During the past year since schools by and large "went virtual," and science teachers have been challenged to figure out how hands-on learning, a key component of good science education, could remain an essential part of student's learning. In this Theme of the Month, our expert panel discusses the challenge as they have encountered it, and the strategies and resources they have used to meet that challenge.

The panelists bring deep experience in the science classroom to this discussion, along with a breadth of activity in teacher-leadership. **Rebecca Vieyra**, the moderator, is the Coordinator of the Inter-American Teacher Education Network at the Organization of American States. Previously, she served as the K-12 Program Manager at the American Association of Physics Teachers. **Channa Comer** started her career in education in 2007. Over the years she has served in the classroom, as a school-based teacher leader, an out-of-school time curriculum director, STEM club founder, STEM instructional coach, teacher mentor, professional learning facilitator, and adjunct instructor. **Nicole Murawski** has been a teacher of physics, earth science and mathematics for the past 24 years. During the 2020-21 school year, she took a leave of absence in order to stay home with her school-aged son and support his remote learning. During this time, she has been involved in Physics Education Research for the American Modeling Teachers Association with the Magna-AR app from Physics Toolbox **Lynn Jorgensen** has been teaching physics for Gilbert (AZ) High School since 2015. When schools shifted online last spring, Lynn developed a fully online optics unit, where students performed a blend of at home experiments and online simulations. She has presented her activities through ITEN, AMTA, and AAPT.

**The challenge**

As soon as it became apparent that COVID would require a wholesale move to virtual classrooms, science educators identified key problems this would present for the science classroom (and not just the K-12 classroom, see Flaherty 2020). Rebecca Vieyra posted a report from the National Academies, *Teaching K-12 science and engineering during a crisis*, which described and discussed the most important, for example:

- The best practices of Science and Engineering (S/E) education place important emphasis on direct experience with phenomena. As teachers know very well, a lab or other investigation takes place in a very rich social and physical setting — while the NGSS advocates 3-D learning, hands-on practice is multidimensional — including the shared interaction with materials, observation of others' attempts and insights, availability of different instrumentation to test and verify emergent questions, and more. On-line, many of these dimensions, which can play significant roles in engagement and motivation as well as conceptual learning, are necessarily filtered out.
In trying to design and implement at-home replacements for lab activities, equity issues become critical. Students differ in their access to good Internet service, computer and other digital tools, and in basic resources like time and space for conducting experiments at home.

Issues of equity place other constraints on teachers' strategies to support empirical work online. If students are to collect, analyze, and compare data, they need access to comparable materials and instrumentation. How does a teacher design for equitable participation?

Good science education, like good science, is a social process. Collaboration online presents a range of difficulties, many of which are rooted in the points already made. There are, however, the well-known problems that can result from Internet use — the potential for distraction, the necessity of vetting and evaluating resources to use, and the challenges that come from a seamless integration of personal computing environment and the Internet, including plagiarism and other kinds of cheating.

In an era when CGI effects are well-known and widely encountered, simulations can lose their credibility and their impact on students.

All these points represent major challenges to teachers' work — planning, choice of materials, and pedagogy.

Lived experience: Our panel experts brought these issues to life from their own experience.

Acquiring the materials.

Early on in the pandemic, there was an outpouring of ideas for the use of simulations, "virtual labs," and other digital resources. (See, for example, the collections of resources posted already for the STEMTL.net.org April 2020 Theme of the Month (bottom of page) here.) Such resources were invaluable for many teachers, during the first "rapid response" when everything was in turmoil. Science and engineering teachers like our panelists agree, however that hands-on engagement is essential to both science and engineering education.

The translation from school-based labs to home-based labs required teachers to examine what materials would serve the students, since they could not come in to use the school's lab resources. From the beginning, equity considerations were front and center. As Rebecca Vieyra asked, "What is reasonable and not reasonable to expect that students have at home?" The answers will vary with the activity and the communities involved, naturally, though "I think it's very reasonable that a child wouldn't have some sort of measuring tool. And if they don't, then I would put it in a kit and have them come and pick it up."

But when some students are in homes with very low incomes, even simple and low-cost materials can't be taken for granted. As an example, Channa Comer pointed out that if cornstarch is not part of a household's normal cuisine, then an "oobleck" activity (for exploring state changes) may be out of reach, if the families can't afford to buy cornstarch for the experiment and then throw away the unused portion. "There will be times when not everyone will be able to do a hands-on activity." Sometimes purpose-made kits can fill in gaps; sometimes, however, video demonstrations will help a child at least see and hear someone else doing the investigation.

Everyone has a mirror: The Optics curriculum

Lynn Jorgenson's optics curriculum is designed to work with anything that can function as a flat mirror. This is a very inclusive definition of the needed apparatus: "Everybody has a flat
mirror. If you have a bathroom, you have a flat mirror. If you have a cell phone, you have a flat
mirror. Everyone has a flat mirror or something that reflects. With this simple equipment,
students can explore a range of optical phenomena. Students would study reflection
phenomena with careful and specific instructions from the teacher, since the virtual setting
makes it hard to debug students' difficulties as one could in person. The next class would be
spent discussing their experience and their results. This enacts the basic inquiry rhythm
includes observations of a system of interest, collection of data, analysis, and discussion with
others.

Learning about data

Learning about data, learning through data analysis, is a skill that underlies all of science
and engineering learning, and even if there is not adequate physical equipment to do all the labs
that are normally part of the curriculum, data work can continue — what can you weigh or
measure or count? Data can be found in every setting. When the resources are available,
there are a number of smart-phone apps that take advantage of sensors built in to their phones.
The simplest of "apparatus" can generate data that brings insight. Nicole Murowski presented
several activities from "Functions from geometry" (illustrated in her slide deck here) in which
data can be taken using very simple objects. For example, any can will serve to generate data
about the relation between revolutions and distance traveled. Graphing this will allow students
to derive a linear equation, and then talk about features of the slope, and other behaviors of the
function. Thus, data from simple activities can build students' capacities to think mathematically
— first in analyzing a data set, and later to develop models that can be used to generate and
analyze experimental questions.

Assessment at a distance: Task design

With students largely invisible during the school day, and performing their hands-on
activities mostly off-screen as well, teachers have been challenged to get enough information to
provide formative feedback and guidance to their students, and to make assessments of what
they have learned, both in terms of content and of science practices. Rebecca Vieyra posed the
question to the panel this way: "How do you really collect evidence of students' engagement
with the lab and help them to illustrate their thinking so that you can properly assess what they
know about science, as content, but also about science as practice?"

In other contexts, teachers have reported (Ferlazzo 2020a, Johnson 2020) that, given the
stress that students are experiencing in the pandemic, and the complexity of in-home learning
with a remote teacher, they have relaxed expectations about student learning, often focusing on
maintaining and perhaps deepening what students had learned before the lockdowns. This has
also been adopted as a strategy to prevent "learning loss" during the time of virtual schooling.

Our panelists, however, advocated the view that labs, hands-on activities, can and usually
should have concrete products that can facilitate student conversation, and also provide the
teacher with evidence from which to work. Rebecca Vieyra and her colleagues developed a
process journal, in which their progress through a project is recorded and commented upon:
"They actually had to go through and make three different prototypes, and in each one of these,
they had to explain their design, what data they collected, what ideas they have, just processing
their thoughts throughout it."

Lynn Jorgenson, whose students are fortunate in being in an area with widespread Internet
access, had her students continue using Google Docs for writing up labs — just as they did
before the lock-down. This enabled the teachers to provide the additional scaffolding of tasks
that the virtual setting requires (the teacher's not always around to answer clarifying questions, for example), and to use a familiar medium to exchange comments and revisions.

**Human factors at the heart of the teacher-student relationship**

One of the participants posted in the chat accompanying the webinar, "I've lost 95% of eye contact, facial expressions, when doing online teaching. Almost none of the usual, helpful immediate feedback." The comment brought home one of the major challenges of the on-line environment, which is the lack of nonverbal clues and contextual information that enriches an in-person lab. Here as in other situations, the attenuation of the human connection is felt strongly, and it affects motivation and the sense of safety that supports whole-hearted learning (a point noted by other commentators in the preceding months, see the References at the end of this synthesis). The panelists shared several strategies they had found useful in enriching the on-line interactions in their classes, from greeting rituals to off-beat project ideas that have science at their core, but can bring a smile, too. As one panelist said, "I think all kids need an opportunity to participate in the conversation every day, even if it's just, "What's your favorite ice cream?" Just getting them to feel a part of the community."

**When "normal" returns, what might we keep? What might require repair?**

Once again, in contrast to worries about "learning loss," the panelists (and the resources they provided) felt that they would re-enter the normal classroom with their practice enriched by new tools and approaches that they had to develop for the on-line setting.

It is true that there will be some lost ground, but not necessarily of the kind most discussed in the media. Since our focus was on the practical work of science and engineering classes, panelists noted that the students had been out of practice with actual lab equipment — probes, measurement tools, glassware, or whatever. One panelist whose students were returning to the classroom said, "When we got back to in-person….in the middle of the year we had to teach them how to use the real lab equipment we're usually use the whole time." And it's not just those technical skills — students need to reconstruct how they collaborate as lab partners, and learn new rhythms of communication in the classroom.

Nevertheless, many of the supplemental resources that teachers have found for the virtual lab will be of use, and make a positive contribution to their classrooms in the future. Panelists spoke of using virtual labs as "pre-labs," to enrich the students' preparation for the actual hands-on engagement. Some teachers have developed a library of demos or other videos that they intend to continue to use, and perhaps add to. Moreover, the tools they've used for students communicate with them around labs, or record and report their labs, will continue to be of value.

In the course of the discussion, the panelists also added some comments from their experience this past year which are unusual in the literature on "teaching during COVID." The moderator asked "How has your time management shifted in the past year from being pre-pandemic to now? Are you busier? Are you less busy? If you are busier, how do you manage that?" Channa Comer pointed out that "in-person" with the students distanced, masked, and working on their individual computers in a separated spaces in an auditorium, may not be all that different from "remote." In this situation, doing hands-on activities is almost as limited as when the students are at home. Consequently, "I actually would rather be home because I can actually do more at home than I can in the school right now."

The time apart has helped teachers clarify their priorities, and re-focus elements of their practice around hands-on activities to better reflect those priorities. Examples include a more
consistent use of standards-based grading; clearer guidance for students so that their learning of practices is better scaffolded; taking advantage of students' newly acquired facilities with computer-based tools — and including the importance of relationships — between teachers, and especially between teachers and students: My number one observation is man, our relationship's more important than I ever realized. And that has been my biggest takeaway.

Finally, it was emphasized that students learn the science practices over time by practicing them. Despite the uncomfortable challenges of "remote labs," students have been able to continue honing some of those practices — not only data-analysis and communication, but observation and the asking of fundamental science questions using everyday materials. So even granted that the "coverage" of science content standards may have lagged, in the context of our subject — doing labs and hands-on activities during COVID, "with science, you're talking about science process skills that are developing over time. So you practice the same skills over and over in different contexts, and students are going to get better. No matter where they start, they're going to get better if they keep practicing."

**Recommendations for teacher leaders**

With practice rapidly developing during the response to the pandemic, opportunities for teacher conversation are critical. While professional learning communities (PLCs) are a key strategy (both during COVID and for "normal" times), other less formal forums for collegial conversation can play a valuable role. Teacher-leaders can play a valuable role in seeking out such channels, testing them out, and making them known to their colleagues. Beyond that, TLs can help their colleagues discuss and share best practices around collegial conversation, so that individual preferences can be bolstered by the intentional use of a shared set of media across the faculty.

In the course of their communication with colleagues, teacher leaders can pay close attention to teachers' social/emotional needs, and helping administrators bear those needs in mind as difficult decisions are being made with respect to resources — especially teachers' time demands, the need for collegial connection, and the fundamental importance of students' relationships with their teachers.

**Recommendations for administrators.**

As in pre-COVID times, teacher collaboration is an indispensable ingredient for the maintenance and growth of a high-quality STEM program. In relation to remote labs, teachers need to spend a lot of time evaluating and testing new resources to choose those most useful for their classrooms. This kind of teacher research is time consuming and collaborative. Administrators need make room and time for teacher collaboration.

Science and engineering (S/E) are involved with the real world, and practical work in labs and hands-on activities is more powerfully motivating and educative when students can see the connections of their work to settings outside the classroom, whether in the local environment, or service projects in their community, or explorations of social factors in science and engineering (such as public health practices). Administrators can build the strength of their S/E program by exploring and building partnerships that can help teachers connect the classroom to the community.

**Recommendations for researchers.**

There are many research questions arising from teachers' experience of remote S/E labs in the past year which might both "inform the field," and be of real service to practitioners. There is a time-sensitive opportunity collect data and develop case studies across a wide range of questions, during this transition period, and before the "new normal" (whenever it arrives)
becomes established and the recent period of crisis and experimentation fades into the past. Some areas that are suggested by this month's Theme and panel are:

• What in fact have been the impacts of remote schooling for students' understanding of science practices? Which practices were hardest to continue teaching, and what effect did that have on students' understanding? The current understanding of science and engineering (S/E) education is that the "three dimensions" (including the practices) are an integrated whole. In cases where students had less opportunity for hands-on learning, what impact did that have on their overall science and engineering (S/E) understanding?

• What impact did inequity have on students' learning of S/E practices by means of remote labs? Where were the critical inhibitors for students — Was it resources (including access to tools)? Reduced collaboration with other students, or with teachers? The challenge of finding space and time in the home environment (perhaps under unusual economic stress owing to the pandemic)?

• Teachers in our panel and in other forums have said that one of their coping strategies for dealing with remote schooling has been to pare down the amount of coverage they expect, or streamline their expectations in other ways. Have there been benefits to this strategy — In some cases, is less more, allowing for deeper focus on fewer topics?

• Many other topics of research are suggested by the changes that teachers have been making in their practice. What are the shifts in practice that teachers bring back to the in-person classroom? Some of these shifts in practice may be a result of teachers' innovations (e.g., with increased uses of video in different forms). Teachers in our webinar suggested, however, that some may be made possible because of students' increased facility with digital tools required by the "remote" conditions. How has COVID pushed technical fluency and literacy among science and engineering students? In what ways can teachers adapt to take advantage of this increased capacity (if it exists)?

• Finally, teachers like everyone else have had to network with each other while working remotely. This suggests interesting questions about teacher collegial communication. Are teachers now more often in communication with colleagues outside their school or district? Are their communications with colleagues changed in frequency or in content? This in turn raises questions about whether the spread of innovations in teaching is flowing along new channels, and whether the exchange is more focused on resources or tools than on changes in pedagogy. The role of teacher leaders in this exchange is also an area that could be investigated, which could enrich our understanding of how teacher-leaders can broker innovation.

References
