Applying Classroom Practices Learned from Virtual Professional Development During a Pandemic

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The COVID-19 (C-19) pandemic forced educators to scrutinize educational best practices that had been used for years in the classroom. Suddenly, educators had to pivot from the known to practices with little or no research to try and figure out what would constitute an ideal virtual learning environment. Educational professional development also had to pivot. In spring 2020, the Institute of Education Sciences (IES) reported that over 77% of the public school in the United States had changed to online distance-learning formats. In addition, the National Center for Education Services (NCES) reported 83% of public schools reported that their F2F classes were moved online, which necessitated a change instructional delivery.[1–3] This shift necessitated not only learning potentially difficult topics in the middle of a pandemic, but also demanded use of a virtual format and lessons that utilized limited equipment and supplies.

This paper reflects upon the challenges of teacher professional development, designed primarily for high school physics teachers, where both content and format were unfamiliar. The content focus was quantum information science (QIS), and the original face-to-face (F2F) environment shifted to an online virtual with only a few months of planning. As a result of C-19, many states are now implementing changes to K–12 education such as virtual options for courses or some type of hybrid learning environment.[4] Therefore, identifying and addressing the challenges faced in providing virtual professional development may be of use to other educators who need to incorporate similar elements in virtual environments.

Workshop background information

The professional development, funded by the National Science Foundation,[5–7] was originally designed as a conference to support high school teachers in learning about QIS and ways to incorporate engaging and inspiring activities into classrooms. We knew that empowering teachers and helping them feel confident to teach quantum-related knowledge and skills in their lesson plans would be challenging. In order to be effective, we planned on providing F2F sessions where there were strong STEM interconnections, engaging activities, and ample opportunities to learn relevant content. However, C-19 hit a week after the project was funded, so plans had to change from an F2F conference to virtual workshops, which added another layer of challenges. Just as educators were struggling to know what to do in classrooms, we were brainstorming ways to change our approach. Thankfully, the leadership team included master high school physics teachers and university faculty content experts, who were familiar with previously known best practices and current C-19 technical challenges. However, the leaders had limited practice teaching virtually in their classrooms, the technology used varied, depending on district availability, and most had not taught any QIS content to students or peers.

The pivot included changing from one large conference to support of two virtual conferences, one in the summer of 2020 and one in 2021. In 2020, the 4-day conference covered four quantum topics (one per day) for a period of about 2 hours each. In 2021, there were eight lessons, each about 2 hours in length, given over a 4-day period. One lesson was in the morning and one in the afternoon, with a lunch break in the middle. The targeted group was high school teachers, but in 2020, there were also a few two-year college educators who were invited to join to assist in feedback and content support.

Below, we describe the components of the workshops that were successful based on our ethnographic study and other evaluations and feedback from the participants. We believe many of these elements would likely also be effective in the classrooms, and our project is presently gathering data on the effectiveness of our model to support classroom implementation and impact.[6,7] The workshop evaluator did conduct an ethnographic study and observed the virtual workshop sessions in both summer 2020 and 2021.The references made from our study to possible classroom connections are only based on the extensive experience of the leaders and feedback from participants.

Community of Practice framework

Our workshop was based on the Community of Practice (COP) framework, in which a group of individuals participate in mutually beneficial activities. In this framework, learning is viewed as social participation in the community.[8,9] For our COP, the domain of knowledge and practice centered on supporting the teachers in learning quantum principles at a level appropriate for high school students in a variety of STEM classes. We focused on creating common ground, encouraging teachers to participate, guiding their learning, and giving meaning to their actions. The notion of a community in the COP framework is to create the social fabric for learning because a strong community can foster interaction and encourage a willingness to share ideas.[8,9] We took advantage of Zoom features such as chat, polling, and breakout rooms to make sure that the community of teachers developed and maintained the core of learning and sharing quantum knowledge in an engaging and interactive environment. Lessons were designed using the 5E learning cycle approach[10,11] in order to model effective pedagogy for engaging students in the learning process. The teachers were actively involved in roles of both students (i.e., learners) and teachers (i.e., peer sharing). As members of the COP, teachers developed models of quantum systems and phenomena, planned and carried out investigations to test their models, analyzed and interpreted data, and obtained, evaluated, and communicated findings. It was made clear to the teachers that they were part of a safe community to learn as well as exchange ideas, and all questions and discussions were valued.

The COP framework has components that can easily transfer to a high school classroom by creating a strong community of supporting peer interactions. Unfortunately, many classroom teachers expressed frustration at the inability to create this type of community, especially an online community, during C-19. As shown in the NCES report, more than 80% of U.S. public schools reported that the C-19 pandemic negatively impacted student behavior and socioemotional development.[2] The 2020 report also showed that less than half (47%) of the public school teachers had scheduled time with their students, a necessary component for COP.[1]

Creating a community of practice entails viewing learning as social participation.[8,9] Two of the great features of Zoom are the chat and polling features. The chat feature was particularly useful for participants who did not feel comfortable unmuting themselves to participate in discussions or ask questions. The workshop participants were given the option to either unmute themselves and participate in the discussions or ask questions, or they could write their thoughts or questions in chat. The leaders were partnered with other peers in order to allow one person to focus on the presentation, one to focus on having videos and supporting material ready, and at least two to focus on monitoring the chat. Questions were answered in the chat as they were posted (by a peer in the leadership team), giving participants immediate feedback. Sometimes the chat feature was the only feature that all participants used, e.g., in icebreaker activities or when the teachers were asked to predict the outcomes in different situations for different units and quantum experiments. The polling feature was used in situations where the answers to the questions posed were in a multiple-choice format as an informal or diagnostic assessment. One of the components of successful interactive sessions was having peers monitoring the chat, answering questions quickly, and stopping the leader if several participants were confused. By stopping to allow for discussion or addressing misconceptions, the leaders modeled how it would also be done in a classroom. It can be challenging to present and monitor the chat at the same time unless this technology is used on a regular basis. One suggestion for both classroom teachers and presenters who find monitoring the chat to be challenging would be to appoint a participant (student or teacher) to help with the monitoring. Empowering these "co-presenters" to help with the chat or be leaders in breakout rooms helps them feel a sense of ownership, and can increase their own understanding when they help others understand concepts.

Regarding use of the polling feature, one teacher commented, "I appreciate having the appendix for using with my students and refreshing my memory of this. Love the breakout rooms—very interactive!!! Poll Everywhere is a good tool to have learned—thanks!"

Effective use of the Zoom main room and breakout rooms also supports COP development. Throughout the workshop, the main room and breakout rooms of Zoom were used effectively by allocating appropriate time for discussion. In keeping with trying to avoid cognitive overload,[12] the main room discussions were normally between 15 and 30 minutes, while breakout rooms were 5–7 minutes. This gave teachers ample opportunities to discuss the quantum concepts in the breakout rooms in small groups varying in size from two to six participants/room. During the discussion time, leaders rotated in and out of the rooms to check on participants, clarify instructions, answer questions, or just facilitate conversations. During certain activities, teachers used the strategy of "pair–share," allowing discussions to be more focused; an example topic was, "How can one use the uncertainty principle to explain what happens to the interference fringes in the double-slit experiment videos when one measured or did not measure which slit the electron went through?" Sometimes the teacher participants used the breakout time to conduct short experiments using the materials they were sent ahead of time. They were encouraged to share predictions, observations, and interpretations with each other and were often provided a journal in the form of an appendix, similar to what the teacher would give the students in the classroom. In some of the breakout group activities, e.g., quantum cryptography, teachers in each breakout group were asked to brainstorm ideas and write down their predictions in a shared online spreadsheet before the general discussion upon returning to the main room.

In the high school classroom, takeaways for breakout rooms could include dividing the lesson into small components, or chunking,[13] providing multiple discussion groups (breakout rooms) so they are small enough for all to participate, allowing appropriate time, and monitoring rooms to address questions and encourage engagement. There are different apps available for the teacher to see what is being written (e.g. on whiteboards) and quickly notice if a student needs closer monitoring. Using electronic journals or whiteboards also allows students to journal results of labs or take notes.

Incorporating icebreaker activities into the session also supported the COP model. Icebreaker activities in the virtual workshop environment entailed asking teachers to use the Zoom chat feature to answer questions after each break. The goal was to increase engagement in the community and/or prepare for the next activity. For example, in one icebreaker, teachers were asked to type in the chat something quantum that they would like to teach their students or already teach them in some capacity. Teachers came up with a variety of things such as "electron diffraction," "superposition," "all quantum particles behave as waves," "electrons are waves and particles," "behavior of light with lasers," "polarizer will either admit or not admit a photon based on probability," "qubits," "a measurement basis is a pair of mutually exclusive states," "when quantum systems interact they become entangled with each other," etc. For the icebreaker questions, after the teachers were finished answering the questions in the chat, a few of them were invited to unmute themselves and elaborate on what they had written and the session leaders validated the teachers as they expanded on their ideas. Another icebreaker question asked teachers to write in the chat what their favorite element in the periodic table is and why. Responses varied from "I am partial to Oxygen because I like to breathe," "carbon-photosynthesis-I like to eat," "I have always been a fan of hydrogen, primordial element and all," "Iron because of supernovae and because it is on top of 'food chain,'" "silicon-computers," "Vanadium because I had to do a project on it in 7th grade—never let it be said that science teachers don't leave a lasting impression," "Tungsten. A student brought me a lightbulb that had turned blue, so we had to solve a mystery!" etc. Teachers were often so engaged with these activities that they posed broader questions, which led to very engaging discussions, such as "What do you consider to be the greatest challenge to growing awareness of quantum among students today?"

In the high school virtual classroom, icebreakers can easily be used to engage students, take attendance, or give a preassessment. Apps with a game-like approach or competition can also entice students to log in and actively participate, especially if they are not required to put their name on their score. However, this does create a challenge if the teacher is using it to take attendance or a daily grade.

Preplanning to increase instructional confidence

Due to the uncertain implications of C-19 restrictions, planning for the 2020 summer workshop was relatively short. In our situation, many of the leaders were Physics Teaching Resource Agents[14,15] and had prior experience leading in-person workshops on many physics topics, but very few had extensive experience using a virtual platform. Therefore, for the summer of 2020, the leadership team (LT) had to rely on classroom practices used in the early months following C-19. These practices included using Zoom, reducing the time for each session to mimic the same as a classroom (1–1.5 hours), and preplanning any foreseeable circumstance. Modeling lessons in an F2F environment is considered to be a best practice, so we modeled virtual lessons for reduced barriers to implementation in the teachers' own classrooms.

The first step for preplanning was to prepare the LT. Discussion at online meetings indicated an increased stress among the LT over how (or if) the sessions would be successful; therefore, it was critical to improve their confidence in this new environment with difficult content (QIS). In 2020, the leaders/instructors relied heavily on virtual collaboration, but they also met in person for several days before the workshop to practice, plan, and modify lessons. Many of the lessons were adapted from resources originally developed by the Institute of Quantum Computing and Perimeter Institute for Theoretical Physics in Canada,[16,17] but needed some revisions. Criteria for each lesson included alignment with standards, incorporation of the 5E learning cycle,[10] inclusion of PowerPoint slides with notes, participant/student pages (called appendix) for taking notes or data, videos, and assessment questions. In addition to planning the sequence and level of rigor for the sessions, the leaders preplanned how to best lead discussions (i.e., via chat or breakout groups), where to focus on a key concept, and how much time would be needed to carry out the tasks for each activity/lesson. All hands-on activities, videos, and appearances by guest experts were planned and practiced ahead of time during the F2F conference in the short (2-day) leadership meeting. This 2020 meeting was an intensive 2-day workfest, where presentations were practiced, timed, discussed, revised, and vetted for accuracy. Feedback from leaders indicated this increased their confidence and was essential to the overall success of the workshops.

To ensure content accuracy and accountability and to increase confidence, workshop leaders were assigned to groups focusing on different quantum concepts. This arrangement of support is similar to professional learning communities (PLCs)[18] used in schools, where educators work collaboratively to determine what students need to know, how to know when they have learned it, and how to respond to difficulty in the learning process. Using principles of PLCs, the workshop agenda was developed collaboratively with the leaders, with regard to

- identifying quantum concepts to be addressed and how to scaffold coherently,
- identifying appropriate place in the learning cycle for specific hands-on activities,
- determining the time period over which each concept should be covered,
- identifying leaders for discussions during each topical session,
- identifying components for the Zoom main room vs. the breakout rooms,
- identifying the optimal number of participants and time allocated for each breakout room activity,
- assigning preparatory homework to maximize time during the virtual workshop, and
- identifying materials to be provided in advance of the virtual sessions.

Multiple comparisons can be drawn between the leadership workshop and school PLCs, but the main takeaway is that they both can be important for instructors, can significantly reduce individual preparation time for courses, and can increase confidence in content by deepening understandings. Unfortunately, classroom teachers do not typically have the luxury of practicing a lesson and getting feedback before presenting the lesson to students. However, especially during C-19, PLCs did provide a structure for collaboration as teachers pivoted lessons, labs, assessments, and activities to the online environment.

Session feedback from the participants indicated a real struggle to stay focused for over an hour in spite of the desire to learn about QIS. Educators have long recognized that students have a cognitive limit (e.g., cognitive overload or cognitive load theory[19]), and our experience suggests that this limit also applies to adult professionals, especially when the content is unfamiliar (e.g., QIS). The fact that they want to learn the content is important, but regardless of the will to learn, there is a process of learning that requires sensory and working knowledge before there can be long-term memory. Working memory often includes rehearsal, which in this case is most closely linked to the discussions and activities provided during each session. Recognition of this limitation played a significant role in our planning for summer 2021 in that we focused on more chunking, engagement, discussions, and even brain breaks. In addition, in 2021, we shipped materials (polarizers, lasers, diffraction glasses, etc.) for activities to the participants ahead of time, and these materials were then used for activities during the breakout sessions. Some universities and a few high school courses tried to do this during C-19, but there are challenges with costs, returns, and liabilities.

Participant feedback

Some of the feedback from teachers regarding difficulty and learning about quantum is listed below:

- "Great activity with very difficult content. I really liked how the spreadsheets worked for this activity."
- "Somewhere it needs to be indicated that teachers will benefit by attending multiple sessions on these topics."
- "This is difficult material. It requires more than only one or even two pass throughs. Having the Sim available really helped."
- "Great job of adapting and clarifying the concepts."
- "Simulation is fantastic. I really appreciate the interactions with the expert guests. Suggest that people try the challenges in the simulation—it really allows a person to know if they have the concept mastered."
- "A good introduction to this topic. More time is needed to fully understand it. As Feynman once said, 'What I can't create, I don't understand.' This would be very interesting for students, therefore, even an old teacher like me will invest time into grasping these concepts better. Thanks."
- "Tough material to understand. I just need lots of practice running through scenarios to start to understand this content to a point where I can present this to students."

Incorporating discussions with quantum expert guests and videos

A benefit of the virtual environment is the ability to provide opportunities for collaboration with quantum experts from anywhere in the world without a significant time commitment. Several experts, including the Perimeter Institute, the Institute for Quantum Computing, and Wells Fargo were part of the virtual sessions and helped clarify concepts in addition to elaborating everyday connections to QIS understandings. The advantage of inviting guest speakers or experts to interact with students in a virtual classroom is underutilized. Students could greatly benefit from virtual interactions with professionals in a career field of interest to them or by talking to researchers with knowledge regarding a relevant content topic.

The virtual platform was also used for discussion of ideas based on selected videos related to specific QIS concepts. Videos used were either freely available on the internet or made by the leadership. Videos from the internet were often edited to maximize the limited session time, or they were used to introduce teachers to appropriate resources readily available for their own classrooms. Videos can be used to engage or extend student understanding in the classroom, provided they are succinct and relevant. Many teachers and students have become quite proficient in making their own videos, so these could be submitted by students as verification of completion of a lab activity or as an explanation of a specific phenomenon.

Professional videos were used along with other resources including Veritassium,[20] Quantum coin toss,[21] a LIGO video focusing on how gravitational waves can be detected (by measuring the small changes in the arms of the interferometer due to the gravitational wave),[22] Mach-Zehnder interferometer (MZI) with single photons,[23] and videos focusing on double-slit experiments and uncertainty principle. Discussions among participants helped connect prior knowledge from other STEM content areas to the current topics, thereby identifying and clarifying potential classroom applications. While the chat feature was used by some, others unmuted themselves to participate. For example, with regard to the interferometers, here are examples of typical questions/discussions posted by the teachers who preferred to use chat: "Not all beam splitters are 50/50 right? Doesn't it depend on the coating?" "When they recombine, the waves were out of phase. Was this because the distances to the mirror were not equal?" "Do they vary the distance to the mirror?", "Building those stable mirrors…a great engineering challenge," "The gravitational waves changed the distances…." There were also great discussions about the fact that an MZI would produce consistent interference patterns at the detectors depending on various path length differences between the arms of the MZI (in the case with a classical beam of light vs. the quantum case when a large number of single photons are sent one at a time). The challenge of clarifying how a single photon behaves as a wave while passing through both arms of the MZI but becomes localized in space like a particle when it is registered by a detector as a click was evident in the discussions. For example, in the context of the MZI, the discussions pertained to analogies between the transmission and reflection of classical and quantum mechanical waves at different types of boundaries. There were also discussions about phase differences and conditions under which constructive or destructive interference would take place at the detector, which indicated the participants were cognitively engaged in trying to understand some of the basic principles.

Session recordings are another potential advantage of the virtual platform because they can be saved and reused at a later time (note that permission forms are needed if the recordings or chat will be publicized). The principal investigators had consent from all workshop participants to record the entire workshop, including their typed conversations using the Zoom "chat" feature. For the LT, workshop recordings and discussions were helpful for reflecting on different aspects of the workshop such as identifying what worked well and identifying content that needed clarification. For participants, the videos were made available to them for review or use in the classroom if needed. Recording lessons has become standard procedure for many teachers to use for students who are absent or need accommodations. Repercussions of recording lessons and the legality of who owns the recordings is uncertain at this time; therefore, many teachers opt to only record portions of their lessons and use them in a blended learning format.

Summary and conclusions

Reflecting on quantum virtual teacher professional development workshops conducted in 2020 and 2021 revealed patterns that can be used for both professional development workshops and high school classrooms. Although preliminary data from virtual teaching during C-19 indicates that teachers feel students did not progress academically, many feel the virtual and hybrid learning classroom environment is here to stay, and therefore, there is a need to continue working to find ways to make it a positive and productive learning experience.

Generally, teacher feedback was overwhelmingly positive, but all feedback was taken into consideration for future lessons and workshops.[6,7] Some suggested a slower pace and noted that they needed more than one exposure to these challenging concepts (in this case, QIS), while others identified specific content they were struggling to understand. Here are some typical examples of open-ended comments from participants about learning quantum concepts:

- "Some of us might need more time to digest/play with concepts and procedure before bringing it into the classroom."
- "This is a very difficult topic to be able to understand completely in 2 hours..."
- Teachers will benefit by attending multiple sessions on these topics..."
- "I think I need to go through this several more times before I really get it."

Experts in the classroom, like the workshop experts, have extensive experience conducting in-person lessons, but experience in the virtual environment was minimal prior to 2020. Pivoting to an online format required extensive planning and multiple levels of support, including professional collaboration. The ethnographic evaluation suggests that these workshops were generally successful in achieving the goal of actively engaging teachers in the learning experience and identified a few major contributions to the success. Pivoting successfully included the development of a strong community of practice through collaboration, communication, and engagement, which increased participant confidence and willingness to learn.

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