Lab-Based Courses

every learner everywhere

intentional futures

Contents

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About the Supporting Organizations

Every Learner Everywhere is a network of twelve partner organizations with expertise in evaluating, implementing, scaling, and measuring the efficacy of education technologies, curriculum and course design strategies, teaching practices, and support services that personalize instruction for students in blended and online learning environments. Our mission is to help institutions use new technology to innovate teaching and learning, with the ultimate goal of improving learning outcomes for Black, Latinx, and Indigenous students, poverty-affected students, and first-generation students. Our collaborative work aims to advance equity in higher education centers on the transformation of postsecondary teaching and learning. We build capacity in colleges and universities to improve student outcomes with digital learning through direct technical assistance, timely resources and toolkits, and ongoing analysis of institution practices and market trends. For more information about Every Learner Everywhere and its collaborative approach to equitize higher education through digital learning, visit www.everylearnereverywhere.org.

Intentional Futures is a Seattle-based design and strategy studio. We work closely with clients across the public and private sectors to solve hard problems that matter and make big, ambitious ideas come to life. Our core offerings include human-centered strategy, data-driven storytelling, intentional, collective learning, and product design and prototyping. To learn more about iF or see our past work, visit intentionalfutures.com.

Lab-Based Courses: Toolkit Overview

Toolkit overview, high-quality indicators, and key questions

Perhaps more so than other kinds of classes, lab-based courses will present challenges when suddenly forced to move online. While there is literature to suggest that virtual simulations may help students master concepts and even skills in practical application of those concepts better than in-person labs, the rapid transition during COVID-19 may make it difficult to ensure that all your students are set up to participate in online labs at home. The crisis has in many ways exacerbated pre-existing inequities in higher education, including those around access and disability accommodation, economic resources, cultural and language barriers, and more. In order to ensure that your transition from in-person labs to online or remote labs creates an equitable and enriching learning environment for all your students, we have laid out some attributes of high-quality online simulations, as well as questions to consider when evaluating how to adjust your lab-based courses:

Attributes of High-Quality Online Labs

There is a lot to consider when moving a traditionally classroom-based course into a digital environment, and lab-based courses present some unique challenges. Though not comprehensive, the list below contains some of the most important attributes to account for when considering the use of digital tools as you transition your lab-based course online:

ADA Compliance: Like with in-person curriculum and activities, online simulations and labs are required to be ADA compliant. Not all online simulations meet these regulations, and so in these cases faculty and institutions must build in accommodations. Beyond ADA compliance, Inside Higher Ed offers some useful tips on attributes to examine for accessibility concerns, including audio quality, text searchability, font size and style, and hyperlink formats. Their suggestions can be found here.

Widely accessible technology: In addition to meeting ADA requirements, the best labs are the ones that are accessible without requiring additional software downloads, browser plug-ins, or high processing speeds/RAM. Because there may be students who do not have a computer of their own, online simulations and other activities that can run on a smartphone provide added ease of access in that particular regard.

Interactive and collaborative: One of the most important learning activities labs offer is the ability for students to test concepts and knowledge themselves. As important as observation is to any lab, the more online simulations allow for students to design, interact, modify, predict, and discuss the outcomes, the stronger it will be at meeting the same learning outcomes as in-person labs. Additionally, labs offer a lot of key opportunities for students to learn and work together. A video watched home alone does not offer the same experience, so the more an online simulation creates opportunities for student engagement and collaboration with each other, the better.

Questions to Ask When Adapting Your Lab-Based Course

Like most in-person courses and perhaps even moreso, lab activities cannot be translated as designed into a digital environment. To create a high-quality online learning experience, it is vital to identify and consider your learning outcomes, and adapt your activities and lessons to make use of the tools and environment at hand. If possible, we highly encourage instructors to consult with instructional designers at their institution to help them learn about the variety of opportunities available with online classrooms and make this transition successfully.

To get started, there are a few questions instructors should think about when designing lab activities for digital learners that will help them create high-quality experiences tailored to their subject matter and learning outcomes:

Question 1: What are the learning outcomes I hoped for the in-person lab to address? Which can be addressed without a simulation?

As mentioned before, the first step in translating any in-person course online is to identify your learning outcomes. For labs specifically, it can be especially helpful to break down those outcomes into two categories: outcomes that can only be addressed by performing a lab, and outcomes that can be addressed through other, alternative means. Because labs typically address so many different learning outcomes, you may have to replace one in-person lab with a few different activities, some of which may or not be online simulations, to make sure that all your learning outcomes are met.

Activities better addressed by simulation, at-home experiment, or hands-on activity: As noted by Linda Strubbe and Sam McKagan at PhysPort1, labs include many activities, some of which prove more challenging than others to replace. Some of those activities include:

- Observing a phenomenon
- Designing an experiment including troubleshooting
- Collecting data (i.e. make measurements)
- Analyzing and visualize data
- Developing technical and practical laboratory skills

As you find components like this in your list of outcome, identifying which you're hoping to replace with an online simulation or remote lab experience will help you evaluate the various resources available to find the lab best suited to your syllabus.

Activities that can be addressed without a remote lab experience: Strubbe and McKagan point out that other components2 of lab activities translate rather easily into a virtual classroom necessarily requiring students to perform a lab themselves:

- Pre-lab and/or post-lab assignment
- Coming up with questions to investigate
- Interpreting data / creating models / reflecting on results
- Writing a lab report
- Creating a class presentation
- Giving each other feedback on any of the above

If the main learning outcomes you are hoping to address in your lab are any of these, you may want to consider alternatives besides simulations. For example, if a major part of a lab was aimed at getting students to interpret data, could the assignment be reimagined to draw on experimental data that already exists? If the goal is to write a lab report or develop questions for investigation, these also may be able to be separated and developed virtually.

Question 2: What obstacles might students face in accessing this simulation? What barriers to entry can I anticipate, and what can I do to support students with varying needs?

As with all learning activities, on or offline, access to resources for students with limited means and access to content for those with disabilities should guide your planning. This may mean having alternatives for different students who have varying access needs and economic resources.3 It can also mean taking technological disparities into account, like which simulations require a software download and which can be run in most web browsers. Create a few channels for students to communicate with you about their needs (some may not feel comfortable coming forward publicly, for example, or may be more forthcoming over email than over video chat). Talk frequently with your accessibility office when you have questions about how you can help your students, and if you're seeking additional resources, consider our Inclusive Instruction Toolkit, which contains several resources for making online learning as inclusive as possible.

As mentioned in our Assessment and Grading Toolkit, teaching during COVID is a critical time to know your students. If you find that a particular online simulation is inaccessible to the majority of students in your classroom (either because of the browser, its lack of certain accessibility features, or not enough students can download it) it may not be the best course of action for your class.

Question 3: How can I make a virtual lab as interactive as possible? What are all the ways I can engage students' critical thinking and self-reflection?

Researchers have noted that there are quite a few learning benefits to activities in which students can "mess about."4 One of the benefits to some online simulations is that they allow for messing about productively5: students can adjust parameters to change the way a simulation performs, without getting drawn into non-productive messing about (like making hats or eyewear out of the lab equipment).

When considering various remote lab options, think about which simulations or activities will best allow students to engage and play with the materials and concepts. Especially because you're not able to supervise in person, remote lab activities that are easy for students to use and provide opportunities for them to interact with the parameters and variables are preferable.

That said, we recognize that some online simulations cover specific content that's necessary to your course, but may not be as interactive as you'd like. So if you find yourself relying on a simulation that is not very interactive, consider supplemental activities you can create to help engage students' critical thinking and "messing about" tendencies in conjunction with observation. In our Non-Simulation Lab Alternatives resource [link to other resource], you'll find a few different activities and practices you can employ to encourage students to reflect on, reason through, and analyze whatever online simulations or demonstrations you provide them with. You may also think about supplementing formative assessments that help you track student progress while encouraging meta-cognition and ownership of their learning journey in your students. See our Assessment and Grading Toolkit for more.

Takeaways

At the end of the day, a simulation is only as useful as its relationship to specific learning goals and its ability to facilitate student engagement. These two factors are highly dependent on your individual situation. If you find yourself looking at a possible online lab that neither clearly corresponds to a learning outcome, or is difficult for whatever reason for your students to engage with, then it may end up creating more work for you and your students without facilitating a rich learning environment. If, on the other hand, you find an online simulation that clearly meets a learning outcome in your syllabus and promises to engage your students, then it's likely to prove an effective supplement to your laboratory course.

**Note: When considering any online courseware, cybersecurity protocols should be one of the many factors your school evaluates with any prospective vendor. Resources for cybersecurity and vendor evaluation can be found at EDUCAUSE's Vendor Assessment Toolkit.*

References & notes

[1] Strubbe, Linday, and Sam McKag. “I Suddenly Have to Move My Lab Course Online! What Should I Do?” PhysPort. AAPT. Accessed May 8, 2020. https://www.physport.org/recommendations/Entry.cfm?ID=119927.

[2] Strubbe, Linday, and Sam McKag. “I Suddenly Have to Move My Lab Course Online! What Should I Do?” PhysPort. AAPT. Accessed May 8, 2020. https://www.physport.org/recommendations/Entry.cfm?ID=119927.

[3] “For Students With Disabilities, A Mass Shift to Online Courses Comes With Deep Concerns.” Diverse Issues in Higher Education. Diverse Issues in Higher Education, March 23, 2020. https://diverseeducation.com/article/170320/.

[4] Hammer, David. “Student Resources for Learning Introductory Physics.” American Association of Physics Teachers. AAPT, January 1, 1970. https://aapt.scitation.org/doi/10.1119/1.19520 and D. Hawkins, The Informed Vision: Essays on Learning and Human Nature (Agathon Press, New York, 1974), cited in Finkelstein, N. D., W. K. Adams, C. J. Keller, P. B. Kohl, K. K. Perkins, N. S. Podolefsky, S. Reid, and R. LeMaster. “When Learning about the Real World Is Better Done Virtually: A Study of Substituting Computer Simulations for Laboratory Equipment.” Physical Review Physics Education Research. American Physical Society, October 6, 2005. https://journals.aps.org/prper/abstract/10.1103/PhysRevSTPER.1.010103.

[5] Finklestein et al., “When learning about the real world is better done virtually,” 2005. https://journals.aps.org/prper/abstract/10.1103/PhysRevSTPER.1.010103.

Remote Laboratory Alternatives

A collection of online databases, free simulations, and additional resources

There are many different ways to translate experimental activities to a digital learning environment. Below we've given an overview of a variety of options including from citizen science projects, at-home lab kits, "kitchen labs," and online simulations. The ones highlighted here were selected for their affordability and coverage of a wide range of disciplines, and in the hopes of offering a wide range of options for instructors to choose from based on their particular learning outcomes and subject matter.

Citizen Science Projects

Citizen Science projects are a great way to get your students engaged in authentic learning by getting them to work on longer-term research projects. These are especially useful for addressing learning outcomes like gathering and analyzing data, and they're also likely to get your students engaged with the knowledge that they're working on real issues that are affecting the world they live in:

Anecdata has a collection of over two hundred citizen science projects students can work on, including projects for organizations like NASA and the New England Aquarium, and many downloadable data sets.

SciStarter has a large database of over eight hundred citizen science projects tagged for college and graduate level students. Their database is also filterable by location, labs that can be done with a smartphone, those that have accompanying materials provided, or activities that can be done entirely online.

Scientific American also has hundreds of citizen science projects to choose from, and can be filtered according to topic and the type of activity you're hoping for your student to address.

Zooniverse has about one hundred projects covering a wide range of topics, tagged under Biology, Physics, Space, and Nature (as well as non-science disciplines). Possible projects students can contribute to include measuring parasite's presence in watering holes in the East African savanna or helping astronomers locate and identify supermassive blackholes.

iNaturalist is a network of projects all focused specifically on biodiversity science. While limited in scope, depending on your learning outcomes and subject matter could have some interesting activities students can do in their own backyard (literally!).

At-Home Labs

If there are labs that feel critical to your learning outcomes, there are companies like Hands-On Labs and eScience Labs that both provide assembled kits and host predesigned labs on their own online platforms. According to the Chronicle of Higher Education, "both companies report being able to have the online platform ready for students within 48 hours, with the kits arriving shortly afterward." Carolina is another option that allows instructors to build their own lab kits. While companies like Carolina and eScience are widely regarded for both the customizability of what they can send and for the quality of their offerings, cost and safety should be key considerations with at-home labs. Talk to your institution about how at-home kits like these might get paid for, and consider the means your students may have. It's also worth noting that because instructors and TAs cannot be in the same room as the students, instructors should be sure to take all necessary safety precautions in how they provide instruction and supervision remotely.

"Kitchen" Labs

For students who may not have access to custom-made kits, instructors can consider "kitchen labs" or experiments that can be performed with common household objects. While these may not be ideal for more advanced lab-based courses, many at-home experiments, coupled with activities like lab reports, predictions, data analysis, etc., can prove very useful in helping students understand certain concepts and build a foundational understanding of their subject matter. The Exploratorium and We Are Teachers have databases of at-home experiments that, while originally aimed at perhaps a younger age range, could provide good fodder and inspiration for at-home experiments to provide your students. Video demonstrations by you or your TA, along with thorough instructions and safety precautions, are important components for those considering this option.

Free Simulations

There are many different simulations and online labs to choose from. The selections below are in no way a comprehensive list. But we've chosen these resources based on their ease-of-access, lack of paywall, and breadth of type of simulation and online resource they offer. Note the first two (SimBio and LabArchives) are designed to pair with open content textbooks and curricula.

SimBio (biology): The labs here correspond to the OpenStax biology book. These are open-ended experiments and built-in feedback include tutorials and guide students in discovery-based learning. Contact sales@simbio.com to find more about their free offerings for the spring of 2020.

LabArchives (math and science): LabArchives' content is focused on lab manuals, protocols, and assignments rather than simulations, but these free materials can help enhance or meet certain learning outcomes components of labs. The materials they already have available correspond to OpenStax' Biology 2e and Chemistry 2e textbooks. You can also supplement the course materials they have in there with your own content as you choose. Like SimBio, emailing is the best way to access their free resources: labbuilder@labarchives.com.

PhET (math and science): This database of simulations, created in part by the University of Colorado Boulder, is searchable either by topic or by grade level, though it is not apparently easy to search by both. The link provided here will take you to over one hundred university-level simulations across math and the sciences. Most PhET simulations can run on the web, and all can be downloaded to run offline. As a bonus, PhET provides an accessibility index that lets you know which accessibility features are already built into which online simulations, as well as information on how they're developing their research and technical implementation keeping accessibility in mind. Keep in mind that PhET runs on Java, though, and some students may not be able to run their simulations on their computers at home.

Viper Simulations (physics): Viper simulations include a wide range of free physics simulations, and have the advantage of being observable from within most web browsers. If you're concerned about students being able to download additional software, these simulations have a low barrier to entry.

JoVE Video Journal (sciences): All JoVE resources are free until June 15, and they're a great resource as the leading peer-reviewed scientific video journal. In their words, the journal "publishes methods articles including text description and video demonstration of experiments." If your students are missing hands-on lab experience, this can be a great supplement to what they may be learning from simulations and lab reports to understand practical skills required for lab work. They may also be able to use this as a resource for experimental data to analyze.

BioInteractive (biology): BioInteractive is devoted to biology, and offers online labs as one of many educational resources, including videos, interactive videos, 3D models, and more. They also have a number of activities, video lectures, and case studies, data points, and lab demonstrations. They also offer planning tools and instructor resources to help integrate their materials into your curricula. Best of all, all BioInteractive resources are provided free of charge through their website.

Paid Simulations

These are simulations that were not necessarily easy to access or free, but depending on your student resources offer some supplemental digital simulations and visualisations:

Labster: Unlike some other simulations, Labster offers an immersive lab simulation in which students can get to know a virtual lab environment, safety precautions, and procedures. They are offering discounted pricing for the next several months in response to COVID.

Visible Body is specifically geared towards teaching biology and physiology, and has a slew of offerings that could work well as a dissection lab alternative. Note that their website offers "3D models, illustrations, and animations" but not simulations. Their website has no mention of any discounts or pricing variations to account for COVID.

Searchable Indexes

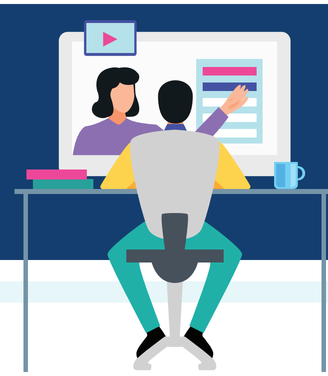
There are many searchable indexes of online laboratories and simulations available. The two listed below stood out because of their large scope, and their searchability by level, subject matter, and type, and their peer ratings and/or notes. While these do not necessarily cover every resource available online, these may help you narrow in on something that will meet your needs quickly.

Online Resources for Science Laboratories: This GoogleSheet is organized handily by type of resource, subject matter, and access (in terms of payment). The notes and description fields are also helpful to understand whether or not this resource will meet your needs, and what other educators are saying about them.

MERLOT: Here you can find a library of virtual laboratory experiences. MERLOT also allows you to filter by discipline, material, and audience so you can hone what kind of simulation you're looking for. They also have peer reviews to help you gauge which simulations are already endorsed by your peers.

National Science Digital Library: While this database includes paid and free resources, it is a huge and comprehensive searchable library of digital resources for science education, including data sets, simulations, labs and more in science, technology, engineering, and mathematics.

Low-Tech Tools and Practices



Maximizing engagement while minimizing barriers

As mentioned earlier in this toolkit, there are many components to labs that don't necessarily have to happen in person. Below are some best practices that we suggest for adapting your course or lab activity online. These best practices enable instructors to maximize student engagement, minimize barriers to entry, and build in exercises that encourage creative and critical thinking.

Best Practices

- **Encourage prediction, reasoning, and explanation.**
  Some of you may use online demonstrations, simulations, or simply scientific reports on experiments as a substitute for students conducting a lab in person. To maximize the students' engagement with the online material, consider asking them to predict what will happen before witnessing the simulation or experiment, and ask them to explain their reasoning. You can ask them to make predictions based on a few different parameters. As they discover the results or observe the outcome, ask them to reflect on how close their predictions were, and why.1

- **Assign interpretation of experimental data.**
  If students aren't able to generate their own data, Dartmouth's remote teaching guides suggest extracting datasets from published literature akin to what they might have been working with in the lab. By providing students with the sample data in the form it may have been collected in originally, you can then ask students to analyze the data as if they themselves had collected it.2 As an alternative to using publicly available data, you or your TA could complete the lab yourself, with students making the observations, measurements, and analyses based on that video. JoVE (a resource covered in our Online Simulation resource) includes some videos of experiments you can already work from.

- **Consider at-home experiments that require minimal equipment.**
  Also consider having students design and carry out experiments with items they have available. For example, you could ask students to demonstrate a concept with household objects, and create a video explanation so they're asked to process and reason through the concepts. If access/resources are a worry, you can also work with students to design their own experiments based on what they have at home, or even consider whether a team in which one member performs the lab over video and the others design and build out the experiment could also meet the needs.

- **Design a hypothesis and an experiment based on prior experiments, studies, simulations or data.**
  Either based on prior experiments they've done or case studies they've reviewed, you can ask students to design their own hypotheses and experiments with predictions as a way to assess their understanding of the material and of laboratory practices and reasoning. Versions of this might also include giving students a set of experimental steps in a randomized order, and asking them to order them correctly with an explanation, or ask students to fill in a blank step in a procedure and explain their reasoning.3

- **Create opportunities for peer review and formative assessment.**
  One additional way to continue encouraging student dialogue, collaboration, and critical thinking, is to create opportunities for peer review of any of the student activities listed above, be it a video demonstration of an at-home lab with an explanation, a prediction for an experiment with reasoning, or a data analysis or lab report generated on experimental data. If there are key lessons or concepts that you're afraid students may be missing because of a lab's absence, using formative assessments (covered in our Assessment and Grading Toolkit) may help you monitor your students' progress and help encourage meta-cognition in them.

- **Get students on their phone.**
  You read that right! There are an increasing number of smartphone apps that allow students to engage in scientific experimentation and observation without needing a computer or any additional equipment. Some apps facilitate data collection, like Nasa's Globe Observer, which lets students contribute to research on cloud cover, land cover, and mosquito habitat. Others, like the AcceleratAR, which creates a simple particle accelerator in augmented reality, offer more accessible simulations. Others still like Google's Science Journal Google's Science Journal app turn your phone's built-in capacities to gather information about the world around you, with light, sound, pressure and motion readings. Popular Science has a selection of their favorites, but depending on your lesson and subject matter there are many different options. As always, prioritize apps that can be accessed for free, and ideally those that are available for both iPhones and Androids.

References & notes

1 Taft, Heather R. "How to Quickly (and Safely) Move a Lab Course Online." The Chronicle of Higher Education, March 17, 2020. https://www.chronicle.com/article/How-to-Quickly-and-Safely/248261

2 "Remote Lab Activities and Experiences." Teach Remotely: How to Teach From Anywhere. Dartmouth College. Accessed May 8, 2020. https://sites.dartmouth.edu/teachremote/resources/remote-lab-activities-and-experiences/.

3 "Remote Lab Activities and Experiences." Teach Remotely: How to Teach From Anywhere. Dartmouth College. Accessed May 8, 2020. https://sites.dartmouth.edu/teachremote/resources/remote-lab-activities-and-experiences/.

External Links

Additional reading and expert recommendations

Chronicle of Higher Education – Quickly and Safely Move Labs Online, written by Heather R. Taft of Colorado State University Global, covers the pros and cons of various lab-replacement tools, techniques, and simulation options. Taft also covers a good overview of essential considerations when moving your lab online, and gives an informed take on some of the different simulations and virtual experiences out there for science students.

PhysPort – Moving Labs Online: This Expert Recommendation is a terrific and comprehensive starting point for what to consider and where to look when moving your labs online. The authors do an excellent job breaking down the different aspects of lab-based courses to consider as you make the leap to online teaching. Topics include experiments to do at home with minimal equipment, software and apps for taking and analyzing data, and ideas for designing an experiment and developing practical laboratory skills remotely. Note that PhysPort suggests reading their overview of how to move a science class online (see below) before diving into this lab-specific resource, so if you find yourself needing more general support, see their next resource below.

PhysPort – Moving Science Classes Online: In addition to their Expert Recommendation on labs, PhysPort also has a guide for moving science classes online more generally. They have some great suggestions here on a range of topics, from the question of synchronous sessions to how to facilitate group work. If you feel like you've already got some clarity around those fundamentals, their next resource on labs may be where you want to go directly.

NANSLO Summary: NANSLO was an "international consortium of online science laboratories operated by accredited institutions in the U.S. and Canada…[that] provided students located anywhere in the world with access to science laboratories via the Internet." Unfortunately, due to funding difficulties the program is no longer active. Fortunately, the consortium left behind a summary packet that includes lab manuals for many different experiments, complete with pre-lab questions and experimental procedures, as well as additional resources to transitioning labs online.

Online Math Instruction Webinar: In this webinar, Mike Flynn, Director of Mathematics Leadership at Mt. Holyoke, covers different ways to enhance online learning of mathematics. While not science-specific, some of his suggested assignments and activities undoubtedly could spark inspiration for activities and authentic problems for students to tackle in order to address key learning outcomes in both math and science.

Dartmouth's Remote Lab Activities and Experiences: This resource combines some suggested activities to supplement certain components of lab work, as well as a shorter index of ten or so online simulations and labs for various subject matters.

Tips for ADA-Compliant Inclusive Design: This article from Inside Higher Ed calls out a number of design components to consider when either evaluating or building out an online learning resource. When looking at the wide variety of online labs or simulations to choose from, you may find the design of some do a better job of meeting accessibility requirements of your students, and this article helps identify those so you know what to look for.