Moving Practice-Based, Secondary Science Teacher Education Online: The Case of Inquiry-Based Labs

by Alice Waldron, Relay Graduate School of Education; Cole Entress, Teachers College, Columbia University; & Daniel Sonrouille, Relay Graduate School of Education

Abstract

Online coursework in science teacher education is becoming increasingly common. However, some content in science teacher education—how to skillfully (and safely) lead laboratory investigations, for instance—can pose a particular challenge when converted to an online format. We describe how we met this challenge in the creation of an online version of a practice-based science methods course focused on leading inquiry-based labs. Specifically, we articulate the design principles that guided our transition to a fully online course that produced student outcomes comparable to in-person sections and generated consistent, highly positive feedback from our graduate students. Additionally, by designing an online course that retained the teaching of lab competencies classically taught in person, we positioned the institution to better support students and instructors who found themselves suddenly online when the COVID-19 pandemic struck in the spring of 2020.

Introduction

Even before COVID-19 sent P–20 schools nationwide scrambling to adopt remote teaching, online coursework at the postsecondary level was becoming increasingly common (Major, 2015; Seaman et al., 2018). Despite its growing prevalence, however, online coursework has retained a whiff of disrepute. Many faculty consider online learning in a mixed to negative light, a view that has persisted, perhaps not surprisingly, after many institutions made an emergency pivot to online learning because of the pandemic (Veletsianos et al., 2021). Science teacher educators are no exception, often subscribing to incorrect notions that online teaching cannot involve meaningful student–student interaction or effective pedagogies (Miller, 2008).

We do not share this pessimism about the potential of online coursework for science teacher education. Online coursework is simply a different medium for instruction with a set of affordances and challenges all its own. Of course, we do not deny the existence of low-quality online learning experiences. Most of us have experienced some of them firsthand—but then, we have also experienced plenty of bad in-person learning experiences. Rather, we want to emphasize that, like traditionally in-person coursework, good online coursework requires instructors to make principled choices and use a design process (Joksimović et al., 2015; Rapanta et al., 2020). The creation of online coursework must, therefore, attend to course aims and to the characteristics of the online modality. This may be easier for some kinds of courses than others. An introductory statistics class, for instance, in which students are mostly responsible for mastering a core set of terms and algorithms, might make for a straightforward translation to the online environment. However, achieving quality in online coursework becomes more difficult when course goals involve things like facilitating inquiry-based labs with secondary students. How does one teach aspiring science teachers to engage in this complex practice from the other side of a screen?

In this article, we will describe our own design process and the instructional principles we relied on as we translated our secondary science methods coursework into a 100% online format, specifically focusing on our instruction regarding inquiry-based labs. This instruction constitutes only a small portion of our secondary science methods work, but the challenges we faced when moving the course to the online environment were emblematic of those we faced across the curriculum. We hope that these principles will aid others in creating rich, online learning experiences, and we also provide data showing that our approach maintained the quality of our coursework even as it moved to a new modality. Like Dani and Donnelly (2021), we hope to illustrate ways that online courses can be made active and productive sites of learning for new science teachers rather than replications of traditional, lecture-style courses.

Context

The secondary science program at our institution, Relay Graduate School of Education (Relay), differs in many ways from a traditional undergraduate preservice program. Relay's program provides graduate coursework, culminating in a Master of Arts in Teaching degree, to provisionally certified teachers or teachers in residence (for clarity, we will refer to our graduate students as *candidates* going forward). Relay is a private, nonprofit institution of higher education with physical campuses in 18 cities across 12 states and the District of Columbia. Relay's candidates, more than 60% of whom identify as people of color, come from diverse backgrounds, which is consistent with enrollment patterns in alternative certification programs generally (McFarland et al., 2018, p. 14). Thus, it is worth emphasizing that our candidates are taking graduate coursework while working in the classroom full-time as teachers or teachers in residence.

Additionally, Relay began offering fully online methods courses in 2017 and has been using technology to support our coursework since well before then. The in-person methods courses that we offered prior to 2017 were in fact hybrid, blending online, asynchronous instruction—during which candidates engaged with research, artifacts of teaching practice (e.g., videos or lesson plans), and checks for understanding—with face-to-face class meetings devoted to activities such as participation in model lessons, giving and receiving feedback on curriculum plans, and lesson rehearsals. Therefore, unlike many institutions that were forced by COVID to jump abruptly into online learning, we had background knowledge of online instruction from which to draw as we transitioned all candidates to fully online coursework.

Our prior experience teaching online informed the design of the course described in this article. For example, prior to our official launch of fully online methods courses in 2017, we piloted fully asynchronous online courses with a small group of candidates. Although these courses allowed for a high degree of differentiation and flexibility, the challenges outweighed the benefits in our context. Candidate success, as measured by course grades, tended to be lower in these courses when compared to our hybrid courses that included in-person instruction. Based on discussions with and feedback from faculty and candidates, we attributed the lower success rate to the lack of community-based accountability and engagement that live touchpoints provide. Our candidates generally felt motivated to complete the courses successfully, but many waited until the end of the term to complete the work in the absence of live touchpoints to help keep them on track. The fully asynchronous courses included staggered deadlines throughout the term, regular reminders, follow-up communications with candidates who missed deadlines, and opportunities for individualized support, but we found that these simply did not work as well as regular live touchpoints. Additionally, with fully asynchronous instruction, candidates missed the live community building, practice, meaning making, and real-time feedback that are features of our in-person instruction. Consequently, Relay's approach to online learning, both in the course described in this article and others, includes regular synchronous instruction blended with asynchronous learning.

Another early challenge that we encountered was a theme in qualitative feedback about multiple tabs being difficult to manage during synchronous class meetings. As a result, we started using an application, Nearpod, that embeds slides, engagement features, and external tools such as Google Sheets and PhET simulations all in one presentation that is accessible by a single link. We were fortunate to have learned these general lessons before lockdowns began, given all the other changes our candidates had to manage during the pandemic.

The final thing to know about our program—informed by the fact that our candidates are currently employed in schools—is that it has a strong clinical emphasis. We are influenced heavily by the research on practice-based teacher education (PBTE; see next section), and we work hard to make sure that our candidates gain fluency with high-leverage practices that will make their everyday instruction more effective in the communities where they work (see TeachingWorks, 2022). The goal of our five-course secondary science methods sequence is to help our candidates master what Windschitl and Calabrese Barton (2016) referred to as the "technical core" of science teaching—though naturally how we define that technical core differs somewhat from other institutions. Our courses spend a lot of time on the implementation of phenomena-based science teaching, literacy practices in science, and the intentional use of instructional models such as the 5E model or the guided-inquiry lab. Assessments require candidates to use these techniques with their students: for instance, to record footage of students engaged in an inquiry-based lab and to pair it with a detailed analysis of student work samples collected after the lesson. Because PBTE is a focus of our program, the next section will introduce it in more detail.

Theoretical Framework: Practice-Based Teacher Education

In the last decade, the notion of *practice* has become increasingly central to both science and science teacher education. Both the *Framework for K-12 Science Education* (National Research Council, 2012) and the *Next Generation Science Standards* (NGSS Lead States, 2013) conceive of science as a set of social practices in addition to a body of knowledge. These documents argue that P–12 students learn science by apprenticing in the practices of science as they learn its core ideas and crosscutting concepts. At the same time, research in PBTE has suggested that teaching is also a set of learnable practices that teacher candidates should begin to master as soon as possible. Grossman et al. (2009) argued that:

> Teacher educators need to attend to the clinical aspects of practice and experiment with how best to help novices develop skilled practice. Taking clinical practice seriously will require us to add pedagogies of enactment to our existing repertoire of pedagogies of reflection and investigation. (p. 274)

Pedagogies of enactment—teacher education activities in which teacher candidates develop their skills in the performance of a teaching practice rather than merely learning about the practice or its theoretical justification—are a key innovation in PBTE.[1] Pedagogies of enactment focus on core (sometimes called high-leverage) instructional practices—teaching moves that occur regularly and engage students in important cognitive and disciplinary activity. Some research groups have developed domain-general accounts of core practices (see TeachingWorks, 2022), but sets of core practices specific to secondary science teaching have also been proposed (Windschitl & Calabrese Barton, 2016; Kloser, 2014). Kloser (2014) articulated “Engaging Students in Investigations” as one such core practice (p. 1197), an idea echoed in a recent report by the National Academies of Science, Engineering, and Medicine (2019) in which they recommended that “science investigation and engineering design should be the central approach for teaching and learning science and engineering” (p. 5). Of course, investigation does not mean stand-alone, hands-on activity—Windschitl and Calabrese Barton (2016) have noted that “material activity by itself is weakly linked with learning” (p. 1138)—but rather, coherent sequences of activity rife with opportunities for student sense making and metacognition.

Efforts to build practice-based science teacher education programs are still in the early stages, and we are far from having a well-substantiated knowledge base about how to do it (Windschitl & Stroupe, 2017). Still, in the last few years, reports about the use of particular pedagogies of enactment in science teacher education, such as lesson rehearsals, have appeared (Davis et al., 2017). Our program has been heavily influenced by PBTE since its inception, and we have long used in-person class meetings to hone teachers’ skills in planning and implementation. Our implementation protocols typically involved partial lesson rehearsals that included elements of deliberate practice (e.g., immediate feedback and the opportunity to improve; Ericsson, 2004). Beginning in 2017, when Relay began to offer fully online courses as a complement to its hybrid courses, we started learning how a practice-based science teacher education program might operate 100% online. Specifically, we had to tackle the question of how teachers can practice enacting inquiry-based labs without peers—or pipettes—close at hand. In the remainder of this article, we will share some of our initial answers to this question and examine data from 3 years of instruction to shed light on the progress we have made.

In Person to Online: Design Principles and Lessons Learned

When translating our coursework for the online environment, we prioritized three key principles. In the sections below, we will describe each of the three principles and provide an example from our coursework on inquiry-based labs. Each of these principles has relevance for designing online, practice-based, science teacher education coursework. The first two principles are relatively straightforward in their application, so we treat them briefly. Because the third principle requires more elaboration, we provide several concrete examples to demonstrate how we translated our coursework and to assist others in doing the same. The discussion of each principle also includes our lessons learned.

Principle 1: Keep Instructional Goals and Assessments the Same

First, we decided that candidates should develop the same teaching competencies regardless of modality. This ensured that all candidates cultivated the knowledge, skills, and mindsets necessary for success with their own students. So, our instructional goals and assessments stayed the same regardless of course modality. This principle may seem obvious, but we include it here because faculty who are wary of online learning (Veletsianos et al., 2021), including science teacher educators (Miller, 2008), may be tempted to lower their expectations for what candidates in online coursework should achieve.

Our science methods curriculum was designed with specific instructional goals in mind, such as the ability to lead all students to successfully conduct an inquiry-based lab. Therefore, all course assessments were identical in the online and in-person environments. In both delivery formats, we relied on an identical, criterion-based assessment rubric that included the two sample items shown in Table 1. The full lab-implementation rubric, consisting of six items, can be found in Appendix A, and a description of the full assessment can be found in the Outcomes section.

Table 1
Sample Rubric Items Assessing Teacher Implementation of Labs

	Exemplary	Proficient	Foundational	Attempting	Lacking
Testable question	The lab is based on a testable question (or questions) determined by students with little to no guidance from the teacher.	The lab is based on a testable question (or questions) determined by students from a list of possibilities provided by the teacher.	The lab is based on a testable question determined by the teacher with input from students.	The lab is based on a testable question determined by the teacher without input from students.	There is no testable question associated with the lab.
Hypothesis	Students create a scientific hypothesis (falsifiable prediction) with a strong justification; the justification includes student research beyond class materials.	Students create a scientific hypothesis (falsifiable prediction) with a strong justification (e.g., based on prior experience or a reading from class).	Students create a scientific hypothesis with a justification, but the justification is vague or implausible.	Students create a hypothesis without a justification (i.e., a guess).	Students do not create a hypothesis prior to the experiment.

Similarly, we kept class meeting objectives the same when translating materials from the in-person environment to the online environment. For example, in both the online and in-person environments, one objective in the first-class meeting in the inquiry series was “evaluate an inquiry-based lab.”

Lessons Learned

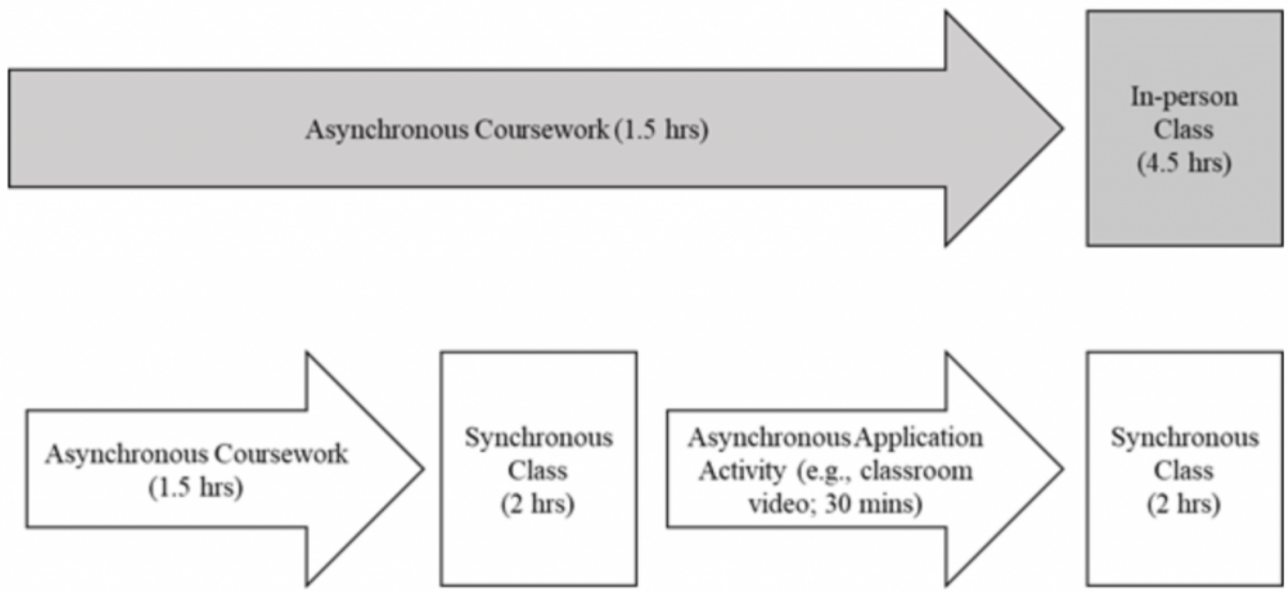
We learned that science teacher educators can and should expect the same outcomes from candidates learning in online and in-person environments. We share the data that supports this contention in the Outcomes section later in this article, but we found that student learning was comparable in both environments and that the students in the online environment had positive experiences. However, science teacher educators cannot reasonably expect that every aspect of a standard in-person course will work well online. Individual activities, and even structural features like the time and frequency of class meetings, may need to be intentionally adjusted as they are translated for the online modality. This is described in more detail in the following sections.

Principle 2: Time and Sequence Online Class Meetings to Maximize Engagement and Interaction

In person, our class meetings consisted of long sessions (4.5 hours) held on weekends. Based on our early lessons learned about online coursework (described in the Context section of this article), we knew we wanted to prioritize regular synchronous instruction to ensure candidates experienced community-based engagement and accountability. For the online version of the courses, we split the synchronous meeting into shorter, more frequent, weeknight sessions (e.g., two 2-hour sessions and a 30-minute asynchronous application activity). Figure 1 shows a sample learning arc for one in-person class meeting and the corresponding arc of learning in the fully online environment.

Figure 1

Sample Learning Arcs in In-Person and Online Environments



Note. A sample learning arc in the in-person environment (gray, top line) as compared to the fully online environment (white, bottom line). Total instructional time was the same in both environments, but classes were shorter and more frequent in the fully online environment. Asynchronous application activities were also added in the online environment (see Figure 5 for an example).

The restructuring of the coursework in this way did not require us to drop any course or class-meeting objectives. Indeed, the objectives covered in the synchronous classes were the same objectives addressed in the in-person class, and the total amount of instructional time for candidates did not change. The asynchronous application activity between synchronous classes was usually a translation of a practice-based activity that we found hard to implement online (see Principle Three below) and also served as a means of keeping course material on the minds of candidates between synchronous meetings.

Lessons Learned

Our scheduling adjustment had three main benefits. First, it helped candidates and professors avoid “Zoom fatigue,” the feeling of exhaustion and difficulty focusing that can accompany extended time on Zoom or other videoconferencing technology (Fosslien & West Duffy, 2020). Second, the more frequent class meetings throughout the term provided more opportunities for interaction and relationship building, something we prioritize in our online courses due to the importance of student–instructor interactions (Jaggars & Xu, 2016; Shackelford & Maxwell, 2012) and a sense of community (Rovai, 2002) in the online environment. The more frequent class meetings also allowed us to overcome some of the challenges we encountered when testing fully asynchronous courses prior to 2017, as described in the Context section of this article. Finally, by giving candidates the chance to try out course ideas with their own students between class meetings, we were able to support the transfer of coursework into practice and discuss candidates’ real successes and struggles in their own classrooms.

Principle 3: Maintain Active Learning and a Focus on Practice

Although we kept class meeting objectives the same, learning activities in the online and in-person environments were adjusted, when needed, to work online. In the online version of the course, our learning sequence on implementing inquiry-based labs included four synchronous class meetings, which corresponded to two longer in-person class meetings. Table 2 shows an overview of these four synchronous class meetings. The class meeting objectives and key learning experiences in Table 2 correspond to identical objectives and similar key learning experiences in the in-person environment, as discussed in Principle One. Key learning experiences in both environments served the same pedagogical functions; however, their exact structure and implementation differed depending on the environment, which is discussed next.

Table 2

Objectives and Key Learning Experiences for Synchronous Class Meetings

Title	Class meeting objectives	Key learning experiences
Introduction to Inquiry	• Evaluate an inquiry-based lab • Identify strategies to support increased student autonomy during each part of an inquiry lab	• Model lab and debrief • Introduction to scaffolding strategies for inquiry
Increasing Inquiry	• Create student-facing materials that support student autonomy during inquiry	• Reflection on implementation of lab roles in own classroom • Comparison of student lab materials reflecting an inquiry and noninquiry (verification) approach • Analysis of a "medium-term plan" for increasing student independence with inquiry skills • Drafting individual teacher lab materials and medium-term plans
Working Toward an Inquiry-Based Lab	• Modify a lab to make it more learner-centered • Create a medium-term plan that includes a spectrum of inquiry-based experiences	• Collaborative analysis of a verification ("cookbook") lab and brainstorming to increase inquiry • Revision of medium-term plan • Choice-based individual or collaborative work time (exploration of resources for differentiation, edits of individual teacher lab materials to be more inquiry-based, peer feedback, or analysis of an inquiry-based lab exemplar)
Lab Skills Practicum	• Implement a think-aloud on one math or one writing skill required for students to complete successful lab reports • Revise medium-term plans to set up students for success in an upcoming inquiry-based lab	• Analysis of sample think-aloud on a lab skill • Planning time for lab skill think-aloud • Think-aloud practice & feedback protocol • Return to medium-term plan to reflect on use so far and revise

In this section, we highlight two key learning experiences that we adjusted for the candidates in fully online coursework: having candidates engage in a model inquiry lab lesson ("Introduction to Inquiry" in Table 2) and lesson rehearsals, which took place asynchronously between the "Introduction to Inquiry" and "Increasing Inquiry" class meetings and during the "Lab Skills Practicum" class meeting. These are common activities in practice-based science methods courses that we felt an obligation to retain because of their importance to our goals and to science teachers' practice.

Translating Model Lab Lessons for the Online Environment

In person, our candidates participated in a materials-heavy model inquiry lab. They investigated settling rate in water and had access to materials that included graduated cylinders, water, stopwatches, digital scales, Play-Doh, and a variety of rocks, coins, buttons, and washers. This was not possible online. We briefly considered sending our candidates packages of materials in the mail (too burdensome for instructors) or sending candidates a shopping list prior to the synchronous class meeting (too burdensome for candidates). Ultimately, we realized that the activity simply needed to change. In the online environment, candidates instead took part in a model lab that used a pendulum simulation from PhET Interactive Simulations at the University of Colorado (2021). The in-person lab allowed for the investigation of the impact of variables such as size, shape, and mass on settling rate. Similarly, the online lab allowed for the investigation of the impact of variables such as mass, string length, and even gravity on the period of a pendulum. Thus, in both labs, candidates developed and investigated their own testable questions, which is one important differentiating factor between inquiry-based labs and verification labs in which students follow a predetermined procedure to answer a predetermined question (Volkmann & Abell, 2003).

However, simply replacing an in-person model lab with a PhET simulation would not have captured many of the important aspects of facilitating inquiry-based instruction. Therefore, we made strategic adjustments, using a variety of online tools, that provided candidates with an active, group experience, one that enabled instructors to model “teacher moves” that candidates could analyze after the model lab, then try out with their own students. Tables 3 and 4 provide an overview of the first two steps of the model lab in the online and in-person environments. These tables show the similarities and differences between the environments and include tips that we learned along the way for translating inquiry-based labs to the online environment. Appendix B includes similar tables for all stages of the model lab learning experience.

Table 3
Framing the Model Lab

In-person environment	Online environment	Commentary and tips for the online environment
• Instructor presents focus questions on PowerPoint slides for candidates to consider from a teacher perspective while participating in the model lab as students (e.g., "how do lab roles support student inquiry?"). • Candidates write an individual focus for participation in the model on a paper handout.	• Instructor presents focus questions on Nearpod slides for candidates to consider from a teacher perspective while participating in the model lab as students (e.g., "how do lab roles support student inquiry?"). • Candidates write an individual focus for participation in the model on a Nearpod Collaborate Board.	Nearpod is an online tool that allows instructors to integrate slides, engagement features, and external tools in one place. Users access the Nearpod on their individual devices. The Collaborate Board in Nearpod allows users to post short responses that show up as virtual sticky notes for all to see; users can also comment on and upvote others' posts. Regardless of whether you use Nearpod or not, choose a tool that allows for information sharing (e.g., slides) and interactive activity while also minimizing the number of tabs users need to have open at one time.

Table 4
Model Lab: Testable Question

In-person environment	Online environment	Commentary and tips for the online environment
• Candidates briefly observe rock samples of different sizes, shapes, and densities, discussing the different characteristics they notice. • Candidates work in lab groups to come up with variables that might impact the settling time of a rock in water, and the instructor circulates and verbally assigns each group a variable based on their discussions. • Instructor assigns each person in a lab group of three to four a thinking and a practical lab role (e.g., evidence manager and materials manager) based on where they are sitting at the table. • Working in lab groups, candidates write testable questions on their lab handouts based on the variable their group was assigned; candidates also write hypotheses and fill out a graphic organizer to identify variables and constants. • Candidates pause within the model lab to consider the focus questions from the framing from their perspective as teachers.	• Candidates have open-ended time to explore a pendulum simulation. • Candidates add one variable they notice that might affect the pendulum's period to the Zoom chat box. (Note: We use Zoom, but many videoconferencing technologies have chat functionality along with other features we use regularly, such as breakout rooms). • Candidates work in lab groups of three to four in breakout rooms in Zoom to discuss the three variables they are most interested in testing; they post their variables of interest on a Nearpod Collaborate Board. • As candidates discuss, the instructor prepares a Google Doc lab template for each group, which includes assigned thinking and practical lab roles (e.g., evidence manager and simulation manager) for each member and an assigned variable to focus on from the group's list of three. • Candidates return to the main room, and the instructor orients them to their Google Doc lab templates by screen sharing. • Candidates go back into breakout rooms to write testable questions in their lab documents; candidates also write hypotheses and fill out a graphic organizer to identify variables and constants. • Candidates pause within the model lab to consider the focus questions from the framing from their perspective as teachers.	Orienting learners to new technology tools can take time. Using a core set of technology tools (regardless of what they are) routinely can help. The first time you introduce a tech tool, you will want to show how to use the tech tool and/or allow learners some time to explore the tool, as candidates do with the pendulum simulation in this case. Then, with subsequent uses, you can spend less time showing how to use the tool. For example, in this case, because candidates are used to using Google Docs already, the instructor orients them to the sections of the lab template but does not need to explain or demonstrate how to collaborate as a group to edit the Google Doc. Similarly, because we use Nearpod regularly, the instructor does not need to explain how to use the Collaborate Board.

As described in Tables 3 and 4 (as well as Tables B1–B5 in Appendix B), many materials were similar in both environments. Figures 2 and 3 show that the two lab templates were similar in each environment with adjustments for the different lab materials and minor formatting differences to provide writing cues in each environment. The amount of scaffolding (e.g., sentence frames) could easily be adjusted up or down in either case.

Figure 2

Section of In-Person Lab Materials

Experimental Question: How does ____________________ impact ________________________?

Hypothesis: Provide a justifiable prediction along with a justification.

If ____,

then ____

because ____

____.

Materials Available:

- 1 100 mL graduated cylinder
- 1 3-ounce container of Play-Doh
- Coins (pennies, dimes, nickels)
- Washers
- Buttons
- Stopwatch
- Digital scale

Note. In-person lab materials were printed for candidates.

Figure 3

Section of Online Lab Materials

Link to simulation if needed (click "Intro" once in)

Our group will test the following variable: ....

Experimental Question: How does .... impact ......?

Hypothesis

Provide a justifiable prediction along with a justification.

If, ...

then, ...

because, ...

"Materials" Available

- Protractor (measures drop angle)
- String (varying lengths available)
- Pendulum Mass (varying masses available)
- Planets (Moon, Earth, Jupiter)
- Friction control
- Ruler
- Stopwatch
- Period Timer

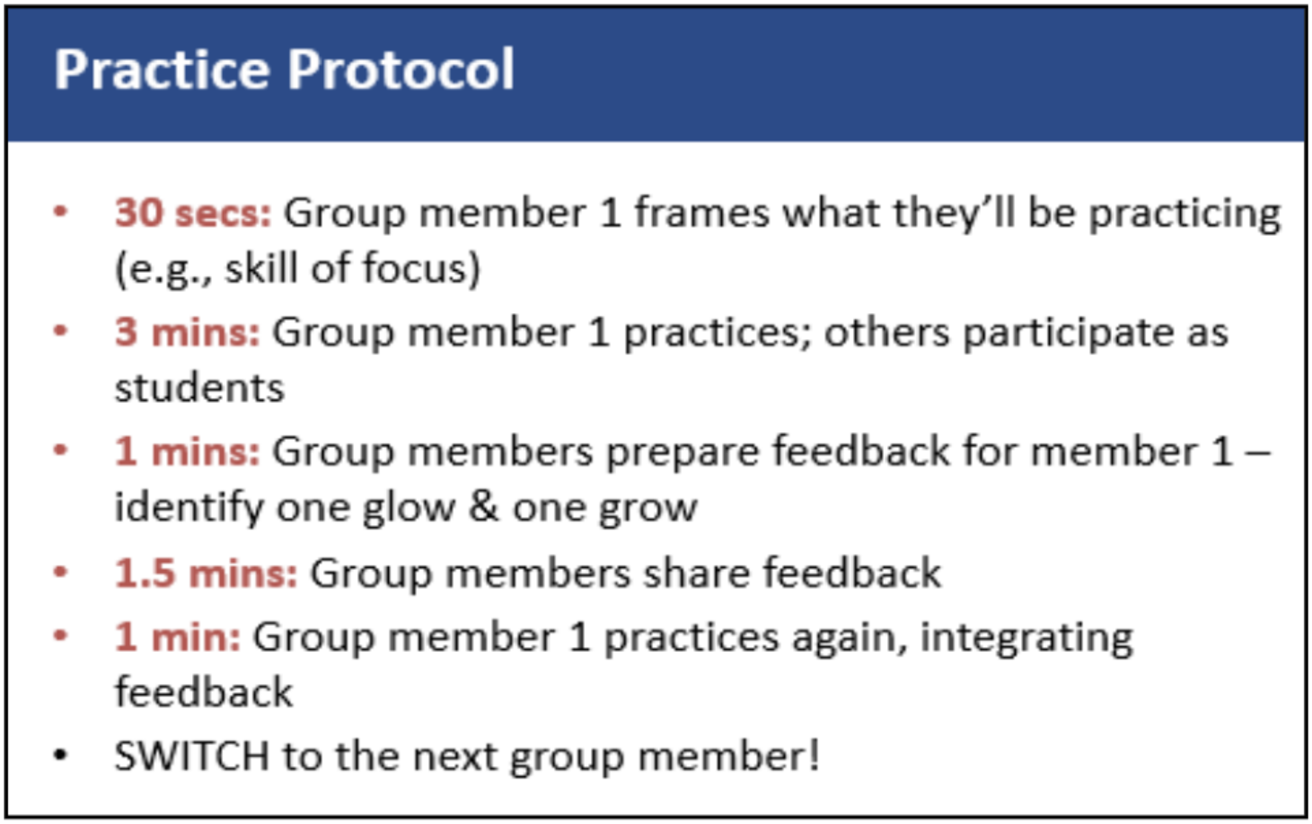
Note. Online lab materials were made available to candidates via Google Docs. The yellow highlighting indicates where candidates should write, and the pink highlighting indicates where the instructor adds information during the model lesson.

Finally, candidates engaged in small- and whole-group discussions throughout the model lab to connect to the bigger picture of the lab, as they would have done in the in-person environment. For example, during the data collection stage of the lab, the instructor modeled asking questions in small groups based on lab roles (e.g., asking the prediction manager for a justification for the hypothesis connecting to scientific thinking or ideas). Then, later in the lab, as candidates began to draw conclusions, the type of questions evolved (e.g., asking the prediction manager what they thought was causing the results they were seeing so far). These small-group conversations were then used to stimulate large-group meaning making. For example, an instructor might close the lab with a discussion of the strength of the evidence for conclusions, connections to scientific principles, and potential sources of error or alternative explanations, calling strategically on candidates based on what they shared in smaller groups. We have found that listening closely to candidates in small-group time—popping into their virtual breakout rooms and taking stock of their discussion as noninvasively as possible—is particularly effective in the online environment to get large-group discussion going (e.g., "I heard group 3 discussing …, what do others think of that idea?").

Translating Lesson Rehearsal for Online Environments

Lesson rehearsal is another example of an activity that we sometimes needed to modify for the online environment. In our experience, lesson rehearsal worked well online in many situations. For example, in the inquiry-based labs learning sequence, candidates practiced delivering a think-aloud to teach a math or literacy skill necessary for success in a lab. In both the in-person and online versions of the course, this lesson rehearsal involved a small-group protocol. Figure 4 shows the slide used to introduce the rehearsal protocol in both environments.

Figure 4
Slide Presenting a Lesson Rehearsal Protocol Used In Person and Online



Although the live version of this protocol worked well in both environments with the think-aloud focus, other teaching skills were more difficult to practice live in the online environment (e.g., those that required more circulation in the classroom to interact with students). For example, instead of having candidates practice introducing and facilitating lab roles live, we asked candidates in the fully online version of the course to film themselves trying this in their own classrooms as an asynchronous activity. To practice introducing lab roles online, candidates would need to direct peers to act as students assuming certain lab roles, then interact with different small groups of these peers to check in on lab role implementation and lab progress. This would be cumbersome to orchestrate on Zoom because candidates are not meeting hosts and do not have the ability to create or move between breakout rooms. We also thought that it would be more authentic for candidates to try out lab roles directly with their own students. Figure 5 shows the asynchronous directions candidates saw for this activity.

Figure 5

Directions for an Asynchronous Activity Requiring Candidates to Film Themselves With Students

Upload your 5-10 minute, unedited video here. In your video, be sure to capture:

- You introducing the lab roles or providing lab role instructions
- Your students working in their roles with audible student discussion, and a glimpse of their work if possible

After you upload, use Studio to annotate the following:

- The lesson objective(s) and a description of the roles
- What impact did the lab roles have on student mastery?
- What are 1-2 specific adjustments you need to make to increase the effectiveness of lab roles in your classroom?

Then, in our next synchronous session, you'll work with a peer to get concrete feedback and ideas based on your video.

Note. Studio is a technology tool that allows candidates to add comments at specific timestamps on the videos that they uploaded.

Moving the lab roles practice to the asynchronous environment allowed us to see how candidates used these roles to support their own students' inquiry and how their actual students responded. As with the in-person practice of think-alouds, the goal was to promote transfer to the classroom through combining the practice of instructional and reflective activities.

Lessons Learned

As instructors, we prize particular key learning experiences. These experiences may give candidates the opportunity to experience how a new instructional technique feels, or they might reliably elicit reflections that help novices overcome their anxiety about trying something new. In some ways, the process of moving our coursework to the fully online modality was a process of learning to identify the active ingredients of these key learning experiences. It wasn't holding the Play-Doh that made our model lab lesson work for candidates; it was the fact that our teacher moves illustrated how to safely release the responsibility for investigation design to students. For lesson rehearsal, the crucial idea was that our candidates could get thoughtful peer feedback on an early performance of the skills required to make inquiry labs work. Sometimes this worked better in the low-risk, methods class environment, and sometimes it made more sense to simply capture early attempts in candidates' classrooms. In both cases, we kept our goals in mind, and we crafted online activities with the right active ingredients to bring candidates closer to those goals.

Of course, these activities remain a work in progress. After the lesson containing the model inquiry lab, for instance, we received feedback from a handful of students (five out of 73 survey responses) regarding the duration of the activity. Four out of the five comments noted that the model lab felt too long; however, one noted there was not enough time to complete the full lab as students. For our next course iteration, we may recommend that instructors facilitating model labs identify two or three steps that may be done more quickly with adults than with secondary students. Then, when facilitating these parts, instructors can call out that they will accelerate instruction and let their adult learners go full speed. This could conserve time for a discussion of the changes an instructor would make when working with middle or high school students. Alternatively, instructors might consider breaking the model up over two class meetings to allow for more processing time after each segment and to reduce the overall amount of any single class meeting spent in the model lab itself.

Outcomes

To determine whether this online coursework served students well, we looked at two sources of data: candidate assessment scores and informal surveys that candidates used to provide feedback on class meetings. The primary data we examined were course assessment scores from the spring term final assessment, which focused on inquiry labs. Specifically, this assessment included a video of the candidate facilitating an inquiry-based lab, an analysis of three student work samples representing trends in student learning (e.g., common areas of strength and struggle), and a reflection that included next steps based on the lesson implementation and student work analysis. As we will discuss below, portions of this assessment needed to be modified during the pandemic due to candidates' shifting teaching contexts.

We examined assessment data from 3 years: 2019, 2020, and 2021. However, given the significant disruptions caused by COVID in 2020 and 2021, we needed to analyze each year separately. Each year's assessment data afforded different insights.

- Assessments from spring 2019 (prepandemic) helped us identify whether candidates in fully online courses were performing comparably to students in our courses with in-person class meetings.
- Spring 2020 assessments afforded a different kind of in-person to fully online comparison. By the time of assessment submission, all courses were fully online, but some candidates had been learning in person prior to a COVID-driven shift early in the term. Assessment data from this year helped us see whether our design principles were robust enough to serve a larger student body and help to prevent learning interruptions that might be associated with going suddenly online.

  Assessments from spring 2021 provided a sense of how assessment format impacted candidate scores. During this semester, our courses remained fully online, but nonuniform school reopenings allowed some candidates to attempt a more challenging assessment option.

To complement our assessment data, we also reviewed data collected from end-of-class meeting surveys in spring 2021, which provided student perceptions of our online science methods coursework.

Course Assessment Data

For each year studied, we compiled average final assessment scores for every section of the course. We also pulled out the averages for a subset of rubric items assessing candidates' skills at planning and implementing laboratory work (as opposed to, say, analyzing student work), which were the skills that we hypothesized might be the hardest to teach online. Table 5 shows the overall and lab-related assessment averages for the candidates receiving in-person and fully online instruction in 2019 and 2020 (recall that in 2021, all candidates received fully online instruction). Kolmogorov-Smirnov tests revealed that all samples were significantly nonnormal, and Levene's test revealed significantly unequal variances among some groups. Therefore, we used the nonparametric exact Mann–Whitney test to compare scores across modalities for each year.

Table 5

Final Assessment Scores for Online and In-Person Methods Courses 2019–2020

		Mean scores (%)	
	n	Overall assessment	Lab implementation-related rubric items only
		Spring 2019	
In-person	130	88.1	85.2
Online	63	89.8	87.0
		Spring 2020	
In-person[a]	158	92.6	90.2
Online	61	92.3	90.5

Note. Group medians are technically more appropriate for nonparametric tests, but means are reported for ease of communication. The medians for each group display the same ordinality within years and differ by less than 3 percentage points from the reported means.

[a] This group of students received in-person instruction during fall 2019 but had to quickly transition to fully online instruction during spring 2020 because of the pandemic.

2019: Baseline Comparison of Online and In-Person Course Sections

In 2019, online sections of the course enrolled about half as many total candidates (n = 63) as in-person sections (n = 130). All students submitted the standard assessment portfolio, including a video of an inquiry-based lab and an analysis of student work. We found that candidates' scores in the online and in-person conditions did not differ significantly for either lab-related items (U = 3573, z = -1.44, p = .152) or for the assessments overall (U = 3451, z = -1.773, p = .076). We did not detect evidence that the students in the online condition were performing differently than students receiving in-person instruction.

2020: A Pandemic Pivot to Fully Online Coursework

In 2020, as the severity of the pandemic became clear, all candidates' coursework went online. This did not constitute a change for candidates already enrolled in online course sections (n = 61) but required a modality shift for candidates in the in-person course sections (n = 158). It also required a change to the assessment portfolio: candidates submitted a detailed plan for an inquiry-based lab in place of a video but still accompanied this with an analysis of student work from the lab they facilitated. (We suspect that this change to the assessment is the reason that candidate assessment scores increased from 2019 to 2020. Even the best-laid plans for inquiry-based labs can go awry in a room full of secondary students, so an assessment without an implementation component is likely easier.) Though we feared the candidates in the formerly in-person group might be disadvantaged by this transition, candidates in both groups achieved high levels of proficiency in competencies related to designing and conducting laboratory investigations. Differences between the performance of our dedicated online sections and our formerly in-person sections were not significant either in the lab-related rubric items (U = 4509, z = -0.74, p = .462) or for the assessments overall (U = 4353, z = -1.11, p = .267).

2021: Video- vs. Plan-Based Assessments in Online Coursework

In spring 2021, all candidates were enrolled in online science methods course sections. However, as school reopenings proceeded in some regions, some candidates were able to return to in-person teaching placements, though they continued to take all their Relay methods work fully online. As a result, some candidates (n = 77) were able to complete the standard assessment portfolio in which they implemented and filmed an inquiry-based lab, whereas the remainder (n = 133) completed the portfolio using a lesson plan, as in 2020. As shown in Table 6, candidates who completed the video-based version of the assessment scored significantly lower than candidates who completed the plan-based assessment. This was true both overall (U = 3543, z = -2.17, p = .015) and for lab-specific items (U = 2598, z = -4.72, p < .001) in which the difference between group medians was a considerable 8 percentage points. These differences appear to support the notion that a video-based assessment is more difficult, perhaps especially when candidates returned to their placement classrooms from remote teaching midsemester.

Table 6

Final Assessment Average for Spring 2021 Fully Online Candidates by Assessment Type

		Overall assessment				Lab implementation-related rubric items only			
	n	*M*	*U*	*z*	*p*	*M*	*U*	*z*	*p*
Video-based	77	89.1	3543	-2.17	.015	83.3	2598	-4.72	< .001
Plan-based	133	91.8				90.7			

Note. Group medians are technically more appropriate for nonparametric tests, but means are reported here for ease of communication. The medians for each group display the same ordinality within years and differ by less than 3 percentage points from the reported means.

Notably, the 2021 video-based assessment scores were similar to the scores received by a pre-COVID comparison group: the 130 candidates from 2019 who attended in-person methods coursework and submitted video-based assessments. The many differences between these groups make the use of statistical tests here inappropriate, but from a practical standpoint, the scores are nearly the same. The 2019 in-person candidates had an overall assessment average of 88.1% and a lab-specific rubric item average of 85.2%; the 2021 online-only candidates achieved a slightly higher overall average of 89.1% and a slightly lower lab-specific average of 83.3%. The similarity between scores of these groups further supports the notion that the significant differences observed in 2021 are a result of the assessment format rather than the switch to online coursework.

Taken together, the available outcomes data seem to suggest that our online and in-person coursework promoted comparable outcomes for candidates both before and after the pandemic. As school reopenings continue, we will continue to look for ways in which the online coursework can better support the lab-related skills our candidates need, particularly with respect to the skills required to implement a successful lab lesson in the secondary classroom.

Student Perceptions: Was Online Coursework Useful?

At the end of each synchronous online class meeting in spring 2021, candidates filled out end-of-class meeting surveys that included a 7-point Likert scale ranging from *strongly disagree* (1) to *strongly agree* (7) on which candidates rated the extent to which they agreed that “This session will positively impact my instructional practice.” As shown in Table 7, analyzed responses (N = 271) from three sections of this course taught in 2021 indicate that candidates agreed that the sessions were impactful: Three sessions scored above a 6, and the remaining session scored a 5.94.

Table 7
Graduate Student Perception of 2021 Sessions About Inquiry-Based Labs

Session	*n*	Mean session rating[a]
Session 1: Introduction to Inquiry	73	6.12
Session 2: Increasing Inquiry	62	5.94
Session 3: Working Toward an Inquiry-based Lab	71	6.07
Session 4: Lab Skills Practicum	65	6.05

[a] Average response to a postclass, single-item question reading "This session will positively impact my instructional practice." Items were rated on a 7-point Likert scale from strongly disagree (1) to strongly agree (7).

Additionally, open-ended feedback included praise for activities that required classroom application—for example, when candidates collected and analyzed student lab work and then engaged in a reflection protocol during class meetings. One candidate wrote, "I really enjoy the CAR [classroom application and reflection] assignments of being able to upload and reflect on student work. I feel like these have been the most helpful types of assignments because they are the most applicable, and I can even take my reflections and implement the action steps in class the next day!" Another theme in open-ended responses was praise for practice opportunities such as "practicing with a partner and getting feedback," as one candidate wrote. Finally, many candidates gave positive feedback to their individual professors, saying: "Love the craft that Professor Grimes has for teaching, warm and welcoming environment"; "Professor Harris expressed a lot of understanding for students [*sic*] individual needs and learning goals"; or "showing love on the way out, no doubt . . . great teaching, Dr. Brady!" We believe the positive qualitative feedback reflects our emphasis on classroom application, practice, and relationships.

The modal response to a question about which activities were less likely to positively impact instructional practice was some variant of "NA." When substantive responses were given to this item, they were generally minor, for example: "I wasn't honestly totally sure what to do with the medium-term planning document at the end," or "I think I may need more guided examples and practice with what is coming up on the final." In these cases, instructors followed up with individual students to provide additional support and guidance as necessary. In addition to minor comments such as the examples given, six responses across all 271 indicated a struggle with applying the learning in a virtual setting (e.g., "hard to apply in a virtual/hybrid setting"). This was particularly interesting given that all instruction and modeling were virtual. Two out of these six comments indicated that the struggle was due to a lack of breakout room functionality with school-based technology, and one out of the six indicated that their school was not doing labs virtually but would return to labs once back in person. Given this, we recommend that instructors with candidates teaching virtually survey candidates about the types of technology they use and provide proactive recommendations based on the candidates' contexts.

That said, the majority of comments were positive, and most were similar to those shared previously. Thus, the available evidence, both qualitative and quantitative, suggests that candidates believed their time in these online class meetings was well-spent and impactful, despite the absence of traditional face-to-face (and face-to-beaker) instruction.

Conclusion

In some ways, the principles that we have espoused here are straightforward. We held our candidates to high expectations, paid attention to the unique benefits (e.g., access to candidate thinking) and pitfalls of online course delivery (e.g., Zoom fatigue), and worked hard to adapt our practice-based learning experiences to a new modality. Some activities did not work as well in the online modality, but we found alternatives that supported the same kinds of community building and active participation on which we have always relied. And, for the most part, we relied primarily on technological tools, such as Google Sheets, that are freely available to science teacher educators. One of the characteristics that we feel has distinguished our approach and that we hope others will build upon is our commitment to pedagogies of enactment in an online environment. Another unique feature of our approach is the continual use of data analysis to evaluate and improve course quality in an online environment. Indeed, we might call the analysis of outcome data the fourth principle of online course design, but it is equally good practice for in-person course instructors.

In the years to come, more science teacher educators are likely to be asked to create online versions of their courses. This can be scary. After all, many things that are possible in person are not possible online (the inverse is also true, though this is less frequently appreciated). However, we found that thoughtful design and careful monitoring of candidate feedback allowed us to maintain quality and support large numbers of candidates when COVID came knocking. We hope that this article will contribute in a small way to the conversation of practitioners dedicated to making online science methods courses the best they can be.

Supplemental Files

Appendices-Waldron-et-al..docx

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