The Quantum for All Project: Student Outcomes and Connection to Teacher Professional Development

Karen Jo Matsler[0000-0002-6751-8264] **and Ramon E. Lopez**[0000-0001-5881-1365I]

The University of Texas at Arlington, Arlington, TX 76019, USA

kmatsler@uta.edu

Abstract. The Quantum for All project is designed to expand Quantum Information Science education in precollege education. The professional development model includes an opportunity for teachers to learn QIS and then teach a summer camp. In this presentation, we will examine growth in student knowledge and confidence in the QIS, as well as attitudes the students have around the topics and careers in QIS. We will also correlate these findings with teacher content knowledge and confidence for the various topics, since some topics were initially unfamiliar to the teachers.

1. Introduction

Quantum information science (QIS) is the foundation for data encryption, security, semiconductors, cryptography, and electronic devices and students who understand quantum effects will be better prepared for and knowledgeable about future careers. Even among non-STEM careers QIS will play an increasingly important role in the future workplace [1], and individuals will be increasingly dependent on QIS to keep personal data secure. To develop a pipeline of future workers capable of operating in an increasingly QIS-dominated environment, precollege students should 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 do not have a strong background in quantum, unless they majored in physics [2].

It is important to prepare secondary students (specifically high school students who will enter the workforce in the next 2-3 years) for the current and future careers, which require understanding of information and communication technology (ICT). The Quantum for All (QfA) Project, funded by US National Science Foundation (NSF# 2048691), targets secondary STEM (Science Technology Engineering and Math) educators and students, specifically high school students in grades 9-12, to increase STEM and ICT career awareness. The aim of the project is to provide content background, peer support, and resources so they can effectively integrate QIS into standard instruction in physics, chemistry, computer science and technology, and math in the classrooms.

2. The Student Summer Camp and Data Collected

The QfA program includes a 4-day professional development (PD) workshop focused on Quantum Information Science (QIS) for teachers, followed by a 4-day student camp [3]. During the camp, the participating teachers lead sessions to help students explore how QIS underpins modern Information and Communication Technologies (ICT). Each year, the topics for both the PD and the camp are selected based on teacher interests, available resources (such as equipment and lesson materials), the students' age group, relevant content, and the feasibility of classroom implementation [4,5].

Teacher applications were solicited nationally, regardless of prior experience with quantum mechanics or modern physics, while student participants were recruited locally. Some of the teachers may have had some limited exposure to the content topics (perhaps in a modern physics course at the university). Very few students would have had any exposure to the content as these subjects are rarely, if ever, taught in the precollege STEM classroom. However, pre-assessments revealed some existing knowledge—particularly in atomic structure, which had higher scores compared to other topics. As shown in Table 1, teacher participants initially scored higher on atomic structure than on topics like maglev, quantum technology, and quantum engineering.

By learning and then teaching the student camps, teachers gain practical experience, which simulates a classroom environment. This learn-practice environment helps them gain confidence and allows them to see student engagement and interest in QIS and ICT, which increases the likelihood of implementing the lessons in their own classrooms. The pedagogy used in the professional development workshops was based on the active learning model [3,6,7]. In the Quantum for All model, teachers participated in small group lessons to mirror their students' learning experiences. Teacher leaders facilitated the learning process by guiding the participants through a mixture of explorations, investigations, quantum phenomena, and group discussions [8]. Additionally, lectures provided historical context and relevant content information related to the topics [9]. Time during the workshop was allocated for teachers to discuss integration of technology and pedagogical approaches on how to teach during the camp as well as their own classrooms. Technology components including interferometers and sensors (i.e. light sensors, spectral analysis, etc.) were integrated into the lessons giving participants an opportunity to develop new technological skills enhancing their own TPACK (technological pedagogical content knowledge) learning experiences and increasing the level of engagement and relevance for students [10, 11,12].

Content assessments were developed to measure the level of content knowledge for both teachers and students. Each assessment question was coupled with a query as to how confident the respondent felt that their answer was correct, and these responses were used to gauge individual levels of confidence for their answers. For the teachers, assessments were given at three different times: before the start of a specific content during the PD (pre), after the teacher PD (mid), and after the teachers taught the content to the students in the camp (post). Students also had assessment questions, but they were only given before the instruction (pre) and after the instruction (post).

For the summer 2023 workshop, student assessment data were collected for three out of the four modules (there was a technical issue with doing the assessment for one of the four, so that is not included). The 2023 three modules covered the following topics:

- Day 1: Maglev and Engineering Design - What is engineering? Understanding magnetic fields (currents, electromagnets, fields), Uses for magnetic fields (such as MagLev Trains), Designing a model of a “maglev” train, quantum levitation and superconductors
- Day 2: Atomic Structure - Spectral lines/observations (electron transmissions, energy), Photoelectric effect, Planck’s constant, Bohr model (and its limitations), Properties of waves
- Day 3: Technology and Quantum - Classical vs quantum computers, Superposition of states (polarization), Quantum key distribution, Cryptography (Note this content was reported by teachers to be the least familiar content area to them)

The scores on the content assessments for the teachers before the workshop (pre) and after the workshop (mid) for the content modules listed above are presented in Table 1 below. These scores represent the state of teacher knowledge as they begin to teach the students in the summer camp. Table 2 summarizes the statistical significance of the changes in teacher content knowledge as measured by the assessments and teacher confidence in that content knowledge. For the three activities, all the increases in the scores resulting from the workshop were statistically significant, but there was no statistically significant change in the teacher content scores after the summer camp, which is the result we have seen in previous summers [12,13]. What can be seen in Table 1 is that the workshop was very effective in producing a substantial increase in teacher subject matter knowledge, with the biggest increase in the least familiar content area (as determined by the initial scores and teacher comments about the modules). The teacher self-reported level of confidence in their understanding of the content (not shown here) was correlated with the content scores before and after the workshop, but there was no statistically significant change in teacher self-reported level of confidence after the student camp.

Table 1. Data on Teacher Content Knowledge and Gain in the Pre-Camp Workshop.

Unit	Pre-test (stdev)	Mid-test (stdev)	N	Postscore %	% of possible gain realized
Maglev & Engineering Design (6 questions)	3.84 (1.46)	5.03 (0.88)	25	83.8	55.1
Atomic Structure (7 questions)	4.32 (1.46)	5.79 (1.30)	25	82.7	54.9
Technology and Quantum (5 questions)	3.13 (1.55)	4.43 (0.73)	23	88.6	69.5

Table 2. P-values for Teacher Content Knowledge and Confidence.

Unit	Item	pre/mid	mid/post
Maglev & Engineering Design	content	0.0001*	0.2921
	confidence	0.0001*	0.826
Atomic Structure	content	0.0005*	0.5374
	confidence	0.0008*	0.3073
Technology and Quantum	content	0.0007*	1.00
	confidence	0.0006*	0.1644

* Indicates statistically significant

The students in the summer camp also took a pre- and post- assessments for each module. These assessments were not identical to those for the teachers, but they used many of the same questions and covered the same content. The student data are presented in Table 3. All the gains were statistically significant, but the magnitude of the gains varied.

Table 3. Data on Student Content Knowledge and Gain in the summer camp.

Unit	Pre-test (stdev)	Mid-test (stdev)	N	Postscore %	% of possible gain realized
Maglev & Engineering Design (5 questions)	2.50 (0.98)	3.22 (0.83)	32	64.4	28.8
Atomic Structure (5 questions)	1.58 (1.05)	2.24 (1.21)	29	44.8	19.3
Technology and Quantum (4 questions)	1.37 (0.97)	3.26 (0.86)	27	81.5	71.9

Table 4. P-values for Student Content Knowledge and Confidence

Unit	Item	pre/post
Maglev & Engineering Design	content	0.0025*
	confidence	0.0001*
Atomic Structure	content	0.0324*
	confidence	0.0001*
Technology and Quantum	content	0.0001*
	confidence	0.0001*

* Indicates statistically significant

As mentioned previously, some of the questions were the same on the teacher and student assessments, others were similar in content and level of difficulty. On the MagLev assessment, there was a specific question on quantum locking that was the same on all assessments (teacher pre, mid, post as well as student pre, post). On the student pre assessment only 34% (11 students) answered correctly and on the post 90.6% (29 students) answered correctly. On the teacher pre assessment 76% (19 teachers) answered correctly whereas on the mid assessment everyone answered correctly (25 teachers) and 1 teacher missed it on the post.

Students were given a Career Attitude survey before and after the camp. Only students who completed both (as indicated by their self-identifying code) were used in the data analysis. For the summer of 2023, there were 4 different sites for the camps, in Maryland, Texas, and Utah. All data was compiled for the analysis. The responses on the career survey did not show statistical significance in the pre and post for most of the questions. This is likely because the students attending were already interested in quantum, engineering, coding, and all the things they knew they were going to be learning at the camp. They were already confident in their own personal skills as well as social skills (working with others), curious as to what quantum involved, understanding how to use creativity and be innovative. Their level of interest in different STEM areas was lowest in math, whereas science, computer science and engineering were all relatively the same with science being the only one that changed at all (increased from average of 3.1 to 3.3, although it was still statistically insignificant. The only two questions showing a statistically significant change were: 1) I like to imagine creating new products and 2) I am confident I can set my own learning goals. See Table 5.

Table 5. P-values for Student Attitude Survey Questions with Statistical Significance

	Pre (Stdev)	Post (Stdev)	P-value	N
I like to imagine creating new products	3.90 (0.88)	4.26 (0.69)	0.0427	43
I am confident I can set my own learning goals	3.84 (0.75)	4.21(0.72)	0.0197	43

3. Findings and Conclusions

Preliminary results indicate both teachers and students had statistically significant gains in content for the topics in the 2023 workshop and camp. This leads us to conclude that the materials, teaching methods, and environment were effective in increasing both teacher and student knowledge, as has been found for previous workshops and summer camps [13,14], even though the final values fell short of expectations for the Atomic Structure model. For the teachers, the statistically significant gain occurred as a result of participation in the workshop. After they taught the modules at the camp, there was no statistically significant change in the scores on the assessments.

As expected, there were some topics where teachers knew more content initially and this was reflected by higher pre scores. However, because most of the students were entering grades 9 and 10, they did not have much background knowledge on these advanced topics, and they had lower initial scores that were not far from random for the Technology and Quantum module. Clearly, however, some topics were easier for students to grasp than others. In particular, the Atomic Structure module had relatively poor results. This module was the most mathematically intense of the modules, and we suspect that that may have had a significant role in the relatively poor student performance on that module. One would expect that the more active the learning environment, the greater the interest by students and higher content gains. However, this should be no surprise because the literature is clear that active learning produces superior students learning outcomes. [15,16]

Another issue is the relationship between teacher content knowledge and student content knowledge gains. There is considerable evidence in the literature that student content knowledge gains are correlated with the teacher content knowledge of the subject being taught [17]. However, inspecting the data from the summer 2023 workshop, there is no correlation between the teacher content knowledge going into the summer camp and the student content knowledge gains in the summer camp. The module with the most gains was the Technology and Quantum module, which had the lowest pre-instruction score for both teachers and students. This is probably a function of the instructional materials, which apparently were well-designed. On the other hand, the teacher gains on the other two modules were quite similar, whereas they were quite different for the students. These results suggest that a closer examination of the instructional materials is warranted to improve student performance in certain topics.

Students attending the camps generally had strong interests in both the specific content as well as STEM fields in general. The surveys given before and after the camp did not show a statistically significant increase for most of the questions, likely because their confidence and interest was already high since they self-selected to attend. The only two showing a statistically significant change were: 1) I like to imagine creating new products and 2) I am confident I can set my own learning goals.

Perhaps the most important limitation of this study is that students who participated chose to attend the camp, unlike the captive audience typically found in a classroom setting. Therefore, to validate these findings, particularly regarding student interest and knowledge, it would be necessary to conduct similar assessments with a regular class during the school year, rather than with a self-selected group during the summer.

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