THE QUANTUM FOR ALL PROJECT: TEACHER PROFESSIONAL DEVELOPMENT MODEL

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Abstract

Quantum information science (QIS) is of growing importance to economic and national security, commerce, and technology. The development of a "quantum smart" workforce needs to begin before college since most students will not major in physics. Thus, it is vital to expose K-12 students to quantum concepts that are relevant to everyday experiences with credit card security, phones, computers, and basic technology and to prepare teachers to teach this content. The logical venue for exposure to basic ideas in quantum science might be a high school physics course, or even a physical science course if a full physics course is not offered. Professional development (PD) for educators typically includes 1-2 weeks of intensive instruction, usually in the summer. Teachers are then expected to remember what they learned and implement it several months after the PD. The model is based on prior research indicating that an educator needs a minimum of 80 hours of PD to become comfortable enough to implement the new instruction in their classroom. However, little research has been done as to how much they actually implement. For the past three years, we have been engaged in a project funded by the US National Science Foundation to build mechanisms (materials and PD strategies) for educating a quantum-ready workforce. Our PD model is based on pedagogical techniques used in classrooms, specifically the components of learn then practice in order to avoid cognitive overload. Instruction is more effective when the learners (teachers or students) are given opportunities to actively engage in the learning process through interaction/collaboration with peers, exploring challenges, and practicing what they have learned. This paper will share the logistics of our new PD new model, challenges, finding from our current research, and implications for future PD in K-16.

Keywords: Quantum, Teacher professional development, STEM.

1 INTRODUCTION

Quantum information science (QIS) is of growing importance across many sectors of the economy, and this requires that education of students keep pace with developments. There are a number of quantum related careers in the near future, including several that can be filled by people without STEM degrees and even without a Bachelors degree [1]. However, teachers are not well prepared to teach topics related to QIS content. Many of the topics were only recently introduced into basic science education in the United States through the Next Generation Science Standards (NGSS) that have been adopted by 20 states and are influencing many more state science education standards [2]. Moreover, many teachers never encountered QIS content unless they majored in physics [3]. Therefore, there is a significant need to support teachers in acquiring both an appreciation and understanding of quantum content, evaluating the professional development providing the content, and helping teaching transition their content knowledge into classroom instruction.

Pedagogical content knowledge (PCK) has been at the forefront as one of the critical attributes for effective teaching for over 20 years. The technology dimension has been added to PCK as one of the features teachers should utilize in the classroom because successful science teachers in the 21st century must be able to present science knowledge using appropriate teaching strategies and technologies [4]. Most efforts in the educational system have focused on equipping teachers with up-to-date teaching technologies in the form of notebook computers, interactive phones, video editing, mobile technologies, interactive software, and internet-based learning [5] [6]. With the COVID pandemic, learning abruptly moved to a technology based virtual format stretching the capabilities of our educational systems and the people using the systems, educators and students. It is doubtful there will be a return to “what was” or “normalcy.” Our worldwide use of technology will continue to escalate, and the future U.S. workforce will not only require a working knowledge of the technology, but also the basis or science behind the technology, which is quantum information science (QIS).

The importance of exposing students to quantum concepts has only recently been advocated by many groups including the government [7] although the scientific community has known about quantum effects

ISBN: 978-84-09-52151-7

for over 100 years. The National Quantum Initiative was established by the National Quantum Initiative act in 2018, amended by the National Defense Authorization Act in 2022 and by the CHIPS and Science Act of 2022. The Initiative was signed into law by President Trump in 2018 to "accelerate quantum research and development for the economic and national security of the United States". Since 2018, scientists, industries, engineers, and research institutes have coordinated efforts to support the Initiative, but most of the focus has been at the university and research level. Educators in K-12 are beginning to realize their role in these efforts because they are the ones who must increase QIST awareness in order to help support the need for a growing quantum workforce. However, resources and support for the efforts are considerably smaller in K-12 than at the university, industry, or research level.

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 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 to be taught using fully integrated STEM lessons. A cornerstone to the project is providing professional development (PD) to educators to help them understand quantum content in a way that is appropriate for a high school class. 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 QAS proposal couples a professional development (PD) model for teachers followed by a student camp. The student camp, taught by the participant teachers (PTs), is designed to help students understand QIS and show how it is the foundation for Information and Communication in Technology (ICT). Teaching the student camps provides practical practice for the teachers that simulate a classroom environment. This environment helps them gain confidence and allows them to see student engagement and interest in QIS and ICT, thereby increasing the chance of implementing the lessons in their own classrooms. More details regarding the rationale and professional development plan are provided in a companion paper in this conference proceedings [8].

2 METHODOLOGY

As described above, and in more detail in the companion paper [8], the basic structure of the professional development is for teachers to have a 4-day teacher workshop focusing on STEM, QIS, and ICT which is followed by 4-day student camps. The student camps are planned and facilitated by teacher participants (PTs) using the information they learned in the workshop, which allows them to practice what they learned in an informal setting. This model has two major research questions that are summarized in Table 1. In section 3.0 of this paper we will present selected evidence demonstrating that the professional development framework used in this project.

Table 1: Research Questions.

Research Question 1	Does this structure of professional development intervention produce significant change in teacher classroom practice as designed? The main research question can be subdivided into two components, content and pedagogy. Do they know the science? Are they comfortable with the pedagogy and technology integration?
Justification for study	Teachers normally cannot devote large periods of time (2-3 weeks) to focus on one component of their curriculum, especially if they are teaching multiple subjects. Model includes 4 days of workshop focusing on content and technology (PCK) followed by practice with students for 4 days at STEM camps. Providing a student camp immediately after the teacher PD will allow teachers the opportunity to work with their peers, internalize the content and technical skills, and practice teaching it to students without fear of doing it for the first time in front of their own students. Workshops address content and technology skills. Camps address the pedagogy. To change practice there has to be sufficient content and pedagogy. This intervention addresses each. Follow-up sessions will provide additional support and opportunities to self-report implementation levels.
Target group	Teachers
Measures for assessing	Pre and post content assessments, surveys to self-report levels of confidence, interest, and ability to implement skills and content in the classroom. Science Teaching Efficacy Belief Instrument (STEBI) was modified to contain quantum related questions.
Collection of data procedures:	Pre and post assessments are administered before and after the workshops. Self-reported data (surveys) is collected before the workshop, post workshop, pre camp, and post camp.

Expected outcomes/impact	A shorter scale intervention will be more accessible to more teachers and if the model is effective it could be used to broadly disseminate. This methodology could be used for other content or skills to increase effectiveness of PD with teachers who cannot devote the larger time to PD.
Research Question 2	Does the design cause a change in student understanding, attitudes, and interest in STEM, ICT, or QIS?
Justification for study	There is an urgent need to quickly develop a quantum-smart U.S. workforce pipeline. Students need rich, engaging, challenging experiences in order to pique interest and motivate them to learn more and seek jobs related to STEM.
Target group	Students
Measures for assessing	Pre and Post assessments that measure both understanding and confidence; self-reported surveys to measure self-efficacy, attitude, and changes in STEM/QIS/ICT interest or perspective were used.
Collection of data procedures	Pre and post assessments are given at beginning and end of camps; surveys are given before and at the end of camps.
Expected outcomes/impact	Structure of activities is designed to be inquiry centered which should naturally produce a change. Students engaged in the content and technology will want more experiences thereby increasing their appetite for learning about STEM, QIS, and ICT careers.

The summer student STEM camps provided an opportunity for teachers to practice what they had learned, but they also provided opportunities for students to learn about QIS. Students and teachers were given opportunities each day to reflect on what they learned, what was still confusing, and what they still needed to know. The leadership team and/or teachers then used this feedback to guide conversations, change activities, or engage students in discussions regarding the feedback.

3 RESULTS

There were evaluation tools designed to gather information as to the effectiveness of the PD, lesson integration, and resource validity. Components include: Content and confidence for both teachers and students, attitude survey for students, STEBI (revised for quantum) for teachers, camp and workshop feedback, and numerous formative assessments given throughout the workshops and camps. All these components will be used in the summer of 2023 and if participants are returning their initial responses will be tagged through 2 years instead of one. Workshops and camps were staggered in order to facilitate equipment sharing and leadership roles.

3.1 Teacher content and confidence

Teacher content and confidence were measured intermittently throughout the PD using short content focused assessments. The questions were similar in content and level of difficulty on the pre and mid/post while some of the questions were the same. The pre was administered prior to when the topic started during the workshop, the mid was given at the end of the topic (during the workshop), and the post was the same test as the mid but given after the topic was taught in the camp.

Table 2: Pre and Post Teacher Assessments Comparisons.

		N=66	***N=41***	***N=56***
Question	***Test***	***Pre % correct***	***Mid % correct***	***Post % correct***
1	***Malus***	10.61%	36.59%	37.5%
2	***Malus***	16.67%	73.17%	75%
3	***Malus***	33.33%	29.2% got all 3	32% got all 3
4	***Malus***	19.7%	29.27%	25%
5	***Malus***	12.12%	97.56%	91.07%
6	***Malus***	19.6 % and all 3 correct	68.2% got all 3	42.8% got all 3

		N=64	N=41	N=55
Question	Test	Pre %	Mid %	Post %
1	Phenomena	54.6%	82.93%	83.64%
2	Phenomena	65.63%	26.8 % ans both correct	47.27% ans all 3
3	Phenomena	45.31%	36.59%	49.09%
4	Phenomena	1.5% got all 4	4.8% ans. both correct	18.18% ans both correct
5	Phenomena	26.5% got all 3	68.29% ans both correct	78.18% ans both correct
		N=47	N=26	N=65
Question	Test	Pre %	Mid %	Post %
1	QKD	36.17%	84.62%	67.69%
2	QKD	31.9% ans. both correct	84.62%	86.15%
3	QKD	19.5%	46.15% ans. both correct	33.85% ans. all 3 correct
4	QKD	72.34%	62.96%	60%
5	QKD	19.15%%	85.19%	64.62%
6	QKD	51.06	85.19%	75.38%

Participants were asked to indicate their level of confidence in their answer being correct as they answered the content questions. Below are the confidence comparisons for the pre and post assessment which generally show an increase in the confidence. The scale was a sliding scale from 1 (total guess) to 5 (being confidence enough to teach it tomorrow), so the lowest score was 1, not 0.

A closer analysis is being done regarding the content and confidence correlations. Looking at the table below it is obvious some topics continued to increase in confidence while others increased after the workshop but regressed again after the camp. Follow-up questions may be necessary to determine the cause of the change. Was it because the students in the camp asked questions that they were unsure of how to respond? Was it because they thought they were confident until they taught it?

Examining the change from Pre to Post indicates the greatest gains for confidence in understanding content was in areas that were likely “most unknown” to them (i.e. Quantum Key Distribution). On the other hand, Malus’s Law for the intensity of polarized light passing through a polarized filter as a function of angle is standard in a physics curriculum. The teachers started with a mid-level of confidence in their answers. Phenomena focused on wave particle duality and included many stations about properties of light. Some of those stations and questions would have been familiar to the teachers, others like LIGO and interferometers were not as common, so the initial level of confidence was about the same as for Malus’s Law.

Table 3: Teacher Assessment Confidence (in Content)

		N=72	N=41	N=56	
Question	Test	Pre	Mid	Post	% Change
1	Malus	2.77	4.29	4.23	34.52
2	Malus	2.65	3.93	4.16	36.30
3	Malus	2.34	3.41	3.78	38.10
4	Malus	2.54	3.34	3.44	26.16
5	Malus	2.51	3.52	3.61	30.47
6	Malus	2.14	3.52	3.6	40.56

Question	Test	Pre	Mid	Post	% Change
1	Phenomena	2.89	4.04	3.91	26.09
2	Phenomena	3.15	4	3.93	19.85
3	Phenomena	2.95	3.54	3.56	17.13
4	Phenomena	1.51	2.95	3.54	57.34
5	Phenomena	2.41	3.17	3.21	24.92
Question	Test	Pre	Mid	Post	% Change
1	QKD	1.31	4.27	3.44	61.92
2	QKD	1.87	3.65	3.49	46.42
3	QKD	1.35	3.46	3.23	58.20
4	QKD	2.2	3.38	3.18	30.82
5	QKD	1.1	3.96	3.61	69.53
6	QKD	1.11	4.04	3.3	66.36

3.2 Student content and confidence

The pre and post student assessments were aligned with the topics throughout the camp. The pre assessment covered all the topics (14 questions), was given at the beginning of the camp and the post was given at the end of the camp. Although the intent was to match individual changes in content understanding, this proved to be difficult because most did not remember their "code" (which was predetermined by them) and therefore the cross matching could not occur since there were no names associated with the assessments.

The questions were similar in content and level of difficulty on the pre and post while some of the questions were the same. Determining statistical significance is difficult due to the items that had multiple answers as some put a few correct answers, but maybe not all. The leadership team will try to redesign questions in 2023 to eliminate some of the multiple choices.

Table 4: Student Comparison of Pre and Post Assessments.

	N=73	N=80
Question	Pre % correct	Post % correct
1	19.18% ans. 3 correctly	80% ans. all 3 correct
2	65.75%	78.75%
3	21.92%	35%
4*	24.66%	15%
5*	17.00%	33.75%
6	15.07%	93.75%
7	71.23%	82.50%
8	15.1% ans. both correct	53.75% ans. both correct
9	27.40%	21.25%
10	15.07% ans. both correct	21.25% ans. all 3 correct
11	47.95%	52.50%
12	43.84% ans. 3 correct	50% ans. all 3 correct
13	42.47%	65%
14	46.58%	83.70%

Students were asked to indicate their level of confidence in their answer being correct as they answered the content questions. Below are the confidence comparisons for the pre and post assessment which generally indicate an increase in the confidence, although the average was never above a 4.0. The scale was a sliding scale from 1 (total guess) to 5 (being confidence enough to explain to a peer), so the lowest they could score was a 1.

Table 5: Confidence Comparisons for Students.

	N=73	***N=80***
Question	***Pre***	***Post***
1	1.33	3.59
2	1.94	3.17
3	1.81	2.39
4	2.1	3.51
5	1.49	2.76
6	1.26	3.74
7	1.22	3.28
8	1.29	3.52
9	1.39	2.74
10	1.51	2.92
11	2.68	3.74
12	2.59	3.52
13	1.62	3.11
14	1.7	3.71

3.3 Student survey data

Students were given a pre and post attitude survey related to their perception of engineers, science, and solving problems. The Likert scale was 1-5. There was not a statistically significant gain between the pre (N=78) and post (N=75) surveys, however there were positive trends seen in the post. Three 3 areas we wanted to see more change are indicated by *.

Table 6: Student attitudes.

Attitude Comparisons	***Pre (N=78)***	***Post (N=75)***
Interested in how things work*	4.30	4.48
It is important to understand cybersecurity*	4.29	4.41
I believe I can be successful in a career in engineering*	3.5	3.73
I believe learning STEM concepts will provide better job opportunities	4.5	4.5

The pedagogical method used for daily feedback on student reflections was simply to use sticky notes that students placed on sheets of paper. Students were asked to use the 3-2-1 approach listing things they learned, things they were still confused about, and what they still wanted to know. Sample responses are listed below.

Examples of "Things I learned":

- Properties of Waves
- Light is photons
- Waves have properties of waves and particles
- Polarization
- What an interferometer is

– Superposition
– How a 3D printer works
– Coding for printers
– Quantum is a “thing”
– Engineering design (is fun)

Things that I am still confused about: (note these were typically addressed the next day)

– How a wave be a wave and a particle?
– How can there be multiple superpositions?
– How does a wave flip?
– Exclusivity
– Cryptography

Things you still want to know: (Note: when possible, these were addressed the next day)

– Uses for 3D printers
– Coding in Glowscript
– Polarizers and applications
– Encryption
– How a beam splitter “splits”
– Quantum computing
– Superposition
– Probability

Figure 1 – Students at the workshop.

3.4 Teacher Feedback

Teachers were asked to provide feedback about the professional development model immediately after the workshop and the summer camp. The following statements capture the response of the teachers.

- Turning around and teaching immediately after doing the training was very useful- I taught better when it was fresh in my mind. Teaching with other people with different skill sets and proficiencies helped me develop my own practice too- especially interacting with the leadership team throughout the two weeks.
- Immediately applying what we learned in the workshop including studying and planning lessons, and especially the collaboration and access to the experts to answer questions on site, helped set the ideas, info, and pedagogy in my mind.
- Having the workshop and camp together was my favorite aspect of this whole adventure - we immediately were able to put into practice what we had learned the previous week. This is effective for building teachers' confidence and ensuring they feel prepared to use it in their own classroom. In conducting the student camp, the 3-2-1 activity was super helpful for assessing

where the students were at each day of the camp and addressing those questions the following day. The hand-on nature of the activities were crucial to capturing students' attention and interest.

- Working hands on with students was really helpful. It showed where issues were.
- I thought the 3d modeling was successful and hands on activities were great
- The manipulatives, especially for Mach Zehnder and Quantum Cryptography, were particularly useful to model the phenomena. Teaching immediately after learning was actually very effective at cementing my understanding.
- Engineering Process connected to careers, wave particle duality and cybersecurity
- Everything! I learned so much by facilitating the camp sessions with students. It's great to have a set of lessons (and tools) to utilize in the classroom.
- The poker chip models were really good for the encoding aspect. Hands on really helped me understand what was going on. Having slide shows (with notes) to use will also be helpful.
- Discussions about pedagogy and specifically what would need to change/add/remove when delivering to students at various levels with varying science backgrounds
- Actually 'Getting' so many of these concepts I've seen or heard before but never clicked for me. Also understanding how to make quantum applicable to high school kids

4 CONCLUSIONS

Overall, the confidence level of the teachers increased over the 4 days of PD in understanding the content, however the confidence level dropped some during the camp (where they were teaching the content), but it did not drop to the prior levels. Participants/teachers indicated the PD model was very effective and they felt it was an appropriate model and had many strengths. The only drawback was the time required to do both the workshop and the camp (i.e. 2 weeks).

Generally, teachers recognized there was a difference in learning something that you are going to have to teach "soon" vs. just attending a normal PD. They appreciated the time to discuss not only the content, but how it would be taught and then reflecting on whether what they did was successful and possible changes for their own classrooms.

At the time of this report, data is still being collected regarding the classroom implementation and potential curricular connections. However, of the teachers that responded, most reported that they used the Light Phenomena Lesson (which connects to wave particle duality) and Malus's Law (light characteristics). These two were the bulk of the workshop and camp and are also closely connected to what they would currently be teaching. Therefore, the transition to these two topics would be more easily integrated than a topic such as quantum cybersecurity. The average amount of time spent on the topics was 2 hours, which would be 1-2 days. Based on feedback, the teachers either did not modify the lessons as they were presented and taught or slightly modified due to time constraints and they generally felt integration to their current curriculum was an easy adjustment. When asked about the level of student engagement in their class, most said the students enjoyed it although one commented that the students said, "it made their head hurt".

ACKNOWLEDGEMENTS

This work was supported by the National Science Foundation of the United States under grant numbers 2009351 and 2048691.

REFERENCES

[1] The Next Generation Science Standards, Accessed April 30, 2023, Retrieved from https://nextgenscience.org.

[2] C. Hughes, D. Finke, D. A. German, C. Merzbacher, P.M. Vora, and H. J. Lewandowski, *"Assessing the needs of the quantum industry,"* IEEE Transactions on Education, vol. 65, no. 4, 592-601, 2022.

[3] D. A. Zollman, N. S., Rebello, and K. Hogg, “Quantum mechanics for everyone: Hands-on activities integrated with technology. *American Journal of Physics*, vol. 70, no.3, 252–259, https://doi.org/10.1119/1.1435347, 2002.

[4] T.C. Lin, C.C. Tsai, C.S. Chai, and M.H. Lee, “Identifying science teachers' perceptions of technological pedagogical and content knowledge (TPACK).” Journal of Science Education and Technology, vol. 22, no. 3, 325-336, 2013.

[5] A. O. Aktürk, S. Mihçi, and I. Çelik, “Metaphors of high school students about the concept of “interactive whiteboard,” *International Journal of Education in Mathematics, Science and Technology*, vol. 3, no. 2, 120-131, 2015

[6] S.A. Kiray, Celik, I., and M. H. Colakoglu, “TPACK Self-Efficacy perceptions of Science Teachers: A structural equation Modeling Study”. *Education and Science 2018,* vol. 43, no. 195, 253-268, https://doi.org/10.1038/120105a0, 2018.

[7] National Quantum Initiative, Accessed May 1, 2023, Retrieved from https://quantum.gov.

[8] R. E. Lopez and K. J. Matsler, “The Quantum for All Project: Rationale and Overview,” *Proceedings of the 15th International Conference on Education and New Learning Technologies,* IATED, 10.21125/edulearn, 2023.