** | **Data** |
| Recruit diverse participants into STEM | Participant demographics: Gender, race/ethnicity, first generation college status, army/veteran status, socio-economic status |
| Increase participant knowledge and interest in quantum: | End of program/experience participant feedback survey – questions about impact on understanding and interest |
| Prepare diverse participants for education and career in QIST: | End of program/experience participant feedback survey – questions about impact on intentions and future plans |
| Retain diverse individuals in STEM: | Follow up tracking: Check in survey or phone call about participant education/career and relation to quantum |
| Create partnerships between institutions and organizations: | Number of participating colleges/universities, other organizations involved in goal attainment |

In addition to the outcomes above, we will also use participant surveys to gather important feedback about the methods and activities, such as what they enjoyed and what can improve about the summer experiences, career development, and hands on experiences in order to make them more impactful. SOAR will prepare a report at the end of each year that will be shared with the funder/centralized evaluators (if asked) that will include a summary of all data collected up to that point. Dr. Boren will also discuss the report and SOAR’s main findings with the project team to help them identify areas for program improvement and to assess progress toward achieving their objectives.

1. **A Note on Sustainability**

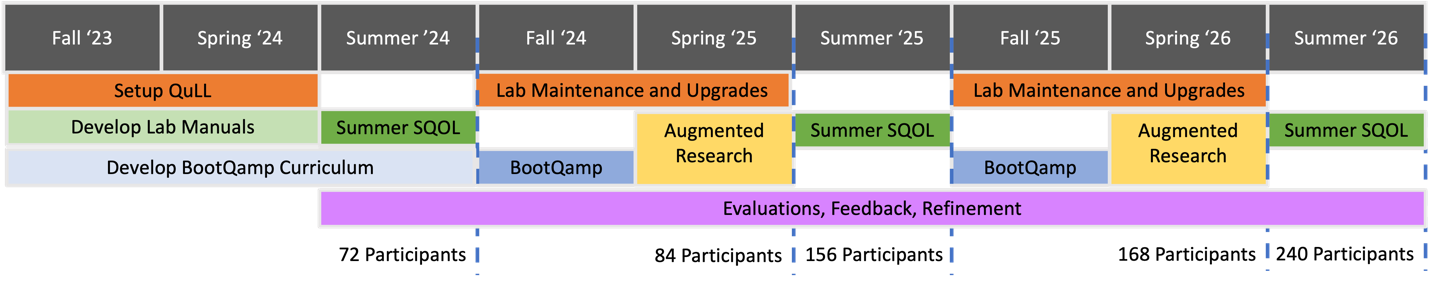
As part of this effort, we plan to engage with industry to better understand desired skill sets of incoming and upskilling employees. This engagement will take many forms, including continued participation in the QED-C Workforce Development TAC by several team members, attendance at QIST workforce development workshops, staying abreast of recent surveys and job posts to better understand QIST hiring needs, and direct engagement through meetings/emails/etc. Our goal is to make the QuLL experiments and learned skills match with industry expectations so our “graduates” can be well-positioned to apply for follow-on opportunities.

A stretch goal is to use this industry engagement to create opportunities to sustain the QuLL lab beyond this 3-year period of performance. We hope that by directly addressing industry workforce needs and skill sets, we can become a valued workforce training resource and establish partnerships and sponsorships to cover some of the continued costs of the Summer SQOL and BootQamps.

1. **Statement of Work and Timeline**

The statement of work listing all these associated tasks, the lead institutions for each, as well as timelines and milestones are listed below.

PROJECT TIMELINE



**1.  Setup QuLL Laboratory (Lead: SNL)**

**Timeline**: 09/2023-05/2024

**Description**:  Identify experimental demonstrations (QuLL team); Set up necessary laboratory infrastructure (SNL, CNM-I, CNM); Order equipment and materials (SNL); Set up experimental demonstrations (SNL – year-round **student/ESR interns** with support from SNL SRs)

**Milestone**:  Experimental demonstrations setup and ready for participants by May 31, 2024

**2. Develop Lab Manuals (Lead: CNM, UNM, NMSU, NMT, NTU, with support from SNL)**

**Timeline**:  09/2023-05/2024, 09/2024-05/2025, 09/2025-05/2026

**Description**:  Assign experiments to faculty at collaborating institutions (QuLL team); Develop multi-tiered lab manuals (QuLL team, year-round **student/ESR interns** led by faculty); Ensure accessibility, inclusivity, cultural relevance (QuLL team, CNM, NTU)

**Milestone**:  Lab manuals prepared and ready for participants by May 31, 2024.  Additional lab manuals for additional experimental demos as requested from industry engagements prepared and ready for future years.

**3. Summer SQOL (Lead: SNL with cohorts from CNM, UNM, NMSU, NMT, NTU, GS)**

**Timeline**: 06/2024-08/2024, 06/2025-08/2025, 06/2026-08/2026

**Description**:  Host cohorts of up to 12 students each for 2-week visits to QuLL (cohorts organized by faculty leads, experiments guided by dedicated **student/ESR interns** with support and training from SNL SRs and QuLL team); Provide time and travel support to participants (QuLL team); Provide resume workshop (QuLL team)

**Milestone**:  **72 participants with QuLL experience each summer, for a total of 216 students throughout the program**

**4. BootQamp (Lead: SNL, CNM, CNM-I)**

**Timeline**: 09/2024-12/2024, 09/2025-12/2025

**Description**:  Develop intensive BootQamp curriculum with just-in-time math (CNM-I, CNM, SNL); Connect with veterans, professionals, workforce development groups, and others to recruit participants (CNM-I, CNM, SNL); Engage with industry for relevant skills (CNM-I, CNM, SNL)

**Milestone**:  **Upskilling opportunities for 12 participants in each of the 2nd and 3rd school years for a total of 24 participants throughout the program**

**Task 5. Augmented Research (Lead: CNM, UNM, NMSU, NMT, NTU, with support from SNL)**

**Timeline:** 01/2025-05/2025, 01/2026-05/2026

**Description:** QuLL will be accessible to **students/ESRs** and faculty for additional research and other learning opportunities (QuLL team)

**Task 6:  Lab Maintenance and Add-Ons (Leads: SNL, CNM, CNM-I)**

**Timeline**: 09/2024-09/2026

**Description**:  Perform lab maintenance and upgrades (year-round **student/ESR interns**, guided by SNL researchers, and coordinated with CNM as needed); Develop additional experimental demonstrations as guided by industry or emerging QIST trends (SNL)

**Task 7:  Evaluations (Lead: NMSU)**

**Timeline**: 05/2024-09/2026

**Description**:  Evaluate learning content and attitudes for community college, undergraduate, faculty, and upskilling participants (NMSU); Use feedback to improve lab manuals, programming, and content as needed (QuLL team).

**IV. Collaboration and Mentorship Plan:**

QuLL participants include 11 faculty at 2-year and 4-year IHEs, 19 year-round students/ESRs annually, 72 Summer SQOL students/ESRs annually, and 12 BootQamp participants in each of the 2nd and 3rd years, in addition to SRs at SNL. The SNL PI will lead the collaboration, ensuring communication and coordination amongst collaborators, timely completion of all tasks, support from SRs as needed, awareness of follow-on opportunities for participants, and an inclusive and supportive environment for all. Our collaboration spanning students, faculty, national lab scientists, and cultural experts provides ample opportunities for mentorship and diverse resources for addressing technical, recruiting, and teaming challenges. Here we outline skills and opportunities and mentorship plans for participants of this project.

1. **Skills and Opportunities:**

**Participants in the Summer SQOL** will work through several QIST experiments during their two-week visit to QuLL, gaining skills/understanding that include interference, wave-particle duality, superposition, entanglement; ultrahigh vacuum, diode laser operation and alignment, optics and detection, spectroscopy, laser cooling, optical and magnetic and quadrupole trapping. Additionally, as graduates of Summer SQOL, those students will have the opportunity to participate in Augmented Research to fulfill degree requirements. They will also be better prepared for internship opportunities at Sandia, DOE National Labs, academia, and industry and for educational opportunities such as graduate school and postdoctoral positions as a result of their newly acquired skills. We will also advertise additional learning opportunities for participants such as Qu-REACH, QubitxQubit, etc [11,14].

**BootQamp** participants will gain all of the above skills and opportunities listed for Summer SQOL participants, but with a more immersive experience, allowing more time for additional math, programming, and troubleshooting skills. We also anticipate a brief independent research project as part of the BootQamp, so students will have the opportunity to present their research in a final workshop. They will also have the opportunity to interface with industry and national lab QIST researchers through career seminars and will be prepared for technician level positions upon completion of the BootQamp.

**Our year-round student/ESR interns** will gain all of the above skills and opportunities listed for Summer SQOL participants. In addition, they will gain experience with curriculum development, lab instruction, troubleshooting, leadership and communication. These students/ESRs will regularly interface with SNL researchers and will be encouraged to consider opportunities for full time follow-on positions at SNL. They will also be better prepared for internship and career opportunities in QIST research and/or education. SNL student/ESR interns who run the Summer SQOL will also have the opportunity to attend QSEEC and IEEE Quantum Week.

**Faculty collaborators** will have the opportunity to participate in Summer SQOL to hone additional skills outside of or complementary to their areas of expertise. Gaining experience with the QuLL lab experiments will provide the awareness and experience to bring similar modules into new or existing courses to expose additional students to QIST at their home institutions. Faculty will also have the opportunity to lead Augmented Research projects with their students, gaining access to equipment that may be prohibitively expensive for their home institutions. Participation will also include opportunities to interact with SRs at Sandia and other collaborating institutions, and awareness of opportunities such as joint appointments at SNL that would give additional access to SNL resources and facilities.

1. **Mentoring Plan:**

In [15], mentorship was listed as the most important factor in STEM graduate student retention, with additional studies indicating the importance of having mentors who are familiar with the challenges facing underrepresented minorities in STEM [16]. Having access to broad opportunities for mentorship through this collaboration has the potential to be very impactful for the underrepresented participants that we are aiming to reach in this program.

There are ample opportunities for mentorship due to the collaborative nature of this project and team. As we develop the lab manuals, faculty, SNL SRs, and year-round student/ESR interns will meet regularly to discuss needed support and challenges in teaching and communicating topics that are usually reserved for graduate-level physics students. The year round student/ESR interns will be mentored by the faculty leads at their institutions, but also have the opportunity to seek mentorship from any other collaborators including SNL SRs. BootQamp participants will have regular career seminars with industry and national lab SRs providing mentorship opportunities beyond the QuLL collaborators. Summer SQOL participants will be mentored by faculty collaborators at their institutions in preparation for Summer SQOL, but will also have opportunities for peer-to-peer mentorship and mentorship with year-round student/ESR interns and QuLL SRs.

**V. Summary**

To the best of our knowledge, the QuLL User Facility would be a first-of-its-kind facility, with potential to draw nation-wide interest and provide a crucial training need for **hundreds of next-generation quantum workers** and prepare a diverse workforce for DOE-SC programs for years to come. With guidance from quantum researchers at Sandia National Labs and statewide collaborators from academia and education/workforce non-profits, QuLL will be largely community driven with:

* relevant experiments determined by national labs, industry, and university researchers,
* lab manuals/curricula developed by a coalition of New Mexico educators and QIST SRs,
* programming staffed and guided by student interns as much as possible,
* cultural relevance interwoven to engage with the diverse communities within our state,
* and a common goal of providing hands-on QIST training to participants from all backgrounds and across the full higher education spectrum.

**APPENDIX 1: BIBLIOGRAPHY & REFERENCES CITED**

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**APPENDIX 2: FACILITIES & OTHER RESOURCES**

This project is a collaboration among multiple institutions with supporting facilities and resources. Lab manual development and student recruitment and training will occur among the partnering IHEs, while the main QuLL facility will be hosted in CNM Ingenuity’s FUSE Makerspace.

**CNM Ingenuity Facilities and Other Resources**

CNM Ingenuity, a New Mexico Research Park entity at Central New Mexico Community College, has a mission to promote the public welfare and the prosperity of individuals and to foster economic development within both the private and public sectors. CNM Ingenuity supports accelerated training opportunities, as well as partnerships that foster job creation. Our accelerated training opportunities are designed to address key workforce needs in our local economy, such as in technology and healthcare, while equipping learners with the skills they need to secure rewarding careers that improve their quality of life. CNM Ingenuity also provides entrepreneurs with a wide variety of support services to help their businesses grow and thrive, which contributes to economic development and job creation. CNM Ingenuity regularly embarks on efforts that have never been achieved before in higher education, allowing us to be at the forefront of innovation in higher education.

**FUSE Makerspace Facilities and Other Resources**

FUSE Makerspace is a community center with tools that allow members to design, prototype, and create manufactured works. FUSE is housed within CNM Ingenuity, the workforce training arm of Central New Mexico Community College (CNM), giving our members access to affordable, high-quality classes as well as mentoring from other makers and community members.

FUSE offers basic operations and safety workshops in all shop areas, including wood, metal, welding, mill and lathe, CNC, Adobe Illustrator, CAD, 3D printing, vinyl printing, screen-printing, powder coating, and laser cutting and engraving. These workshops are open to members and non-members alike. We also offer a rotating selection of specialty classes and host various events and markets. During the past year, we offered approximately 200 workshops serving 800 people. As of April 2023, FUSE has 78 members.

CNM Ingenuity’s Internet of Things & Rapid Prototyping program is based at FUSE Makerspace. Internet of Things (IoT) is a ten-week program that teaches participants to code and build smart devices. It covers C++, electric circuits and soldering for circuit boards, Solidworks 3D design software, 3D printers, laser cutters, and wood and metal fabrication equipment.  It’s a hands-on experience and a great pathway for students transitioning from manufacturing and mechanical work to the technology field; people who want to work in robotics; and artists, tinkerers, and anyone interested in the how and why of the way things work.

**QuLL Facilities and Other Resources at FUSE Makerspace**

QuLL will be hosted at CNM Ingenuity’s FUSE Makerspace in downtown Albuquerque, NM. The industrial tools and equipment described above will be accessible to QuLL participants in the BootQamp and Augmented Research programs to assist with independent research projects. FUSE Makerspace is staffed by several machinists, technicians, safety officers, and security personnel to support the makerspace members and associated activities.

QuLL space will be co-located with the makerspace in a 1100 square foot lab with standard power, sink, and fume hoods already installed. We anticipate adding five 4’x6’ optics tables for experimental support, in addition to workbenches, computer stations, and whiteboards. None of the experiments that we’ve chosen for QuLL require any specialized facilities or infrastructure.

Despite being led by Sandia, we felt it important to host QuLL offsite to facilitate easier access to the lab from the many non-Sandian participants that we hope to attract. Facilities at FUSE Makerspace allow easy access to participants without the many security requirements that would be needed to access a space onsite at Sandia.

**Sandia National Laboratories Facilities and Other Resources**

Sandia National Laboratories is a U.S. DOE NNSA FFRDC laboratory that supports numerous federal, state, and local government agencies, companies, and organizations. Sandia is a premier science and engineering laboratory for national security and technology innovation, working at the forefront of innovation, engaging broadly in collaborative research with universities and companies, and exploring new high impact science and technology through discretionary research projects. Sandia’s Quantum Information Program targets advances in the understanding and mastery of quantum systems for enabling the manipulation of information with greater sensitivity, speed, and security than is possible with classical information processing methods. The program spans the entire breadth of Quantum Information Science (QIS) through focused research programs and by utilizing its unique technical capability areas: micro-electronics and quantum device fabrication, nanotechnology, tailored materials, and high-performance computing. With both established and exploratory quantum programs in both California and New Mexico, Sandia has expertise and capabilities in a variety of disciplines, including both theoretical and experimental work and multiple QIS platforms and applications. While QuLL will be located off-site at facilities provided by CNM Ingenuity, QuLL team members will have access to Sandia experts in QIS. Additionally, Sandia team members, including Sandia’s student/ESR interns, will have access to Sandia QIS facilities to support the development of the laboratory and experiments. Specific Sandia assets that could provide useful for this effort include:

* **Microsystems Engineering, Science and Applications (MESA)**: Sandia’s MESA Complex integrates the numerous scientific disciplines necessary to produce functional, robust, integrated microsystems for critical DOD and DOE missions, and represents the center of Sandia's investment in microsystems research, development, and prototyping activities. Through sustained investment in research and development activities over the past 15 years, Sandia’s MESA facility has built expertise fabricating quantum processors, quantum sensors, and quantum communication devices that it distributes throughout the world. MESA presents the opportunity for CSU students and faculty to learn from Sandia’s highly specialized expertise and advance manufacturing in the QIST field.
* **Quantum Systems Accelerator:** The Quantum Systems Accelerator has strengthened the California-New Mexico partnership in advancing the quantum research ecosystem and supports a network of national labs, industry, and universities that addresses a broad spectrum of technological challenges. Sandia serves as the leading partner for QSA and is focused on leveraging other QSA partners, such as Berkeley Labs in CA, to make workforce development a critical element of the initiative.
* **Quantum Scientific Computing Open User Testbed – QSCOUT:** QSCOUT is a 5-year DOE program funded by the Office of Science’s Advanced Scientific Computing Research (ASCR) program to build a quantum testbed based on trapped ions that is available to the research community. As an open platform, it will not only provide full specifications and control for the realization of all high-level quantum and classical processes, it will also enable researchers to investigate, alter, and optimize the internals of the testbed and test more advanced implementations of quantum operations. QSCOUT provides unique insights into quantum hardware and can serve as a key resource for workforce development and technical engagements for CSU.

**Central New Mexico Community College Facilities and Other Resources**

**Central New Mexico Community College (CNM)** is New Mexico’s largest undergraduate higher education provider with a Fall 2022 enrollment of over 19,000 students across five campuses and four additional training facilities. 53% of the student population is Hispanic/LatinX, 6% Native American, and 3% African American. STEM academic pathways include biology, biotechnology, physics, engineering, mathematics, geology and geography in the School of Math, Science and Engineering. The School of Business, Hospitality and Tourism offers computer science, and the School of Skilled Trades and Arts offers a number of applied technology programs. CNM ranks first in the nation in number of associate degrees awarded to Hispanic and Native American students, and second in the number of associate degrees and certificates awarded to all students. CNM is also a federally recognized Hispanic-Serving Institution.

**Learning Facilities**—CNM personnel involved in the management of the grant will be located on CNM’s Main Campus in southeast Albuquerque. Each will have office space, a computer with all software necessary to complete the proposed work, and access to computer labs and technology-rich conference rooms. All of CNM’s conference rooms are equipped with wireless access and either have computers or the capability to connect laptops wirelessly to project on the screen to aid in meetings conducted virtually.

STEM courses are offered on all campuses and some of the training facilities. Main campus offers the widest option of STEM courses. For the School of Math, Science and Engineering, the majority of STEM courses are offered in Max Salazar Hall, Jeanette Stromberg Hall, and the Lab Science Building. The Lab Science Building was renovated in 2016 and CNM finished an extensive remodel of Max Salazar Hall in 2020. All newly constructed and renovated buildings at CNM campuses achieve at minimum, LEED Silver Certification. The MS renovation team aspired to achieve LEED v4 Platinum Certification.

The Lab Science Building is two stories tall and 43,000 square feet. The renovated facility has five Biology labs (three are for general Biology labs and two are for Anatomy and Physiology), three Chemistry labs and one Astronomy/Physics lab. In addition to the labs, there are three regular-sized classrooms accommodating up to 30 students and two large classrooms, accommodating up to 50 students. One of the Biology labs is also used for Geography lab classes and Earth and Planetary Science lab classes. Approximately 2,000 students take lab classes in the Lab Science Building each term, and many others have lecture classes in the Lab Science Building classrooms.

Students will also have access to meeting and conference rooms with various capacities, computer laboratories, student lounges, and the CNM Library.

**Office of Digital Strategy (ODS) & ITS**—These departments provide technical assistance to all faculty, staff, and administration, including support for software, desktop environments and peripherals, network connectivity, computer password maintenance, and hardware and software configurations. ODS serves CNM’s students and employees by creating a data-driven culture through highly available, secure, easily maintainable, and clearly defined information including accreditation, institutional research, surveys and assessments.

**CNM’s Business Office**—The Business Office has systems and processes in place to manage contracts and grants and is always timely and accurate in reporting. CNM is fiscally stable and has a long history of successfully managing federal funds and programs. It is versed in the federal reporting process as a grantee or pass-through grantee for agencies such as the Department of Education, Small Business Administration, Department of Health and Human Services, and Department of Labor. The CNM Business Office fiscally manages over $40 million in restricted funds each year.

CNM adheres to Generally Accepted Accounting Principles (GAAP) and reporting directives from the New Mexico Higher Education Department and other regulatory entities. CNM utilizes the Ellucian Banner software to track revenues and expenditures, which allows the college to account for allowable grant and match expenses and income streams, and provides accuracy in the monitoring of grant transactions and billing. CNM’s Purchasing Department manages procurement for services in alignment with the New Mexico Procurement Code (the department annually oversees approximately 4,000 purchase orders worth $80 million). CNM’s financial statements and internal controls are reviewed annually by independent auditors.

The Contract and Grant Accounting Office has a staff of three accountants. Minimum qualifications for this position require a bachelor's degree in Accounting or similar degree, three years of relevant experience, and at least 15 academic accounting hours. The office is responsible for managing grant awards and all subawardee monitoring for CNM and its two affiliated non-profit organizations. Each accountant works with PIs on a daily/weekly basis and is required to provide budget status reports monthly.

**Student Wrap-Around Support Services**—All CNM students have access to wrap-around support services designed to help them succeed academically and flourish in life. Connect Services supports students from the moment they enroll with academic coaches, online advisement, career exploration, transfer information, Job Connection Services, food assistance, and resources to find financial assistance for child care. The Disability Resource Center assists students with documented physical, mental, learning, visual, speech, or hearing disabilities. The Veterans Resource Center provides resources and help for veterans and their families who currently attend or plan to attend CNM.

**Univeristy of New Mexico Facilities and Other Resources**

The proposed activities at the **University of New Mexico (UNM**) will be conducted at the Center for High Technology Materials (CHTM). CHTM is an interdisciplinary research organization with faculty and students representing the departments of Electrical and Computer Engineering, Physics and Astronomy, Chemistry and Chemical Biology, Chemical and Biological Engineering, Mechanical Engineering, and interdisciplinary graduate programs in Optical Science and Engineering, Manufacturing Engineering, and Nanoscience and Microsystems Engineering. Its mission is to encourage and strengthen interactions between the University, government laboratories, and private industry, and to promote and assist in economic development within New Mexico. At present 23 faculty, approximately 60 graduate students, approximately 10 undergraduate students, and 27 staff (20 technical and 7 administrative) are associated with the Center.

CHTM occupies a dedicated 60,000 sq. ft. building, with a 3500 sq. ft. cleanroom and 11,000 sq. ft. of laboratory space with supporting chase areas. Six lab spaces are situated on a vibration isolation pad. Professional staff of engineers and technicians is available to assist in the maintenance and operation of all equipment and facilities.

**New Mexico Institute of Mining and Technology Facilities and Other Resources**

The following laboratory facilities, instrumentation, equipment in the New Mexico Tech will be available for this project.

**The Laboratory of Dr. Nikolai G. Kalugin** at New Mexico Tech is located in the Jones building on the campus of NMTech. It is equipped for electrical and optical characterization materials, including electroluminescence, absorption/transmission/reflection measurements, photoconductivity and photovoltaics, in a very wide spectral (wavelengths from 0.5 μm to 500 μm) and temperature (from 1.4K to 300K) range. Dr.Kalugin’s group also uses the **facilities of the Materials Engineering Department of New Mexico Tech** for testing of graphene, MoS2, and related devices.

**Profesor Sanchari Chowdhury** has her own lab space(600 sqft) and office (120 sqft), including a synthesis facility containing fume hoods equipped with the Schlenk line and stirring hot plates for synthesis of functional epoxies capable of reversible polymerization; Fume hoods for nanoparticles synthesis; and Vacuum ovens (×2) for thermal treatment.

The machine shop and electronic shop at New Mexico Tech Facility will be used when needed.

Computers in all the above labs and in a graduate student office of NMT Chemical Engineering department will be used for the data analysis, calculation and writing.

**Professor Wenyang Gao Lab:** The department of chemistry at New Mexico Institute of Mining and Technology is located in the newly inaugurated Lopez Hall, a 40,000 sq. ft. facility dedicated for chemistry. Gao has been assigned 788 sq. ft. of laboratory space, which was specifically designed and equipped for synthetic chemistry research. The laboratory has four 6-ft. hoods for handling of chemicals and ample bench and storage space. Services in the laboratory include cold and hot water, vacuum, natural gas and compressed air lines.

**Navajo Technical University Facilities and Other Resources**

**Space, Capital Equipment, and Access to Existing Facilities.**

Navajo Technical University maintains 3 undergraduate laboratories for Physics, Chemistry, and Biology teaching and research, libraries, and research facilities on its main campus. These facilities support strong science and engineering programs. All these resources will be fully available to the PI/Co-PIs of this project. Some of these resources related to the proposed project are described below.

***NTU Physics Department Core Facilities***

The approximately 2000-square-foot NTU Physics Lab is located at the TECH Building. The Lab has the capacity for 20 students at a time. It is equipped for teaching and research with workbenches and enough space for student demonstrations. The room has built-in demonstration tables and a big lecturing screen. The Lab is equipped with mechanics, optics, electricity, and magnetism experiments for physics courses ranging from introductory to calculus-based physics courses.

***NTU-Chemistry Department Core Facilities***

**Wet Chemistry Laboratory:** The wet chemistry laboratory contains basic wet chemistry synthesis with a fume hood, balance, chemicals, DI water plant, filtration, hotplates, ultrasonic bath, and enough space to conduct research.

**Major Instruments:** The chemistry lab has a bi-potentiostat, rotating ring-disc electrode setup, pH meters, UV-vis spectroscopy, Atomic absorption spectroscopy, FT-IR spectroscopy, and Arbin battery cycler (4 channel).

**Computers and Software:** The chemistry lab has 3 PCs (desktops) available for students and laboratory personnel with Windows, Microsoft Office, COMSOL Multiphysics, and SPARTAN software.

Independent **Research Microfluidics Laboratory:** An independent research microfluidics laboratory includes a Micropipette Puller Machine, New Era Pumps (x4), an Amscope fast camera microscope with a camera, consumables for creating glass capillary microfluidic devices, and a computer for data collection with software.

**New Mexico State University Facilities and Other Resources**

The Department of Physics is located in the 60,000-square-foot Gardiner Hall, including ~1,500 square-foot teaching labs. The teaching labs provide tables for students to conduct experiments individually or in groups. Most of the lab space is used for hands-on experimentation to complement introductory physics courses, featuring mechanics, optics, electricity, and magnetism experiments. The lab spaces also support experiments in thermodynamic and modern physics in higher level courses.

**Southwest Outreach and Academic Research Facilities and Other Resources**

For the evaluation, the Southwest Outreach and Academic Research (SOAR) office at NMSU is well equipped to handle the necessary tasks outlined in the narrative. SOAR has all Microsoft Office tools available for our staff, with sufficient personal computers for all students and staff as well. SOAR is also a private suite with additional private offices. NMSU also maintains REDCap (Research Electronic Data Capture), the secure survey tool that we will use to input all hard copy data and to collect any online data as well. For data sharing among the SOAR team, they regularly use password protected storage in NMSU OneDrive, and the SOAR Director only grants access to project data for the specific SOAR staff who need it.

**APPENDIX 3: EQUIPMENT**

This is a collaborative project spanning multiple institutions, though equipment is only expected to be available at Sandia National Labs and CNM Ingenuity’s FUSE Makerspace. The bulk of the specific equipment for QuLL will be purchased through this funding opportunity. Equipment listed here from our other partner instutions may be available to participants at those institutions as complementary equipment which can provide additional exposure and opportunities to participants.

**FUSE Makerspace Equipment**

FUSE Makerspace is a community center with tools that allow members to design, prototype, and create manufactured works. FUSE is housed within CNM Ingenuity, the workforce training arm of Central New Mexico Community College (CNM), giving our members access to affordable, high-quality classes and equipment as well as mentoring from other makers and community members. FUSE offers a large selection of industrial manufacturing and fabrication tools, including wood, metal, welding, mill and lathe, CNC, Adobe Illustrator, CAD, 3D printing, vinyl printing, screen-printing, powder coating, and laser cutting and engraving. FUSE also offers basic operations and safety workshops in all shop areas which are open to members and non-members alike. This equipment will be available to QuLL participants in the BootQamp and Augmented Research programs.

**Sandia National Laboratories Equipment**

Sandia National Laboratories is a U.S. DOE NNSA FFRDC laboratory that supports numerous federal, state, and local government agencies, companies, and organizations. Sandia is a premier science and engineering laboratory for national security and technology innovation, working at the forefront of innovation, engaging broadly in collaborative research with universities and companies, and exploring new high impact science and technology through discretionary research projects. Sandia’s Quantum Information Program targets advances in the understanding and mastery of quantum systems for enabling the manipulation of information with greater sensitivity, speed, and security than is possible with classical information processing methods. The program spans the entire breadth of Quantum Information Science (QIS) through focused research programs and by utilizing its unique technical capability areas: micro-electronics and quantum device fabrication, nanotechnology, tailored materials, and high-performance computing. With both established and exploratory quantum programs in both California and New Mexico, Sandia has expertise and capabilities in a variety of disciplines, including both theoretical and experimental work and multiple QIS platforms and applications. Sandia equipment will be made accessible to Sandia researchers and interns as is appropriate to support the development of QuLL objectives. This could include manufacturing and fabrication equipment or laboratory equipment used in ongoing QIS experiments at Sandia spanning trapped ions, neutral atoms, photonics, superconducting qubits, and silicon quantum dots.

**University of New Mexico Equipment**

The Center for High Technology Materials (CHTM) facilities include a complete, vertically integrated line of equipment necessary for design, growth, fabrication, and testing of optoelectronic devices. The Epitaxial Growth Facilities consist of four reactors capable of growing very high quality III-V semiconductor devices, including lasers, detectors, photovoltaics and electronic devices. A separate Crystal Growth Facility building houses one MOCVD system growing GaN, InGaN, and AlGaN compounds, for a wide range of optoelectronic and electronic device and materials. Cleanroom and Device Fabrication Facilities comprise four bays with associated service chases. The first bay, designated for photolithography and rated at class 100 or better cleanliness, contains two UV mask aligners, a microscope with a CCD camera and thermal printer, two spinner stations, a development bench, several ovens for photoresist baking, a metal lift-off station, and two solvent benches. The remaining three bays are rated at class 1000 or better. The second bay houses an acid and a base wet benches, a stylus profilometer, two reactive ion etchers with desired gas capabilities, a rapid thermal processor, a rapid thermal annealer, an oxygen plasma photoresist descummer, and an inspection scanning electron microscope. The third bay is dedicated to a reactive ion beam etching system, and two electron beam metal evaporators. The fourth bay has an ellipsometer and a load-locked inductively coupled plasma etcher utilizing chlorine, boron trichloride, silane, hydrogen, argon, and nitrogen process gases. A second tool, an electron cyclotron resonance plasma processor utilizes argon, silane, silicon tetrachloride, hydrogen, nitrogen, and oxygen process gases. An evaporator is dedicated to dielectric film growth, and a plasma enhanced chemical vapor deposition system is dedicated to silicon nitride film growth. Other device fabrication facilities, located outside the cleanroom, include an oven modified especially for steam oxidation, a wire bonder, a laser scriber, a lapping/polishing machine, and a die cutting saw.

CHTM has a wide range of material characterization equipment that allows us to fully analyze a variety of nanocrystalline materials. This equipment includes optical microscopy, a high-resolution field-emission scanning electron microscope, an atomic force microscope, a scanning tunneling microscope capable of performing localized capacitive measurements, a field-emission scanning electron microscope with backscatter electron detector and energy dispersive x-ray analysis capability, located on a vibration isolation pad, a scanning near-field optical microscope, an FTIR instrument for infrared measurements, a spectrophotometer, an XRD apparatus, etc.

The Integrated Optoelectronics Laboratory headed by Prof. Osiński contains a two-stage, Gifford-McMahon (G-M) cycle cryo-refrigerator operating in closed loop with a temperature controller for measurements down to 10 K, a customized cryogenic testbed with 100-GHz microwave connections and optical fibers reaching the 4 K stage, various temperature controllers, current sources, voltage sources, light sources, detectors, measurement equipment, monochromators, integrating sphere, optical spectrum analyzer, lifetime spectrofluorometer, wire bonder, optical fiber splicer, etc.

**New Mexico Institute of Mining and Technology Equipment**

Within the laboratory of Dr. Nikolai Kalugin, the following equipment will be available for this project:

* HORIBA Jobin-Yvon LabRAM Aramis micro-Raman system. The 532nm and 785 nm lines of a solid state lasers and the 632.8 nm line of a HeNe laser are used for excitation.
* The advanced step-scan Fourier Transform Infrared Spectrometer (Thermo-Nicolet Nexus 870), equipped with full set of beamsplitters and detectors ( Si liquid Helium-cooled bolometer the far-infrared/ THz region, liquid Nitrogen-cooled MCT and InSb detectors for the mid-infrared, Si photodiode for near-infrared and visible spectral regions)
* Ametek-made amplifiers and lock-in amplifier
* Tektronix 3052B oscilloscope
* Keithley multimeter and source meter (K2000 and K2400)
* Custom-made low-noise electronics (suitable for extremely low-noise measurements of phototransport properties of carbon nanotube field-effect transistors)
* High magnetic fields are available using the cryogenic superconducting magnets 8T Spectramag (Oxford Instruments, UK) and 8T magnetotransport measurement system (American Magnetics Inc) with the sets of control equipment and power supplies.
* Growth of 2D materials: for growth of graphene, MoS2 and GaSe, Dr.Kalugin’s group uses the custom-made chemical vapor deposition (CVD) setup. The setup combines quartz growth reactor, furnace (Thermo Blue Ray), equipment for temperature and gas flows control, and two-cascade vacuum system for control and maintenance of growth pressure. The vacuum system allows graphene growth on catalytic substrates (Cu, Ni) in both ambient and low-pressure variants, and growth of other 2D materials from corresponding sources. In growth, we use mixtures of methane, argon, and hydrogen.
* For optical experiments in Far- and Mid-IR region, Dr.Kalugin’s group has the variety of laser sources, including Far-IR p-Ge and quantum cascade lasers ( emitting in the wavelength range of 100-300 mm), and the Synrad CO2 laser emitting in the 10 mm-range. For cryogenic/magnetic field experiments with Far/Mid-IR irradiation, Dr. Kalugn’ group uses custom design ctyo-inserts equipped with copper waveguides , with KBr and ZnSe IR-transparent windows.

Equipment is also available in the Materials Engineering Department of New Mexico Tech for testing of graphene, MoS2, and related devices:

* Nikon Eclipse 150 optical microscope equipped with color CCD camera
* Variable Pressure Scanning Electron Microscope Hitachi S3200N with Energy-Dispersive X-ray (EDX) analysis capability
* Field-Emission SEM Hitachi S4100
* UV/VIS spectrometers Beckman Coulter DU-730
* Auger spectrometer Perkin Elmer PHI-600

Equipment in S.Chowdhury lab includes:

* Fourier-transform infrared spectroscopy (FTIR) equipped with the accessories for diffusion reflectance, temperature controlled praying mantis reaction chamber and Attenuated total reflectance options to determine formation of reaction products and conversion of the reverse reaction: Thermo Nicolet Nexus 8700,

### Thermoscientific UV-Vis Spectrophotometer with integrating sphere for the measurement of diffusion reflectance and also with Peltier control and cooling unit

### Optical microscopes equipped with CCD camera for studying 3D printed structure.

### Spin coater and Dip coater

### Different wavelength LED light source (Ranging from 365 nm to 800 nm)

### Thermolyne Furnace

### Vulcan Furnace

### QSonica Probe Sonicator

### Spectrofluorometer

Professor Gao’s synthetic laboratory features four Schlenk lines for air-free synthesis and 8 hot plates, as well as two refrigerators. Other major equipment in the laboratory includes an autosorb iQ gas sorption analyzer from Quantachrome Instruments, a DTG-60 unit from Shimadzu for simultaneous thermogravimetric and differential thermal analyses, a mixer mill MM 400 from Retsch for mechanochemical synthesis, a Thermo Nicolet AVATAR 370 DTGS Infrared Spectrometer with a smart performer ATR accessory, a solvent purification system (THF, dichloromethane and diethyl ether), two rotary evaporators connected to circulators/chillers, two glassware drying ovens, three programmable gravity convection ovens for solvothermal/hydrothermal reaction, one immersion cooler for –40 °C to –90 °C reaction temperatures, and one Buchi Reveleris X2-UV Flash Chromatography system. Our laboratory also owns two analytical balances, one K-400 stereo microscope, and two dozen of autoclaves. Meanwhile, the Gao laboratory has two laboratory desktop computers (one Windows PC and a Mac) equipped with printers and access to Internet. Software for preparing presentations and word processing, analysis of NMR data and chemical drawing (ChemDraw) is installed and available on each of these computers. A network attached storage from Synology Diskstation DS220+ with a storage capacity of 10 TB is available for the Gao group. Prof. Gao also has an office laptop, with the same capabilities.

**Navajo Technical University Equipment**

**Equipment in NTU Physics Lab:** Basic kinematics and dynamics complete lab sets (from PASCO Scientific Lab Equipment), simulations, and virtual experiments on Newtonian mechanics, electricity and

magnetism, Optics, conservation of energy and momentum, and rotational motion.

The Lab also has advanced complete lab sets/kits for optics, fluids dynamics, electricity and magnetism, sensors, interfaces, and data collection and analysis software from PASCO Scientific Lab Equipment Company.

**Computers, Software, and Printers in NTU Physics Lab:** The Physics Laboratory is equipped with 15 PC desktops with printers available for students and laboratory personnel. All of the computers are equipped with Windows and Microsoft Office, Matlab/Simulink, COMSOL Multiphysics, PASCO Capstone™, PASCO SPARKvue, and Model 850 Universal Interface modules, which allow for wired and wireless connectivity with physics equipment. Additionally, these computers can run simulations and virtual experiments developed by the PASCO Lab Equipment Company.

**Equipment in NTU Wet Chemistry Laboratory:** The wet chemistry laboratory contains basic wet chemistry synthesis with a fume hood, balance, chemicals, DI water plant, filtration, hotplates, ultrasonic bath, and enough space to conduct research.

**Major Instruments:** The chemistry lab has a bi-potentiostat, rotating ring-disc electrode setup, pH meters, UV-vis spectroscopy, Atomic absorption spectroscopy, FT-IR spectroscopy, and Arbin battery cycler (4 channel).

**Computers and Software:** The chemistry lab has 3 PCs (desktops) available for students and laboratory personnel with Windows, Microsoft Office, COMSOL Multiphysics, and SPARTAN software.

**Independent Research Microfluidics Laboratory:** An independent research microfluidics laboratory includes a Micropipette Puller Machine, New Era Pumps (x4), an Amscope fast camera microscope with a camera, consumables for creating glass capillary microfluidic devices, and a computer for data collection with software.

**New Mexico State University Equipment**

**Physics Lab Equipment:** Mostly pre-assembled kits (PASCO Scientific Lab Equipment) for students for hands-on exploration of course content, including Newtonian dynamics, impulse, momentum, and rotational motion; kits for electrical circuits, magnetism.

**Computer Lab Equipment:** The computational lab space at NMSU Physics hosts ~20 PCs, accessible to all Physics and Engineering Physics students, they run Windows and Microsoft Office, and provide access to Matlab/Simulink, and Mathematica.

**APPENDIX 4: DATA MANAGEMENT PLAN**

This effort will generate data falling into three main categories: Evaluation data, Lab manuals and curriculum data, and independent research data. **Evaluation data** will include:

1. Evaluation data: Data generated through participant surveys and other assessment tools aimed at determining the effectiveness of the project elements.
2. Student records data: Academic and demographic information for participants in all planned programming, including enrollment year, major, and GPA.

This data will be collected and managed by the SOAR team with specific details and information outlined in the **SOAR Evaluation Data Management Plan** section below.

**SOAR Evaluation Data Management Plan**

Evaluation data collected will include participant surveys and demographics. Hard copy surveys and forms will be transferred into REDCap for data entry. REDCap (Research Electronic Data Capture) is a FERPA compliant tool created by the National Institutes of Health that NMSU manages. Online surveys will be collected using a REDCap link that participants will complete like a regular survey. Data will be stored in Excel for analysis and summaries will be created in Word. Hard copy data will be kept for three years per Institutional Review Board (IRB) regulations and then deleted.

All data collection, retention, and storage will follow the guidelines established by the IRB at New Mexico State University. The evaluator will ensure IRB approval is received prior to any data collection initiation and will work with the PI to make sure all IRB rules for data collection, storage, and presentation are adhered to.

Evaluation data will be stored securely in password protected storage that only the SOAR team has access to. REDCap is also very secure as it requires two-factor authentication to access. Hard copy surveys will be kept in locked offices by those who are collecting the data on site.

Access to all electronic data will only be for those on the SOAR team who are involved in the evaluation. Though project staff will help gather hard copy surveys, only SOAR will have access to the full datasets that include all individual level participant information. We are gathering participant demographics that fall within FERPA regulations and will ensure that demographic information is secured along with the survey data. Data will also only be reported in aggregate and never at the individual level.

If requested by the funder, de-identified data will be made available with any identifiers removed that would breach participant confidentiality.

**Lab Manuals and Curriculum Data Management Plan**

This project will produce lab manuals to accompany the experimental setups in the laboratory and a bootcamp curriculum. These lab manuals and curriculum will be created with the goal of clear communication to a broad audience of participants, in formats produced for external sharing and public dissemination for the purposes of communicating methods. These records will be captured at the Sandia corporate level using the formalized web-based Review and Approval (R&A) system. This system provides a methodology for management authorization of the release of information, and also ensures all documents are captured in the Sandia Digital Archive, currently housed within the EIMS FileNet, to provide long-term electronic records retention and availability for research validation for at least 10 years. In addition, once approved for public release, these materials will be made available on a project website created and maintained by Sandia National Laboratories.

**Independent Research Data Management Plan**

Additional data may be generated throughout the project in the form of lab demonstration results, observations, and measurement and recorded either manually in written or digital lab books or automatically, as a result of experimental demonstrations/exercises during the Summer SQOL and BootQamp or as a result of independent research performed by our BootQamp participants or collaborating IHEs. When appropriate, this data will be synthesized for public release and captured at the Sandia corporate level using the formalized web-based Review and Approval (R&A) system.

**Additional Considerations**

When appropriate, raw data will be synthesized into formats produced for external sharing and public dissemination for the purposes of communicating results and enabling validation of results. These records are captured at the Sandia corporate level using the formalized web-based Review and Approval (R&A) system. These records may also be made available on a project website created and maintained by Sandia National Laboratories.

Peer-reviewed publications produced by this project that are approved for unlimited release are captured externally by DOE’s Office of Science and Technology Information ([www.osti.gov](about:blank)), where the documents can be accessed by the public either at that web address or at a number of private external search engines. Research data displayed in publications resulting from the proposed research will be made available immediately on the hosting journal website as Supplementary Information (SI); as archived data at [www.osti.gov](http://www.osti.gov); and, on request, via Sandia’s Digital Archive.

Communication formats typically include presentations (.PPTX), Sandia Reports (SAND reports), conference abstracts, and journal articles (.DOCX or .PDF). Data required for validation of published research results will be fully described to include data structure, file formats, associated metadata, and processes used to generate resulting dataset. Datasets approved for public release will be registered at the Office of Scientific and Technical Information (OSTI) and assigned a persistent Digital Object Identifiers (DOI) using one of the approved Data ID services used by OSTI.

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**APPENDIX 5: PROMOTING INCLUSIVE AND EQUITABLE RESEARCH (PIER) PLAN**

This project will provide opportunities for student participants through Summer SQOL and Augmented Research, and for upskilling participants through BootQamp. For Summer SQOL and Augmented Research, outreach and recruitment efforts will occur at the collaborating institutions, with each educational institution being funded to support up to 12 student visitors to QuLL each summer in addition to year-round students who will help develop the lab manuals. All of our collaborating institutions meet the requirements for classification as Hispanic-Serving Institutions (HSIs). Upskilling participants in BootQamp, we will leverage CNM Ingenuity’s successful track record of developing technology-focused workforce training bootcamps that attract participants spanning multiple facets of diversity. We will leverage existing resources at these institutions to ensure diversity and representation among QuLL student participants. The Sandia PI also plans to travel to each of our partner institutions to support recruitment efforts through workshops and seminars aimed at broad audiences.

Economic stress is a very real concern among the communities we plan to reach here in New Mexico. To ensure no participant needs to choose between working a job to support themselves and their families and attending the QuLL Summer SQOL, student participants will be provided with stipends and travel support. Year-round students/ESRs developing lab manuals will also receive financial support for their participation. The BootQamp will be free for all participants during this program, and we plan to work with various STEM foundations and economic development associations to reduce or eliminate costs for future years.

**Central New Mexico Community College (CNM)** is a minority majority Hispanic Serving Institute with a current enrollment of approximately 19,000 students. For Fall 2022, student demographics demonstrated 54% of students identified as Hispanic, 7% as Native American, 3% as African American, and 3% as two or more ethnicities. CNM is unique among Hispanic- and Minority-Serving Institutions in that the demographics of students enrolled in STEM academic programs mirrors the general student population. For Fall 2022, 52% of STEM students identified as Hispanic, 6% as Native American, 2% as African American, and 4% as two or more ethnicities. Although enrollment of underrepresented students in STEM careers is robust at CNM, supporting the retention, persistence and completion of academic programs among these student populations remains an important challenge.

Student outreach and recruitment efforts at CNM will be assisted by several existing strategic initiatives focused on supporting the academic and career pathways of students underrepresented in STEM. All of these programs have included the support of students engaging in valuable hands-on experiential learning activities, internships, and undergraduate research opportunities. These programs include a STEM Summer Bridge Program and STEMCore cohort program to accelerate underrepresented students through their mathematics pathway, leading to internships; a partnership with Arizona State University and their NSF INCLUDES ALRISE (Acceleration LatinX Representation in STEM Education) program to develop infrastructure and a culture of undergraduate research and internship opportunities for Hispanic/LatinX students; initiating a cohorted internship model in collaboration with UNM to provide experiential learning and research experiences and to support transfer bridge initiatives for students moving into baccalaureate programs; and additional academic initiatives focused on accelerating students out of developmental mathematics into the college level courses necessary for their STEM degrees.

**The University of New Mexico (UNM)** is a HSI and the only Carnegie Research University with very high research activity (RU/VH) in New Mexico and the only RU/VH flagship University in the country with over 30% underrepresented minority (URM) enrollment. The School of Engineering has an undergraduate student body with 47% Hispanic students, but only 9% of graduate degrees are awarded to Hispanic students, offering tremendous opportunity for increasing Hispanic and Native American populations at the graduate level.

UNM will devote substantial effort to recruiting and retaining talented students from underrepresented groups by employing local UNM resources and working with national organizations representing women, veterans, and URMs. Outreach efforts will include QIST workshops, QuLL lab tours, and advertisements in classes. Students will be supported by broad campus resources including the Engineering Student Success Center, various diversity and inclusion groups, peer mentoring, and will be encouraged to pursue graduate education in QIST. We will develop a culture of shared values that will attract and retain Native American and Hispanic students. This will allow us to not only recruit applicants for the QuLL program, but also to ensure that they have the connections and community that are known to be critical for retention and success of underrepresented students. A UNM graduate student will support the lab manual development and better prepare student cohorts for Summer SQOL.

**New Mexico Institute of Mining and Technology (NMT)** will leverage its existing diverse STEM student body to recruit participants for this effort, which includes an undergraduate student body of 50% from minority populations (39.6% Hispanic) and 31% female in Fall 2022. 97% of students graduating from NMT receive a STEM degree. Outreach will include utilizing QuLL curriculum in NMT’s quantum materials-related classes, organizing summer activities for NMT’s QuLL cohorts, designing research projects to increase participation of undergraduate students, and building awareness through faculty members already actively engaged in increasing representation in STEM.

NMT faculty participants have a strong track record of promoting an inclusive and equitable environment for students of all levels, including mentoring undergraduate and graduate students. Prof. Kalugin is an active member of NMT’s Hispanic minority education improvement effort; participates in NMT’s Title V US Dept of Ed supported language and early advising programs; and recently organized a quantum science session at the American Indian Science and Engineering Society Region 3 Conference. Prof. Chowdhury has mentored around 20 undergraduate and 10 graduate students, approximately 50% of whom are female and 40% are from underrepresented groups, participates in numerous outreach efforts.

NMT will support several graduate students to develop hands-on experiments and manuals, who will also act as role models and peer-models for improving undergraduate student retention. Regular student-faculty contact via group meetings, cooperation, and interaction among students via a peer model, active learning using hands-on experiments, and respect for diverse talents and ways of learning will also be key to improving the involvement and retention of students from underrepresented groups.

**Navajo Technical University (NTU)** will leverage its existing student body to recruit participants from underrepresented groups for the QuLL project. NTU’s undergraduate enrollment in 2022 includes 523 undergraduate students: 54% were female, 97% were Native American Indian/Alaska Native, and 100% were Federal Pell Grant recipients. Work done at NTU will ensure the experimental demonstrations and corresponding curricula align with the cultural values and perspectives of their students, with the additional help of a Diné Studies scholar to incorporate Navajo Nation values and traditions.

NTU will also provide support services and accommodations to ensure all students can fully participate regardless of race, gender, national origin, disability, or age. To promote equity, we will provide equal access to training opportunities, resources, and tools for all students in the cohort. We will work with the NTU Disability Accommodation Resource Office to identify and address any disparities in access to resources or opportunities. Additionally, we will provide ongoing support and mentoring to ensure students can apply the skills and knowledge learned.

**New Mexico State University (NMSU)** is a land grant, public, research, and diverse institution with a student population of approximately 21,000. The university's institutional demographics reflect the diverse culture and heritage of the state of New Mexico. According to the 2021 enrollment report, the student body at NMSU is 48% Hispanic/Latino, 34% White, 5% American Indian/Alaska Native, 2% African American, and 10% other ethnicities. Thus, NMSU is considered a Hispanic Serving Institution. This diversity is also reflected in the faculty and staff population, with 28% of faculty and 37% of staff identifying as Hispanic/Latino. NMSU's commitment to diversity and inclusion is further demonstrated through the numerous student organizations, centers, and programs that celebrate and support diverse communities on campus.

At the participating NMSU site, PIs Kiefer and Badawy will advertise the QuLL program in the colleges of Arts and Sciences and Engineering via mailing lists and direct advertising by visiting courses. They will use the same mechanism for recruiting students into a joint quantum technology reading group (one 75-minute meeting per week) where they will discuss quantum technologies in the news. The reading group has no prerequisites and by design is accessible to students with diverse backgrounds who are curious about quantum technologies and its opportunities. Moreover, we will discuss the scientific and engineering aspects of QuLL experiments and prepare students for QuLL lab experiences. This will be an equitable and inclusive learning environment that removes entry barriers to student engagement in QISE.

Students will be primarily recruited from the interdisciplinary cross-listed “Introduction Quantum Computing” an upper-level undergraduate cross-listed with an entry-level graduate course co-taught by instructors from Math, Physics, Computer Science, and Electrical and Computer Engineering. Historically we got a very diverse set of students in the classroom. We will use the QuLL program as another recruitment “Carrot” to boost enrollment into the class. Also, physics will recruit students who take their Quantum Mechanics.

**Growth Sector** will leverage its existing STEM Core network of cohorts at 30+ community colleges and 4-year universities.  The STEM Core, currently supported by the National Science Foundation, Department of Energy, and Department of Defense, is primarily made up of students who enter college et entry-level math or below.  The program begins with broad-based outreach to feeder high schools, workforce agencies, and local community-based organizations and feeds into a paid pre-college bridge program.  Currently, across the country, 88% of STEM Core students are students of color, 39% are female, and 67% are Pell Grant eligible.  Each STEM Core cohort employs a campus-based Student Support Specialist who closely monitor and support participants by attending cohort classes, meeting individually to set goals and monitor progress, facilitating study skill and career development workshops, and centralize campus supportive services including tutoring, financial aid, and wellness.  This intrusive and pro-active support model has proven effective across the country at promoting academic and careers success- especially for populations underrepresented in STEM.  When promoting attendance at extracurricular technical activities, like the quantum learning lab, the Student Support Specialist plays a critical role for students who may be unaware these critical skill-building and career-development activities.  Additionally, many STEM Core students benefit from the Student Support Specialist’s guidance in arranging travel and coordinating purchasing- a significant barrier to access for low-income students.

**CNM Ingenuity:** CNM Ingenuity has a successful track record of developing technology-focused workforce training bootcamps attracting participants spanning multiple facets of diversity. In their Internet of Things (IoT) bootcamp, while the average student is in their early thirties and looking for a career change from hospitality/retail into a technology field, the students come from all walks of life and a variety of backgrounds. The IoT Bootcamp has trained learners as young as 18 and as old at 68. About 25% of the students are veterans. On average there is roughly an equal mix of male and female learners and the majority of them are underrepresented minorities. Learners also come from a wide-range of socio-economic backgrounds and are often individuals that have not had the opportunity to experience other STEM-related programs. The IoT bootcamp has a 92% graduation rate and has improved individuals’ economic circumstances: 60% of graduates successfully secure jobs within a few months of graduating, on average more than doubling their pre-bootcamp salary; 25% of graduates continue their STEM education towards a CNM associate degree; 15% start their own companies. We plan to continue on this successful foundation for BootQamp, by working closely with quantum employers to train for relevant and in-demand skills and provide the same supportive resources for participants.

**APPENDIX 6: OTHER ATTACHMENT**