THE QUANTUM FOR ALL PROJECT: RATIONALE AND OVERVIEW

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Abstract

The future of economic and national security, commerce, and technology are becoming more dependent on quantum information science (QIS). In addition to traditional STEM fields, there will be a broad need to develop a "quantum smart" workforce, and this development needs to begin before college. Since most students will not major in physics, it is vital to expose precollege students to quantum concepts that are relevant to everyday experiences with information security, smart phones, computers, and other widely used technology. This project, funded by the US National Science Foundation, provides opportunities for students to learn about various aspects of quantum science, regardless of whether they take a physics class. This project provides opportunities for secondary educators to learn and practice QIS. Project partners include universities, businesses, and professional organizations such as Science Teacher Association in Utah and Texas, American Association of Physics Teachers, Institute for Quantum Computing, and Perimeter Institute for Theoretical Physics. In particular, we utilize a trainer of trainer approach, however, the teacher professional development is tied to summer camp experience for students during which the teachers can test their delivery of the material with students in the summer camp. In this paper we will discuss the content areas and provide an outline of the professional development model.

Keywords: Quantum, STEM, Teacher Professional Development.

1 INTRODUCTION

Quantum Information Science (QIS) has emerged as critical to future economic prosperity. Moreover, QIS will become more and more important in the future workplace even among non-STEM careers [1]. In the United States, the National Quantum Initiative act was signed into law January 2019. It was designed to expand the nation's commitment in QIS by investing in activities to develop QIS and technology workforce pipelines, and many relevant documents are available at the National Quantum Initiative website [2]. These national efforts are necessary in order for the United States to maintain a leadership role in QIS and technology applications in an increasingly competitive global quantum landscape. Currently, there is not a sustainable American workforce pipeline for careers related to Science, Technology, Engineering, and Math (STEM) that contains specific QIS connections. Quantum information science is the use of the laws of quantum physics for the storage, transmission, manipulation, or measurement of information and therefore it is the basis for our national security (data encryption, cryptography), communications (phones, satellites, TVs), medical fields (MRIs, scans), technology (semiconductors, LEDs), and much more. In order to develop a pipeline of future workers who are capable of operating in an increasingly QIS-dominated environment, precollege students must be introduced to the importance of being quantum-smart, which by default means educators must learn how to teach quantum mechanics and QIS applications. However, most precollege educators are not prepared to teach principles and applications of quantum information and technology as they are not taught these concepts unless they are a physics major [3].

Despite the fact that national initiatives around QIS are being launched and that documents that guide the development of state standards are including more of this content [4], this area been largely ignored by K-12 educators. Research into why this is the case is lacking, but the experiences of our colleagues indicates the following: 1) lack of recognition of how the "abstract" quantum concepts are relevant to their classrooms, student careers, or the economy in general, 2) lack of preparation or background in quantum mechanics by the teachers responsible to teach these concepts to K-12 students, 3) lack of opportunities to learn the relevance and how QIS and ICT are connected through an appropriate venue that addresses the needs of the teachers as well as the students, 4) lack of age appropriate resources that have been specifically designed to incorporate content, pedagogy, technology, and other disciplines (STEM), and 5) lack of affordable (it is usually unique) equipment necessary to provide hands on learning experiences for students in the classroom.

To address these needs, The Quantum for All Students (QAS) proposal was submitted to the US National Science Foundation and funded in March of 2021 with a budget of about $1 million. The

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targeted audience includes secondary STEM educators and students, specifically high school students in grades 9-12. The content emphasis is quantum information science (QIS) and is taught using fully integrated STEM lessons. The science components are physics, chemistry, and computer science, technology includes applications and coding, engineering design is woven throughout the interventions, and math is addressed as it relates to quantum concepts such as probability, vectors, and matrices.

The remainder of this paper will discuss the research in teacher professional development which was the basis for the design of the program. We will then discuss the major features of what was proposed in 2020 and funded in 2021. Of course, what was not expected was that there would be a global pandemic that would delay our professional development project. We adapted and modified our project to use a virtual environment, which will be only briefly discussed. Finally, as the pandemic eased, we returned to the face-to-face (F2F) environment we had originally designed. A companion paper in this publication [5] provides results of our research into the effectiveness of the QAS teacher professional development model with regard to the two research questions posed by the project.

2 RATIONALE FOR THE DESIGN OF THE PROFESSIONAL DEVELOPMENT

Few would argue that technological applications are not important or that the uses and innovations are not amazing, intriguing, and usually useful. However, change in educational systems tends to move slowly, so while the educational system struggles to integrate basic technology, such as internet and Chromebooks, new technology has already replaced that implementation. Teachers, especially STEM teachers, are expected to be on the forefront to integrate content and pedagogy with technology quickly [6] [7] [8]. This has led to the concept of technological pedagogical content knowledge (TPCK or TPACK). Research indicates pedagogical content knowledge (PCK) has a critical role in teachers' technology integrations. In addition, content knowledge (CK) directly and positively influences technology content knowledge (TCK) and PCK, and this effect is greater than the effect of TK and PK. Data of the QAS intervention and research could lead to a model supporting CK and PCK in order to increase TPACK self-efficacy of teachers [9]. The QAS model follows this approach and is designed to cover the CK and PCK while integrating relevant and appropriate technology.

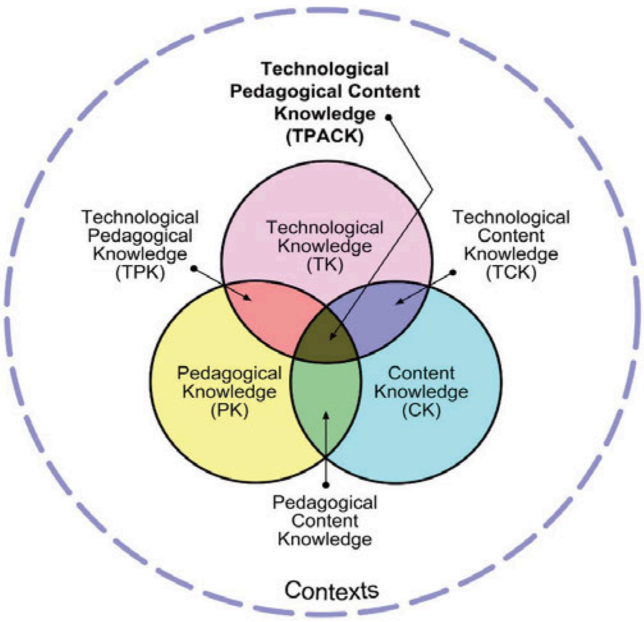

Figure 1. The TPACK Framework and Its Knowledge Components (Koehler & Mishra, 2009)

In [10], technological knowledge, pedagogical knowledge, and content knowledge are shown as three sets of intersecting Venn diagrams. The intersection of these three sets was given the name TPACK, but now TPACK is conceptualized as integrating pedagogy and technology knowledge onto special content knowledge. When the content knowledge is taken as science in the diagrams of Koehler and Mishra [10], the TPACK concept becomes special to science [11]. In the study of TPACK adaption to science education, the 7 components that emerged in Koehler and Mishra's Venn scheme (Figure 1) has been discussed [12].

The theoretical model of TPACK, states the knowledge of CK, PK and TK should be considered in an interactive manner, not independent of each other [10]. A teacher wanting to use inquiry in the classroom needs to understand the content knowledge about the subject, the pedagogical knowledge, and the technology knowledge. The teacher should also understand how to integrate technological tools into the teaching process by considering the students' preliminary knowledge, concepts that may be difficult to understand, and misconceptions [13].

As experienced classroom science teachers, professors, faculty, researchers in educational institutions, and students (life-long learners in a changing environment), the QAS Leadership Team Members (LTMs) and advisory members recognize that the model of TPACK makes perfect sense and adheres to our own traditional teaching practice. However, teaching quantum information science (QIS) is not traditional. It is not something we totally understand, it is weird, it is abstract, and while research studies the why of what happens, we grapple with what it does regardless of the reason. QIS is not something most educators were taught, so there is little basis for understanding the CK. If teachers don't understand the content, pedagogy and technology it will not be implemented. In addition, teachers need confidence and self-efficacy in what they are teaching before it will be effective. In has been noted [14] that "… concepts involved in it (quantum) are complex and counter-intuitive. They need a lot of time and reflection to be absorbed properly. Therefore, it would be desirable for students to meet these ideas early in their career, even in high school if possible. Unfortunately, quantum mechanics is also a subject which most students traditionally find very abstract and difficult, and its teaching has not changed much since it was invented early this century." It is challenging to learn and teach the content of QIS. This challenge must be addressed because research indicates the teacher must have sufficient knowledge in terms of PCK to make an application about how to make the subject more concrete and understandable by using appropriate technologies (simulations, animation, video, etc.) [12]. Although research confirms teachers who integrate various educational technologies with pedagogy and science knowledge in an inquiry-based learning environment increase in their self-efficacy [15], many still view "technology" only as a calculator, computer projection system, or a phone app. While all of these can be useful, they are not true integration. Unfortunately, student engagement with their phone is usually in the context of social media, not learning.

3 ELEMENTS OF THE PROFESSIONAL DEVELOPMENT PLAN

To address the issues discussed above, the QAS project developed an innovative professional development scheme. The project designed a 4-day teacher workshop that focuses on STEM, QIS, and ICT followed by 4-day student camps where the teachers who attended the workshop (PTs) help plan and teach the camps using the information they just learned. In this way, participating teachers have the opportunity to immediately try out activities that they have just learned in a simulated classroom environment with real students. This design enables teachers to have a test run at teaching the QIS activities and lessens the anxiety that would arise if teachers were to go back to their regular schools and teach recently learned, and perhaps unfamiliar, content. It also allows for supporting experts to immediately resolve any technology issues, raising teacher confidence in that area as well. The teacher workshops were held at 5 sites in Texas, Wisconsin, Maryland, and Utah. The student camps were held at the main sites immediately following the workshops. Teachers who completed the workshop/camp experience in 2022 are eligible to receive support for providing district camps to their students in the summer of 2023. Many of these sites are rural to facilitate underserved student populations in rural areas that may not have equal access to either STEM camps or teachers with the background to teach QIS and ICT.

The student camps incorporate several components designed to enhance the overall experience, build on student interests and strengths, and encourage further STEM interests. Those components currently include ensuring all lessons are inquiry based, age-appropriate, and connected through all STEM areas. By utilizing two-year colleges and universities where possible, the students can meet with other students, researchers, and professors on campus. The students initially received a small stipend to encourage participation, retention, and support of the family, especially if the students typically work to help support the family, but this proved cumbersome to administer and was eliminated for 2023 camps. The last day of each camp hosted an open house where family and friends were encouraged to come see what they had made with the 3D printers and share some of the activities they felt were intriguing. As an added bonus, the *Perimeter Institute of Theoretical Physics* and the *Institute for Quantum Computing* provided help by virtually engaging with the students at a deeper level to expose them to the opportunities possible by learning the science behind technology.

The PD leaders have teaching experience in appropriate pedagogy and extensive content backgrounds. Many were also involved in preparing and/or vetting the QAS lessons used for the camps and workshops. These workshop leaders, called Instructional Leaders (ILs) include advisory members, faculty, master teachers, and Physics Teaching Resource Agents (PTRAs). There are 2 ILs and 1 LTM assigned to each teacher workshop and student camp. There are approximately 30 PTRAs currently trained in the QIS resources, a process that has been ongoing for the last 10 years through our strategic partnerships. Instructors at the 2023 student camps will consist of a teacher who attended the 2022 PD and at least 1 supporting leader (either IL or LTM).

More details on the specific activities used in the teacher professional development and the science camps, as well as brief bios of the project leadership can be found on the project webpage [16]. The webpage also provides information on the upcoming 2023 summer camps, as well as information for teachers who would like to get involved in the project.

The model synchronized five sites across the country where teachers worked for 4 days, had the weekend off, and then had 4 days of student camp. Teachers were given time at the conclusion of each module/topic to debrief, make notes related to the upcoming camp, and collaborate with their teaching peers as to assignments for the co-teaching at the camp. The last day of the workshop provided for a few hours for teachers to redo powerpoints, gather supplies, and prepare for the camp. The evaluation instruments identified above were given during professional development and camps during the dates and locations indicated below.

Table 1: 2022 projects sites and dates

Location	***Workshop***	***Camp***
Arlington, TX	June 7-10, 2022	June 13-16, 2022
Katy, TX	June 14-17, 2022	June 20-23, 2022
Baltimore, MD	June 21-24, 2022	June 27-30, 2022
Provo, UT	June 14-17, 2022	June 20-23, 2022
Wisconsin River Falls, WI	June 27-July 1, 2022	NA

The sequencing of the workshops and camps was deliberate in order to allow for collaboration between the sites and still have continued improvement across sites. In addition to having all the documents available to both leaders and attending teachers, there were weekly meetings via zoom to discuss changes, potential issues, and successes. For example, on Thursday of week 1, the leaders of the Arlington site shared a spreadsheet where there was a breakdown for each activity, actual times for the lessons, suggestions for changes, and revised powerpoints with scripts. The sites that were starting the following week then had a better idea of how to improve their own PD workshop. This process was repeated each week, but in week 2 (June 16) the discussion revolved around changes/suggestions for the student camps. By the end of the cycle, there were multiple versions/revisions of the activities so the leadership team took the compilations, made some edits, and posted them on the website for teachers to use in their own classrooms. This allowed teachers access to documents that they worked on as well as documents revised by teachers at other sites. The intent is to use suggestions/feedback from their classroom experiences to compile a more usable curriculum.

Figure 2: Teachers in the Professional Development workshop

4 CONCLUSIONS

In this paper we describe the challenges in providing effect professional development to teachers around QIS, which is becoming increasingly important, and not only for people in STEM careers. Because of the technology component of the instruction, the traditional combination of CK and PCK is somewhat inadequate to the challenge. One must consider all of the elements required to provide teachers with TPACK in an effective and efficient format. Our solution was to combine more traditionally oriented (but still active learning) teacher professional development with a summer science camp for students. The student camp provides a simulated classroom with real students in which the teachers can "test drive" new activities and solidify their knowledge in an integrative fashion to build true TPACK. The presence of a cadre of skilled professionals on the Leadership Team provided support in all three dimensions that span the TPACK space during both the teacher professional development and camp. The addition of a practicing STEM camp ensures that participating teachers will have just-in-time solutions to most of the implementation problems that might arise in their own classroom. This should provide a firm foundation and a high level of confidence for the teachers to take this content into the classroom. Our companion paper [5] examines data collected during these workshops, indicating that the theory-based plan for professional development around a challenging topic has significant merit.

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