

# THE QUANTUM FOR ALL PROJECT: STUDENT LEARNING IN THE SUMMER CAMPS

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## Abstract

Quantum information science (QIS) undergirds a set of critical technologies that will affect information security, smart phones, computers, and other widely used technology. There is a broad need to develop a "quantum smart" workforce in addition to traditional STEM fields, and this development needs to occur in precollege education. The US National Science Foundation has funded the *Quantum for All* project to provide professional development opportunities for STEM educators to learn about QIS and how to implement it in the classroom. 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 outcomes for students in the summer camp for the various content areas presented and relate that back to results of research on teachers and their performance in the professional development experience.

Keywords: Quantum, STEM, Teacher Professional Development, Student STEM learning.

## 1 INTRODUCTION

The goal of the NSF project Quantum for All Students and Teachers [1] is to provide opportunities for teachers and students to learn about Science Technology Engineering and Math (STEM) and ICT (Information and Communication Technology), which is recognized as important for a wide range of careers [2]. High School STEM teachers accepted to the program are provided 4-5 days of professional development (PD) with strong focus on pedagogical content knowledge (PCK) and integrate technology (TPAK) [3] which is related quantum information science (QIS). The QAS proposal components include: a 4-day teacher workshop focused on STEM, QIS (Quantum Information Science), and ICT followed by 4-day student camp where the teachers who attended the workshop help plan and co-teach the camps using the information they just learned. Lesson modules are designed to complement and integrate into current curriculum, so teachers do not need to "find space" for quantum in their classes.

The PD instruction is designed with research-based pedagogy and materials [4], [5], and the student camps provide a means for teachers to practice what they have learned. The camp provides opportunities for teachers to 1) learn how to implement what they have learned in a safe, supportive, peer environment, and 2) practice what they have learned within a short time frame of learning it thereby helping solidify the ideas and skills before taking it back to their classroom. The student camps are designed to engage students in technology-rich STEM/QIS experiences and increase awareness of career opportunities related to STEM, ICT, and QIS. Curriculum components include lessons that are inquiry based, age-appropriate, and connected through all STEM areas (science, technology, engineering, and math).

The student camps began in the summer of 2022, but this paper only includes data from the 2023 camp. Topics for the 2023 camp, which corresponded to the topics for the teacher workshop, are summarized below.

### *Day 1: Maglev and Engineering Design*

What is engineering design? Understanding magnetic fields (currents, electromagnets, fields), identifying applications for magnetic fields such as MagLev Trains, designing a model of a "maglev" train, quantum levitation (superconductors, flux pinning, frictionless motion, forces)

### *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, quantum key distribution, phases, quantum gates

### *Day 4: Laser Cooling*

Energy levels, conservation of momentum, Doppler effect, Magnetic fields, Quantum Field Theory

The main 2023 student summer camp was held in Arlington, TX with 36 students attending the 4 days of camp. The grade classification of the students was as follows: 27% Freshmen (starting 9<sup>th</sup> grade in Fall 2023), 38.89% outgoing Freshmen (starting 10<sup>th</sup> grade in the fall), 11% incoming seniors, and 5.56% graduating seniors, and 1 who did not identify the grade. Students identified their age as of June 1 and nearly half (47.2%) were 14 years old and 30.6% were 15 years old, which is 75% of the students who attended. The breakdown of gender and ethnicity was: 56% male, 41% female; 16.7% Latino, 8.3% African American, 30.6% Caucasian, 33.3% Asian, and 11.1% multiracial. In addition, there were 6 sites that were much smaller (individually), but which allowed teachers the opportunity to offer this experience to local students who would not normally have access. There were 44 student attendees (each had 4 days of camp) at these sites. The data reported in this paper are only from the main site in Arlington for the 2023 summer camp.

## 2 METHODOLOGY

Data collected from all participants (teachers and students) were used to measure the effect of the workshops and camps on content knowledge and confidence in that knowledge. Student data was taken using both surveys (for attitude) and assessments (for content). Content assessments for students were very short (4-5 questions each) and targeted the topics to be taught on one day. Daily pre- and post-assessments were given since prior experience showed data to be inconsistent if there was an overlap to the following day, particularly if someone was out due to another activity, arriving late, etc.

Content assessments were developed by the leadership team and vetted through peers and advisory committee members. When participants answered the content questions, they were asked to rank their confidence in knowing the correct answer on a Likert scale of 1-5 with 5 being totally confident in their answer. The 2023 topics were (as described above) MagLev and Quantum Levitation, Atomic Structure and Energy, Classical to Quantum Technology, and Laser Cooling. Fig. 1 shows students in the summer camp working with superconducting magnets in the MagLev topic. Unfortunately, the student pretest for Laser Cooling had a technology glitch and did not get recorded, therefore, the post results are of little value other than to see what they now know, which is not necessarily what they learned.

Questions on the content assessments were either identical on the pre and post or very similar. If the questions were not the same, the level of difficulty and content being assessed were as similar as possible. In addition, some questions were used on both teacher and student assessments. Since research [6] indicates participants might put the same answer on pre- and post-assessments even if they now know the difference or the correct answer, or knowing the correct answer after the pretest the subject could answer correctly without really knowing the content, the instruments had a mix of questions that were exactly the same, and those that were different in text but addressed the same content.

We present here a two sets of sample questions (correct answer in bold), one where the pre- and post-questions were identical, and one where they were not identical but addressed the same content. The first question comes from the Maglev topic (question #3), and in the case the when the pre- and post-questions were identical. The student score on the pre-test was 46.88% correct (15 out of 32) and the score of the post-test was 84.38% correct (27 out of 32).

*A magnet becomes a superconductor*

- A. **it is cooled below the critical transition temperature**
- B. *there is no magnetic field present*
- C. *it is at the critical transition temperature*
- D. *it conducts only when moving at supersonic speeds*

In contrast the Classical to Quantum Technology topic (question #3) had the following pre-test question, and students answered 40.74% correct (11 out of 27).

*In Quantum Key Distribution, if the basis of polarization match between the sender and receiver,*

- A. **Both people will always read the same value for the photon polarization after measuring**
- B. *Measuring means both people can never read the same value for the photon polarization*
- C. *The receiver's photon will be in a state of superposition*
- D. *The value for the bit will be "1".*
- E. *The value for the bit will be "0"*

The post-test question (question #3) addressed the same basic concept, but in a different way and 66.66% (18 out of 27) of the students selected the correct response.

*A photon is polarized horizontally and is measured with a polarizer at 45 degrees.*

- A. the measurement is not guaranteed to be the same every time**
- B. the measurement will always be the same
- C. the photon will never go through
- D. the photon will be in a state of superposition after measurement

All assessment questions were anonymous as students were asked to make up a code and use it on all assessments for comparisons. To compare pre- and post- gains/losses for the students, both pre- and post-assessments were analyzed. For teachers there were 3 assessments: 1) pre (i.e. before the topic was taught, 2) mid (i.e. after the topic was taught, same day), 3) post (i.e. after the teachers taught the camp). Therefore, if a participant did not fill out confidence for any of the questions, their responses were removed to ensure all comparisons were as accurate as possible. There were a few students who had conflicts (band practice or soccer practice) and arrived late, thereby missing the pretest, which resulted in their data also being eliminated.



*Figure 1. Students during the summer camp working on the MagLev topic with superconducting magnets.*

### 3 RESULTS

The results of the pre- and post-tests for the students are given in Table 1. Instruction in every topic resulted in statistically significant gains in student content knowledge. However, there were significant differences in the total gain as a percentage of the possible gain, with the Atomic unit showing the lowest gain. The differences in the post-scores between Atomic and Magnetic Levitation ( $p=0.0004$ ) and between Atomic and Technology and Quantum ( $p=0.0007$ ) were statistically significant. The difference in the post-scores between Magnetic Levitation and between Technology and Quantum was not statistically significant ( $p=0.8567$ ).

Table 1: Student Content Assessment Scores for 2023 Summer Camp

| Unit/topic             | Pre-Score (std) | Post-Score (std) | P-value | Gain as % of possible gain | N  | # questions |
|------------------------|-----------------|------------------|---------|----------------------------|----|-------------|
| Magnetic Levitation    | 2.50 (0.98)     | 3.22 (0.83)      | 0.0025  | 28.8                       | 32 | 5           |
| Atomic                 | 1.58 (1.05)     | 2.24 (1.21)      | 0.0324  | 19.3                       | 29 | 5           |
| Technology and Quantum | 1.37 (0.97)     | 3.26 (0.86)      | 0.0001  | 71.9                       | 27 | 4           |

Teacher knowledge for each of these topics was essentially the same as measured by the post-workshop content test [7], so the differences were not due the variable teacher knowledge. The major difference between the Atomic unit and the others was that the level of mathematics in the Atomic unit was significantly higher than for the others. Moreover, student confidence in the correctness of their answers also had lower absolute values as well as lower percentage gains for the Atomic unit in comparison to the others, as can be seen in Table 2. In fact, the post values of confidence were statistically significantly different between Atomic and Magnetic Levitation ( $p=0.0001$ ) and between Atomic and Technology and Quantum ( $p=0.0026$ ). Clearly the students themselves knew that their knowledge of the Atomic topic was significantly weaker than their knowledge of the other two.

Table 1: Student Self-reported Confidence Content Assessment Scores (5-point Likert scale)

| Unit/topic             | Pre-Score (std) | Post-Score (std) | P-value | Gain as % of possible gain |
|------------------------|-----------------|------------------|---------|----------------------------|
| Magnetic Levitation    | 2.12 (0.79)     | 3.83 (0.55)      | 0.0001  | 60.1                       |
| Atomic                 | 1.52 (0.63)     | 2.77 (0.79)      | 0.0001  | 35.9                       |
| Technology and Quantum | 1.75 (0.83)     | 3.48 (0.89)      | 0.0001  | 53.2                       |

## 4 CONCLUSIONS

An examination of student content knowledge gains resulting from the summer camp in 2023 held by the Quantum for All Students and Teachers project shows that in all the content areas, there was a statistically significant increase in student content knowledge. This validates the design of the instructional materials, so that if they are used in classrooms, they will have a statistically significant positive effect on student content knowledge in these topics. There was, however, a significant variation across the three units in the percentage of the possible gain seen in the data. The Atomic unit had much lower gains than the other two. This was not due to differences in teacher knowledge, which was the same for all three. The Atomic unit was, however, more mathematically oriented, and this may be the origin of the poorer student performance since over 75% of the students were incoming freshmen or sophomores and would have less math background. The students themselves were significantly less confident in their knowledge about the Atomic topics than the other two topics.

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