THE QUANTUM FOR ALL PROJECT PROFESSIONAL DEVELOPMENT MODEL AND THE EFFECT ON CLASSROOM IMPLEMENTATION

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Abstract

The adoption of innovations in science education into classroom instruction always presents a challenge, particularly if the innovation involves content that is unfamiliar to the teacher. Teachers need adequate instructional materials and supplies as well as professional development on their use in the classroom. Quantum information science (QIS) is a rapidly developing field that has significant implications across many areas, not just science. The US National Science Foundation funded a project to meet the challenge of providing teachers with the resources and support they need to take QIS into high school classrooms. We will discuss the professional development model developed by our project and report on the effect on classroom implementation by teachers who have participated in the program. The major innovation in our model for professional development is that the teacher's professional development is tied to the summer camp experience for students, during which the teachers can test their delivery of the material with students in the summer camp. We will report on teacher and student knowledge growth around QIS topics based on data collected during the teacher workshop and the subsequent summer camp. We will also present evidence that the summer camp was an important factor for the teachers when considering if and how to use the QIS materials in their regular classrooms.

Keywords: Quantum Information Science, Teacher Professional Development.

1 INTRODUCTION

Nation-wide efforts in the USA, like the National Quantum Initiative, are designed to provide and support efforts for the USA to maintain a leadership role in quantum information science and engineering (QISE) and technology applications in an increasingly competitive global quantum landscape. Educational systems are already using quantum-based technology, but they do not teach students the fundamentals of how it works. QISE is not just about the circuits in a phone or computer or flying a drone; it impacts traffic control, weather forecasting, material science development, finance, agriculture, medical procedures and equipment, drug development and much more. Thus, it is important for K-12 students to learn the principles of quantum, which means educators must learn how to teach quantum mechanics and QISE applications. However, most K-12 educators are not prepared to teach principles and applications of quantum information and technology because they are not taught these concepts unless they are physics majors [1].

The US National Science Foundation funded a project called Quantum for All (QFA) to address these issues [2]. To help educators overcome their fear of quantum, QFA lessons were structured around traditional content to which quantum concepts were added. This design reduced teacher anxiety while supporting/increasing understanding of foundational STEM content. By integrating QISE into current curricula, teachers realised the focus was to teach QISE throughout the course, not just at the end. To increase engagement, QISE concepts were introduced through natural phenomena, integration of engineering design and/or by identifying real-world applications [3,4]. An example is a unit on magnetic levitation [5], which begins with students engineering a maglev car supporting weight while travelling down a track at a specific time. The lesson was based on content related to fields, motion, magnetism, and real-world examples of maglev trains. The extension of the lesson was quantum levitation, where students designed a track (using magnets and a superconductor) to support a specific amount of weight.

The QFA project provided support, content, and resources for high school STEM teachers designed to integrate QISE into high school STEM classrooms. The basic structure was to have a 4-day teacher workshop focusing on STEM, and QIS, followed by a 4-day student camp facilitated by teachers who participated in the workshop [6]. The summer camp provided an opportunity for the teachers to "test-drive" the activities with high school students. However, these students were not the teachers' students from their schools during the regular school year, so there was no pressure to meet demands of any statewide assessments or administrator demands regarding what topics to be taught. Thus, the teachers could just focus on delivering the instruction to students and their responses. The motivation

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behind this was to learn if a live experience with students and no instructional pressure would result in a greater implementation of the materials in their regular classrooms since the teachers had a chance to practice teaching real students with the materials provided.

The instructional materials were developed by a leadership team of skilled educators working with physicists from research institutes and universities. Leaders started with currently available resources, embedded them into 5E learning cycles, and identified connections to standards (NGSS and Q-K12 [7,8]). Many of the QAS team had expertise in physics education research, which is a well-established field in physics [9,10] and were familiar with specific research regarding the learning of quantum-related topics [1,11]. The QAS focus was to address the goals of the National Quantum Initiative in K-12 education.

2 METHODOLOGY

For the past three summers, the teachers learned about four modules of instruction on topics (different topics each year) in a 4-day workshop. This was followed by a 4-day summer camp with high school students [5]. Assessments to measure content knowledge were collected for both teachers and students. For the teachers, "pre" refers to the assessment score before the workshop on the topic, "mid" is the assessment score after the workshop, and "post" is the assessment score after the summer camp. In addition to the content assessments, subjects reported their confidence in their content knowledge.

For the summer 2024 workshop, the four modules of instruction were as follows:

1 Particles – This unit was an investigation of the properties of subatomic particles (hadrons, leptons), and the technologies used to study them (like cloud chambers and accelerators).

2 Radioactivity – This unit examined radioactive decay (α, β, γ), neutrinos, Feynman diagrams.

3 Photoelectric – This unit examined the Planck quantum hypothesis, the photoelectric effect, and the quantum model for atoms.

4 HEP – The unit discussed the Heisenberg Uncertainty Principle, and how it arises from a wave description of particles with wave-particle duality.

Previous publications [5,12,13] have documented that the previously developed instructional materials and pedagogical structure of both the workshop for teachers and classroom instruction with students results in statistically significant content gains for both groups, although the actual amount of content gain varied across the topics. There was a significant correlation between teacher scores on the content assessments and self-reported confidence. This indicates the teachers have good self-awareness of their level of content Regarding the content gains, the statistically significant content gains occurred over the course of the workshop, but there was no statistically significant content gain from doing the summer camp with students. The same pattern was seen in teacher' confidence in their content knowledge. There were no statistically significant gains in confidence in their content knowledge as a result of teaching the summer camp.

Table 1. Data on teacher content knowledge.

Unit	*Pre-test (stdev)*	*Mid-test (stdev)*	*Post-test (stdev)*
Particles (6 questions)	3.84 (1.46)	4.28 (0.84)	5.16 (1.03)
Radioactivity (7 questions)	5.33 (1.36)	6.33 (0.83)	6.26 (1.20)
Photoelectric (7 questions)	5.44 (1.19)	6.00 (0.92)	6.11 (0.89)
HEP (7 questions)	3.89 (1.12)	4.70 (1.23)	4.59 (1.34)

Tables 1-3 present the data from the 2024 summer workshops. In general, the pattern that emerged from the previous assessment data is reflected in these data, with one exception: Particles. For that unit, there was a statistically significant gain in content knowledge because of teaching the student camp. We suspect that this is really a case of not knowing it until you teach it, but it is the first such example we have seen in 3 years of data.

Table 2. Data on teacher confidence in their content knowledge.

Unit	Pre-test (stdev)	Mid-test (stdev)	Post-test (stdev)
Particles	2.01 (1.33)	3.53 (0.92)	3.87 (0.80)
Radioactivity	2.59 (1.05)	4.10 (0.95)	4.37 (0.74)
Photoelectric	2.63 (1.26)	3.97 (0.82)	4.26 (0.69)
HEP	2.51 (1.12)	4.14 (0.83)	4.21 (0.82)

Table 3. p-values for change in average values (= statistically significant)*

Unit	Item	pre/mid	mid/post	N
Particles	content	0.1977	0.0018*	25
	confidence	0.0001*	0.1702	
Radioactivity	content	0.0020*	0.7927	27
	confidence	0.0001*	0.2592	
Photoelectric	content	0.0582	0.6673	27
	confidence	0.0001*	0.1658	
HEP	content	0.0147*	0.7524	27
	confidence	0.0001*	0.7436	

3 RESULTS

The quantitative data collected indicating growth in teacher content knowledge and confidence in that knowledge, which is a basic requirement before teachers will take the plunge and implement these activities in their classroom. A key aspect of the QFA PD model is the summer camp. By providing an opportunity to test the materials with live students, but without the pressures of regular classroom instruction, the proposition was that teachers would be more inclined to teach this unfamiliar, and at times challenging, material. While there are many other factors that could inhibit teachers from introducing QISE topics in STEM classes, we collected data to see if the teachers would point to the summer camps as a significant factor for deciding to implement the materials in their regular classrooms.

During the summer 2024 workshop, a focus group was held with the participant teachers who had attended the prior year to examine factors related to classroom implementation of the modules. The teachers were asked to discuss factors related to implementation in their own classrooms. One major factor identified was the summer camp. Out of 13 teachers who had attended in 2023, eight identified the summer camp as a critical factor in the successful implementation of at least some activities in their own classroom during the 2023-24 school year. A representative comment was: "*That second week allowed me to watch the students and have the questions on a student level presented. And that is what I'm trying to do, which made me think harder: how am I going to take this back and do it with my own students, seeing the problems that I already saw in that one-week camp?*"

Teachers also expressed that they grew in confidence because of the camaraderie developed during the PD, discussions regarding how to connect QISE content to the core curriculum, and strong content connections. As one teacher remarked in a focus group session, "*I like doing all the activities too because It's like, if you guys were just sitting up at the board explaining everything, it would be like sitting in a lecture, and I'd be zoning out not paying attention, but having activities and have trying to figure things out on my own and having my questions answered by my peers, I think it's very, very important. It makes you more likely to discuss and ask questions and say, okay, well, is it like this, you know, is this kind of the right thought? It is for me.*"

The comments recorded in the focus groups also indicate that there was a shift by teachers from a focus on the content during the PD to a focus on TPCK (Technological, Pedagogical, and Content Knowledge) during the summer camp [14,15]. This is probably why there was no change in the content knowledge after the summer camp; the teachers were focused on pedagogy and the technology of the modules. For example, during the focus group, one teacher said "*The opportunity to be persistent to get through* *the… like we were working on today with LED bulbs just trying to get that place constant and narrow down our percent error. I had the ability to really focus in and be given a little bit more room to be persistent and had people around me to help me. Understand what is it that I'm doing? … Um, and that gave me the courage to then do that with the kids because in a classroom you're going to see the same kind of problems, you know? Like, all right this connection wasn't working. So, if I fixed this…"*

4 CONCLUSIONS

The instructional materials and the pedagogical model developed by the QFA project continue to result in statistically significant content gains for teachers (and for students in the summer camps). The units developed for the 2024 camp continue the pattern of previously developed units, with one exception. For the Particles unit, a second round through the materials provided by the summer camp resulted in a statistically significant gain in content knowledge by the teachers. Interviews with the teachers indicated that the summer camp is an exceptionally valuable component of the PD model and that it does play an important role in the decision to do these activities as part of regular, school year instruction.

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