THE QUANTUM FOR ALL PROJECT: TEACHER CONTENT KNOWLEDGE AND CONFIDENCE

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Abstract

Quantum information science (QIS) is critical to the future of economic and national security, commerce, and technology). There is a broad need to develop a "quantum smart" workforce with some on critical topics, such as quantum concepts that are relevant to everyday experiences in information security, smart phones, computers, and other widely used technology. The *Quantum for All* project, funded by the US National Science Foundation, provides opportunities for students to learn about various aspects of quantum science by providing professional development for STEM educators to learn and practice QIS. We utilize a trainer of trainer approach. In this paper we will discuss the content areas and provide an outline of the professional development model. We will also examine growth in teacher content knowledge and their confidence in that content knowledge. Our preliminary results are that the workshops are effective in raising both metrics as measured by pre- and post-surveys, however, there are differences between the content areas. We will examine these differences and provide possible reasons for the results.

Keywords: Quantum, STEM, Teacher Professional Development.

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 Information and Communication Technology (ICT). These topics have been identified as important for current and future jobs in a wide range of specialties, not just in STEM-focused occupations [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] related to quantum information science (QIS). The professional development model [3} comprises a 4-day teacher workshop focused on STEM, QIS, 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 expectation is that the teachers will be more willing to use the materials in the classroom once they have had practice teaching students. Determining if this expectation is correct is the subject of ongoing research.

The PD instruction is designed with research-based pedagogy and materials [4], [5]. The materials themselves were developed by a leadership team of skilled teachers working with professional physicists from research institutes and universities. In addition, some of the physics professors in the leadership team (including the Co-I of the proposal) have expertise in physics education research, which is a well-established field in physics [6], [7], and includes specific research around learning quantum-related topics [8], [9]. The topics for the 2023 PD and student science camp are given below.

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 (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

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Day 4: Laser Cooling

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

The hands-on components of the materials were designed to be broadly accessible and inexpensive so that they would be affordable for schools. These hands-on activities provide "anchor phenomena" that undergird and motivate the content knowledge. The learning cycle structure of the materials then builds on these anchor phenomena communicate the content knowledge. Fig. 1 shows teachers engaged in the hands-on activities in small groups as well as a large group discussion facilitated by a member of the Leadership Team.

Figure 1. Scenes from the Teacher Professional Development Workshop.

2 METHODOLOGY

Participating teachers completed content assessments to measure content knowledge at three points during the summer PD to measure the effect of the workshops and camps on content knowledge and confidence in that knowledge. Assessment data were collected prior to PD around a topic (which we refer to as "pre" data), after the PD workshops (which we refer to as "mid" data), and after the teachers used the content to teach in the summer camps (which we refer to as "post" data). For each content question, the participants 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 content assessments were developed by the leadership team and vetted through peers and advisory committee members. The 2023 topics were (as described above) MagLev and Quantum Levitation, Atomic Structure and Energy, Classical to Quantum Technology, and Laser Cooling. 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 [10] 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 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, and in the case the when the pre-, mid- and post-questions were identical (correct answer is in bold). The teacher score on the pre-test was 48% correct (12 out of 25), the score on the mid-test was 92% correct (23 out of 25), and the score on the post-test was 88% (22 out of 25).

MagLev technology has been used in many types of technology including MagLev trains. Which of the following statement(s) apply to this type of MagLev technology?

A. *EM Suspension (electromagnetic suspension) where attractive forces are used for guiding*
B. *ED Suspension (electrodynamic suspension) where repulsive magnets are used for guiding*
C. *Incorporation of upward magnetic forces to balance downward gravitational forces*

D. A and C only

E. B and C only

F. A, B, and C

The second question is an example of where the pre (3.) and the mid (3.1) questions were different, but the mid and the post questions were the same. These questions come from the Atomic unit and are presented in Fig. 2., with the correct answer in red. The teacher score on the pre-test was 56% correct (14 out of 25), the score on the mid-test was 80% correct (20 out of 25), and the score on the post-test was also 80% (20 out of 25).

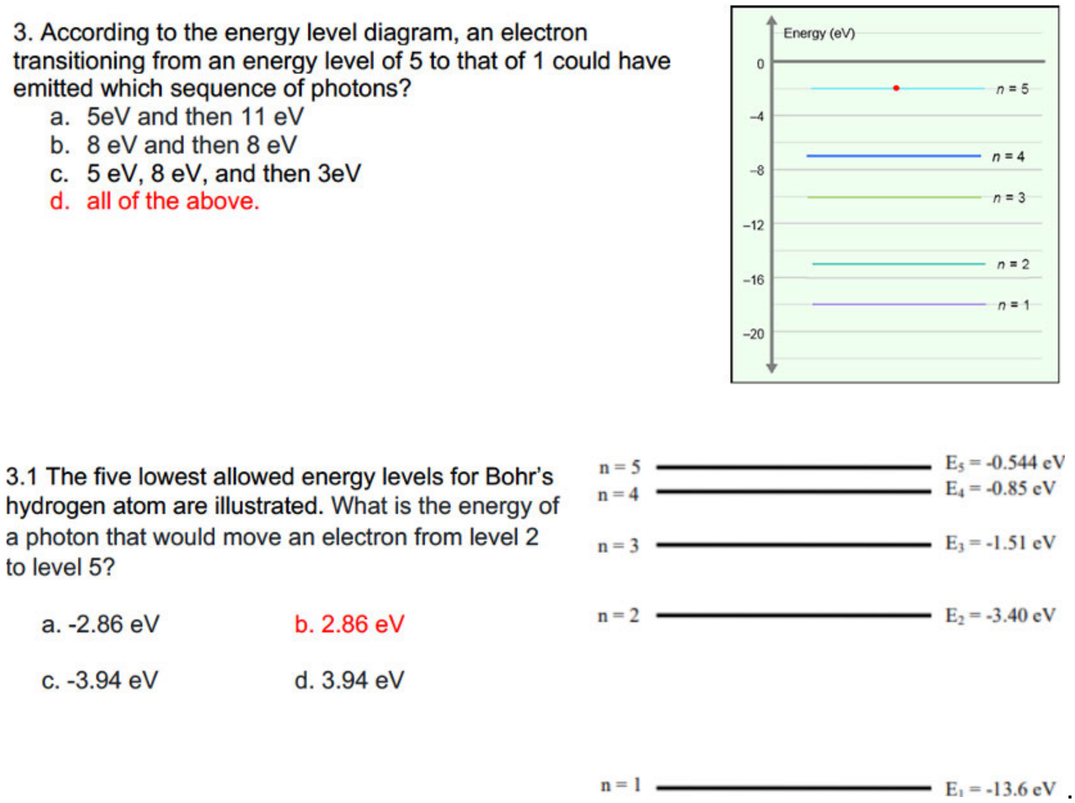

Figure 2. Content questions for teachers with the same subject but different questions.

3 RESULTS

The data on teacher content knowledge are presented in Table 1. The four topics of instruction are indicated on the leftmost column, and the values for the pre, mid, and post tests are given with the standard deviations. The percentage of the possible gain obtained between the pre and the mid tests is given in the last column. Preliminary results of content gain have been reported [11], and these results corroborate the earlier finding that the PD was effective in increasing teacher knowledge of the selected topics. All of the topics had gains of over 50% of the possible gain after the pre-test score.

Table 1. Data on teacher content knowledge.

Unit	*Pre-test (stdev)*	*Mid-test (stdev)*	*Post-test (stdev)*	*Gain as % of possible gain*
MagLev (6 questions)	3.52 (1.50)	5.04 (0.89)	4.76 (0.97)	61.3
Atomic (7 questions)	4.32 (1.46)	5.79 (1.30)	5.58 (1.08)	54.8
Technology (5 questions)	3.13 (1.55)	4.43 (0.73)	4.43 (0.90)	69.5
Laser Cooling (5 questions)	2.77 (1.41)	3.95 (1.00)	3.95 (0.95)	50.6

While there were (as we will see) significant gains made in teacher content knowledge as a result of the PD workshop, the student summer camp that followed does not appear to have had any significant impact on teacher content knowledge. This was noted in the preliminary analysis of a more limited data set [11], but now we see that this is true across the board.

Table 2 presents the data on teacher confidence in their answers to the content questions. Just as with the content knowledge, there were gains across the board in the teachers' confidence in their content knowledge over the course of the PD workshop (pre to mid). However, teaching in the student summer camp did not result in any significant change in the teachers' confidence in their content knowledge, at least as measured by the self-reported survey.

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

Unit	Pre-test (stdev)	Mid-test (stdev)	Post-test (stdev)
MagLev (6 questions)	2.34 (0.89)	3.92 (0.99)	3.85 (0.93)
Atomic (7 questions)	2.57 (1.17)	3.73 (1.11)	4.01 (0.78)
Technology (5 questions)	2.33 (1.35)	3.75 (1.26)	4.19 (0.80)
Laser Cooling (5 questions)	1.92 (1.00)	3.54 (1.00)	3.77 (0.86)

Table 3 presents the p-values from the two-tailed T-test for changes from one test/survey to the other. This table validates the statements made above. The increases from pre to mid in both content and confidence were statically significant, while the changes from mid to post were not. Teaching the summer camp the week after the PD workshop had no effect on teacher content knowledge or confidence in that knowledge. The content knowledge scores of the teachers on the mid test (which measured their knowledge just before they taught the students) for the three units for which have students pre and post data (excluding Laser Cooling) were all similar. Therefore, the variation seen in the student content gains [12] are not likely to be due to variations in teacher content knowledge, or confidence in that knowledge, which were also very similar.

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

Unit	Item	pre/mid	mid/post	pre/post	N
Levitation	content	0.0001*	0.2921	0.0011*	25
	confidence	0.0001*	0.826	0.0001*	
Atomic	content	0.0005*	0.5374	0.0011*	25
	confidence	0.0008*	0.3073	0.0001*	
Technology	content	0.0007*	1.00	0.0011*	23
	confidence	0.0006*	0.1644	0.0001*	
Laser Cooling	content	0.0026*	1.00	0.0022*	22
	confidence	0.0001*	0.418	0.0001*	

The initial study [12] found that the self-reported values of confidence are well correlated with the actual level of content knowledge. With a larger data set and a broader array of topics we can investigate if this initial finding holds true. Fig. 3 presents scores on the content assessment as a function of self-reported confidence in content knowledge for the four topics covered in the 2023 workshop before any instruction (the pre state). Three of the four topics have significant correlations between the two quantities, however, the Laser Cooling showed an almost complete lack of correlation (R^2=0.0797).

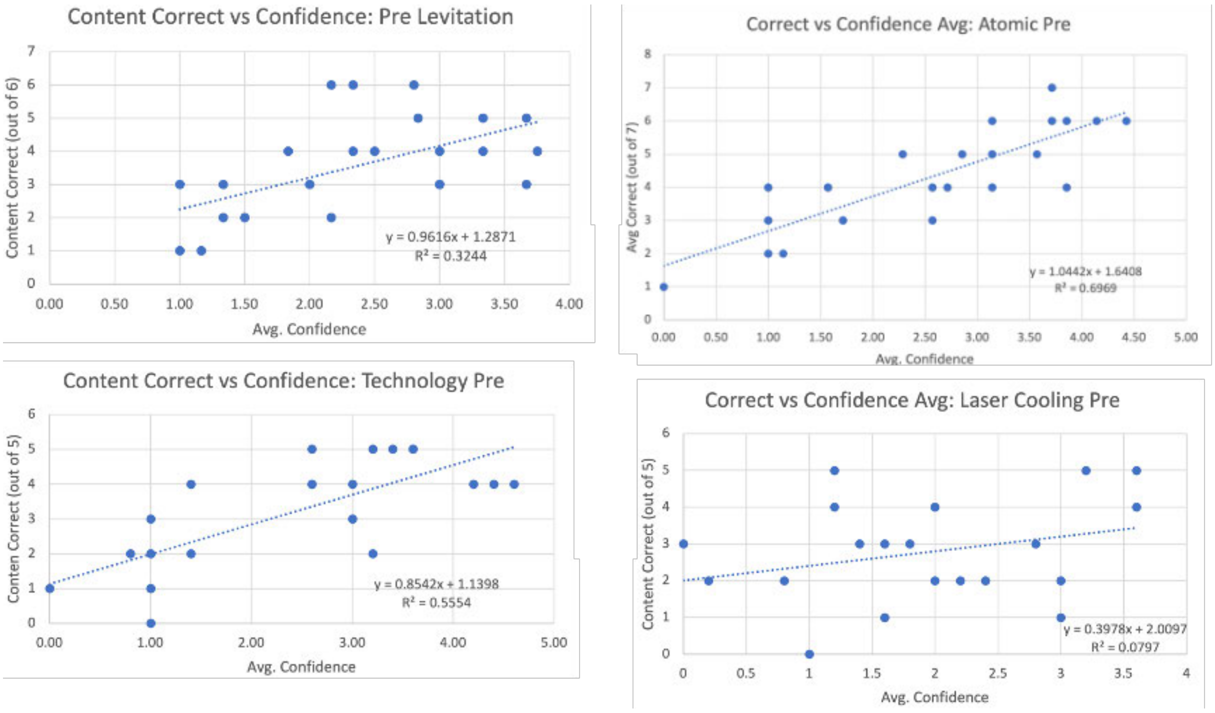

Figure 3. Content score as a function of confidence level prior to the PD workshop.

Fig. 4 presents the same correlations as Fig. 3 using the data after the teacher PD workshop (the mid state). We do not present the post data versions of these correlations since there was no significant difference between the mid and post scores, thus, the plots would be almost identical. The pattern identified in Fig. 3 is present if Fig. 4, with the Laser Cooling showing poor correlation despite a wide range of data.

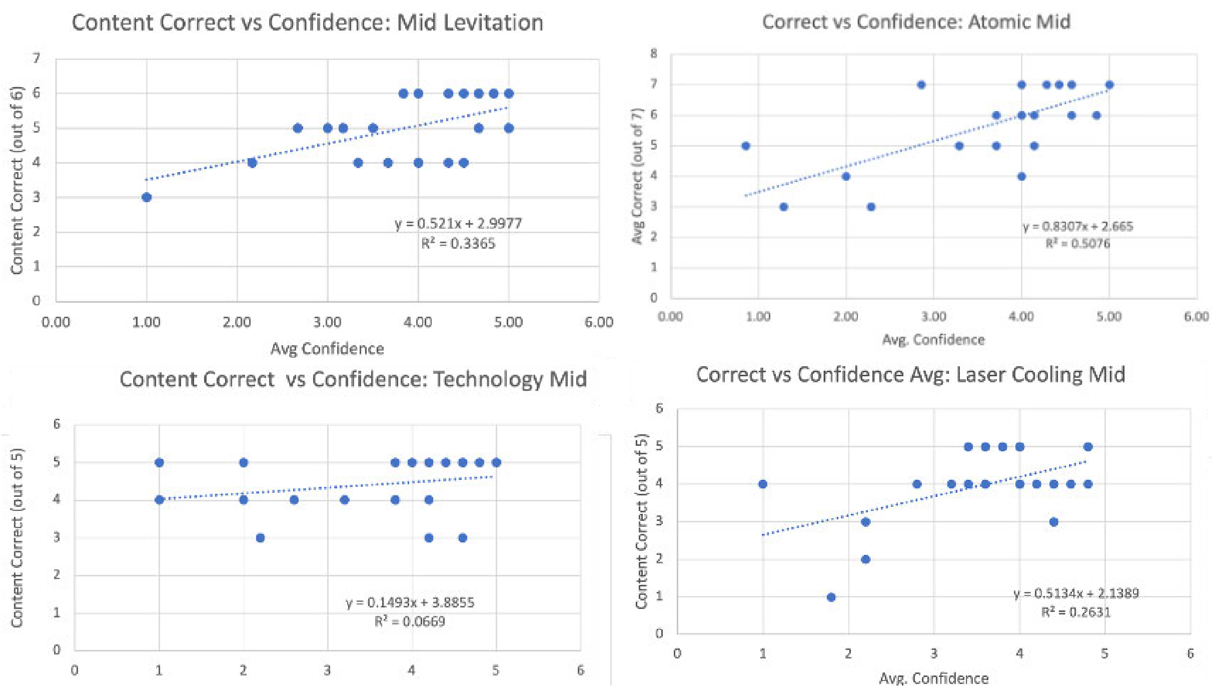

Figure 4. Content score as a function of confidence level after the PD workshop.

This is a curious and unexpected result. It seems that for some content areas, perhaps those that are particularly unfamiliar, teachers are not able to adequately judge their competence in the contest, whereas in most other areas they can. This has some significant implications for teacher professional development and the deployment into classrooms of unfamiliar content, like quantum science topics. It is notable that the content score for this unit were the lowest of all the four topics. This issue is worthy of further study and the development of mechanisms to ameliorate the negative effects that this phenomenon could have.

4 CONCLUSIONS

Analysis of results on surveys of teacher content knowledge and confidence in that content knowledge for various quantum science related topics indicates that the structure of the professional development is very effective in increasing teacher scores in both areas. The participating teachers were able to identify their strength in content knowledge given the correlations between scores on the content assessment and self-reported confidence in their knowledge of the content. However, there was one significant exception to this pattern. For the unit on Laser Cooling, there was no correlation scores on the content assessment and self-reported confidence in their knowledge of that particular content. This issue is deserving of more study and perhaps the PD could be adjusted to address this issue.

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