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ORIGINAL ARTICLE

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Providing interactive and field laboratories while teaching university marine biology classes in an era of COVID-19

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Abstract

An entirely online upper-division university marine invertebrates course modeled after a field experience-intensive course that also provided interaction with live animals and research experience was offered at Rosario Beach Marine Laboratory in the summer of 2020. We describe online methods we used for providing field experiences to students participating online, as well as a workstation and interactive method for identification and detailed anatomical examination of live macroinvertebrates with students. Students were also involved as active participants in a field research project. Nearly all of the equipment involved is inexpensive or readily available in most university biology laboratories or classrooms.

KEYWORDS
interactive learning, live animals, marine invertebrates, online instruction, student research

1 | INTRODUCTION

As COVID-19 closures and restrictions swept across the country in 2020, teachers of university science classes faced special challenges. Although online tools exist for the lecture portions of courses, and some standard laboratories can be conducted as simulations, conducting hands-on and field-experience laboratories remotely has proven especially challenging (Pennisi, 2020) and few online options are available. This article describes how we solved some of these problems in a summer marine invertebrates course, which is field and hands-on intensive and also includes a research component. The course was an upper-division biology course taught at Rosario Beach Marine Laboratory (RBML), a small marine laboratory in the San Juan Islands, WA, run by Walla Walla University. Running seawater tanks are incorporated in the classrooms and laboratories at RBML, which is close to many coastal marine sites including rocky, sandy, and muddy habitats. Most students in the course are juniors or seniors, with a few beginning graduate students. For most, this is the first upper-division marine course they have taken. The course takes place over 8 weeks, occupying all day (8 a.m. to 5:30 p.m., with a break for lunch, when not on a field trip) for 2–3 days of each week. In a typical year, the laboratory portion focuses on visiting marine habitats including the intertidal and offshore islands, pelagic and benthic sampling, and examining and sampling species using a variety of techniques including scuba diving. Students conduct hands-on study and identification of a wide variety of local marine species, emphasizing live individuals. Besides the broad sampling, each student is assigned to become a "class expert" on two or more of the invertebrate groups, which vary in taxonomic level depending on the number of species students are likely to encounter. In addition, students design and carry out a substantial research project addressing an ecological or physiological question regarding one or more of the species they have studied. In the most recent iteration of the course, D. Cowles was the course instructor and K. Onthank was a supporting assistant.

The COVID-19 challenge directly impacted the summer 2020 course. It was decided that although faculty members could be on site, it was not safe for students to come to RBML. All courses were to be taught entirely online. The challenge then was how to provide a rich online experience that kept the 15 students in the course engaged, and that replicated as much as possible the usual hands-on, field, and research foci of the course. Traditionally, for many of the students this is one of their first upper-division courses to incorporate independent research and hands-on experience, and we wished to maintain that focus.

2 | METHODS

2.1 | Materials for the course

Required textbooks for the course included Brusca et al. (2016) and Kozloff (2000). The dichotomous key by Kozloff (1996) was also required because the course was online and students would not have access to this reference at the laboratory. At the beginning of the course, students were introduced to *Invertebrates of the Salish Sea* (Cowles, 2021), a Rosario Beach Marine Laboratory website with photographs and descriptions of over 450 local marine macroinvertebrate species from 18 phyla, 31 classes, and 87 orders. This website serves as an important online reference site for macroinvertebrates on the Pacific Coast of North America and includes all of the common marine macroinvertebrates local students would be likely to encounter during the summer, along with many less common taxa. Students were also made familiar with taxonomic reference sites such as the Integrated Taxonomic Information System Online Database (https://itis.gov/) and World Register of Marine Species (www.marinespecies.org/). These along with occasional access to other internet sites constituted all the materials the students needed while we provided the online access to the marine habitats and species as described below.

2.2 | Field experiences for students

Field experience in areas with strong 4G cell phone reception was conducted live. There were several such areas near the laboratory. The authors (wearing masks) led the students on virtual trips through local rocky and muddy intertidal sites, with the instructor doing the leading and the assistant following with a smartphone sending real-time audio and video feed to the students. This allowed us to dialog with the students in real time, discuss some basic ecology, and introduce invertebrates and their anatomy while in the field. A Bluetooth headset connected to the cell phone provided much better audio to the students than using the onboard cell phone microphone, and also allowed the assistant to directly hear spoken questions posed by the students. The cell phone used the Android operating system, and the call to students was handled on the Microsoft Teams mobile application, the preferred video conference software for Walla Walla University. However, other mobile conference applications such as Zoom also have a mobile application and could have been used instead. Students then could view and interact with the field trip on any device that supports Microsoft Teams, including cell phones, tablets, or laptop or desktop computers. Students were also able to submit questions in real time using the Teams chat feature, which the assistant would then relay to the instructor.

Field sites with poor or no cell phone reception, which were most common, required a different approach and were far enough from the station that the instructor traveled there alone. Visits to these sites were recorded offline and provided to students later after minor editing. The core piece of equipment used was a GoPro™ Hero 7 camera. This camera is small, light, inexpensive, and has many different mounts readily available. The two most useful mounts were the head mount and the chest mount. Both of these allowed hands-free operation of the camera while recording the scene and individual species being examined. For detailed photographs of animals, a Nikon™ SLR digital camera with a series of close-up attachments was used.

A simple device which proved to be extremely useful for these one-person forays was a square two-chamber mop bucket with handle, such as the Rubbermaid commercial double pail plastic 19 quart bucket. A flexible mounting arm with GoPro mount on the top and a clamp on the bottom such as the Suptig Jaws Flex Clamp Gooseneck Mount could easily be clamped to the partition between the two chambers. This provided a stable, dry, clean platform on which to attach the GoPro while filming more detailed tasks such as digging for clams or other burrowers. In addition, one of the bucket chambers was used as a wet chamber to place specimens, while the other chamber was a dry chamber for keeping extra lenses, the Nikon camera, and dry cloths to wipe hands before handling the camera equipment. Several small sampling jars were also kept in the bucket for segregating small samples that were collected. If the flexible arm and GoPro camera were stretched at an angle, a stone could be temporarily placed in the bucket to provide stability. We created a sample video using these methods and introducing students to an intertidal site and the marine species there (https://www.youtube.com/watch?v=yr4Zm76JyPU&t=7s). See the end of that video for a view using the bucket and flexible arm as a base for recording with the GoPro camera.

The video sequences taken in the field were subsequently merged together to provide a record of each field trip. Each sequence typically began with an introduction using Google Earth or Microsoft PowerPoint, a map, and narration about the site, all recorded to video using Panopto software. Field video sequences were then strung together, starting with views of the access to the site. Videos and narration about the different species found while moving around the site were then interspersed with close-up photographs of the invertebrates taken with the Nikon™ camera. Text panels were sometimes used instead of narration to identify species or point out special features. Not having experience with video editing software, the instructor used the free Microsoft Video Editor program to create the videos. This program appears to be mainly designed to convert a series of photographs to a video, but it was reliable for producing videos up to 30 min long, and it had a simple, easily learned interface. After production, the videos were uploaded to Panopto and links to them were posted to the class learning management system (Brightspace D2L [d2 l.com]) for viewing by the students (e.g., https://www.youtube.com/watch?v=yr4Zm76JyPU&t=7s).

2.3 | Detailed, close-up examination of invertebrates

The most detailed examination of invertebrates took place interactively in the classroom. During field trips or at other times outside of class time, a wide range of invertebrates was collected and maintained in RBML's seawater tables until use. These were studied during class using a video workstation set up for this purpose (Figure 1). This video workstation was a Dell Optiplex 7010 tower running Windows 10 with Open Broadcast System (OBS) and Microsoft Teams installed. OBS had the VirtualCam plugin installed that allowed OBS output to be treated as a webcam by programs like Microsoft Teams and Zoom. Attached to this computer were three webcams: one Logitech c920 Pro HD, and two inexpensive Vcloo HD webcams with manual focus. The Logitech c920 was placed on the computer monitor to face the instructor, while the two Vcloo manual focus webcams were placed on flexible camera mounts that could be clipped to the edge of the table. These two cameras were positioned to face directly down at the table surface from ~8–45 cm above, depending on what was being viewed. One of these cameras was positioned above the Kozloff (1996) key, while the other was used as a macro viewer of the invertebrates being examined. We also used a DSLR mounted to a dissecting microscope for examining small features of organisms. This DSLR was connected to the video workstation by connecting the HDMI output of the camera to an Epiphan AV.io 4 K ESP1360 HDMI to USB 4 K Capture Card. The webcams and DSLR video capture card were used as video sources in OBS, with each camera's output as a different scene. This allowed the instructor to easily switch between camera views by switching scenes in OBS. The video output from OBS could then be used in Microsoft Teams by either using it as a webcam via the VirtualCam plugin, or screen sharing the video preview from OBS. We found that screen-sharing the video preview provided the students with the sharpest image, but those results would likely vary depending on the video conference software or operating system used because VirtualCam is implemented differently in Windows, Mac, and Linux environments. We also used several fiber-optic portable light sources to illuminate organisms under the dissecting microscope and under the macro webcam.

Class keying sessions began by maximizing the OBS screen, then sharing the workstation desktop via Microsoft Teams. Species chosen for each dichotomous keying session represented a variety of groups recently covered in lecture, plus a few not yet covered. Live organisms were used, occasionally supplemented by shells or preserved materials. Each identification started with the instructor asking what type of animal this was and therefore what taxonomic group should we start with in the key. Keying was led by the instructor at first, but the students quickly caught on and the keying was usually enthusiastically led by them while the instructor manipulated the species before the appropriate cameras to help them view the features being discussed. Any student in the class could be chosen to lead the group in keying a species, although students specializing in a group were most frequently chosen. The keying was collaborative with broad support and feedback to the student leading the keying, so the whole class learned the distinctive features. Each keying session lasted several hours, covered six to 10 species, and was recorded via Microsoft Teams and posted online for later review. After each keying session, the instructor took a series of close-up photographs of identifying features of each species using the highest-resolution cameras available and posted the collection in an online Dropbox™ for students to use in making their photograph species collections. Besides these group keying sessions, students who could do so were encouraged to visit marine sites near them and identify species on their own. A number of students had opportunity to do this and reported back their own identifications enthusiastically.

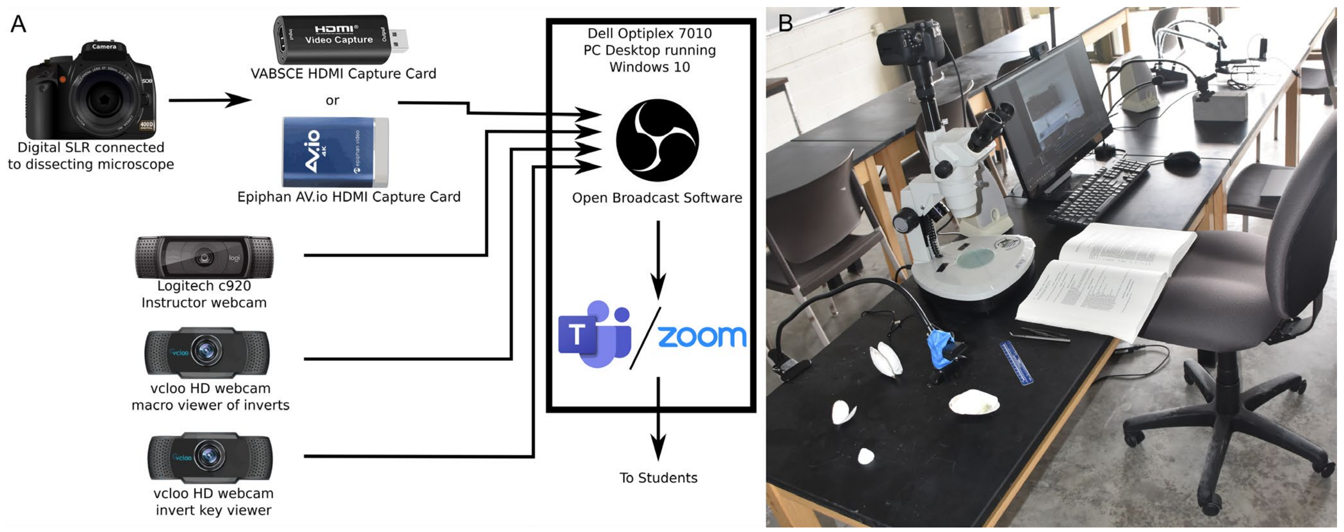

FIGURE 1 Video workstation setup. **A**. Schematic diagram of the hookup of the laboratory workstation components. **B**. Photograph of the workstation in use. From left to right: macro viewer focused on an invertebrate; dissecting microscope with attached digital SLR; monitor with instructor webcam, running both Open Broadcast software and Teams videoconferencing software; and webcam for viewing the invertebrate key (Kozloff, 1996). The invertebrate key has been temporarily moved to the left of the monitor in the photograph, and the Dell tower PC is behind the desk

2.4 | Research project

Rosario Beach Marine Laboratory is located next to Deception Pass State Park, the most visited state park in Washington State. The easiest access to extensive rocky intertidal habitat in the park is at the Urchin Rocks portion of Rosario Head, right next to the laboratory. The park is within easy driving distance of Seattle and several smaller cities, so the Urchin Rocks intertidal area is heavily impacted by thousands of people per year. To minimize trampling, in the late 1990s a docent system and marked trail were established in the rocky intertidal zone. Visitors are encouraged to explore the intertidal but stay on the marked trail. The goal of the class research project was to assess what ecological impacts the trampling had on the Urchin Rocks intertidal zone and whether ecological diversity was being preserved there. The control site was on Northwest Island, a rocky island 1 km offshore in Rosario Bay, with a similar rocky intertidal zone oriented in the same direction that was only occasionally visited by kayakers. One belt transect of 20–25 m length was laid across each site from high intertidal to minus tide level by 50-m tape and divided up into 1-m^2 square quadrats. The intertidal height of each square meter quadrat centered along the transect was determined by laser level and referenced to the 0 tide line using NOAA tide tables. A 0.25-m^2 (0.5 × 0.5 m) PVC quadrat square, divided into a grid of 10-cm squares by stretched cords, was then laid down in each corner of the quadrat. Four squares were needed to mark each 1 m^2. A ceramic tile marked with the quadrat number was placed on the 50 cm mark of each meter just outside the 0.25-m^2 quadrat. The high-resolution Nikon digital camera was used to photograph each of the 0.25-m^2 quadrats within the square meter, with the index tile visible in the corner of each photograph. After the four 0.25-m^2 quadrats were photographed for each square meter, the algae cover was removed and the exposed invertebrates were photographed again in the same way (Figure 2). Laying out the belt transects, measuring the intertidal height of each quadrat, and photographing the quadrats took the two authors ~3 days per transect, timed to spring low tides. Obtaining this many optimal low tides required two 2-week spring tide cycles before the students could become involved in the project. These photographs were all then posted in the Dropbox online. Students also needed to become familiar with the species they would encounter in the photographs beforehand. After students became acquainted with the species involved, they were assigned to groups focused on different aspects of quantifying or analyzing the samples. One student group analyzed the percent algal cover of each quadrat by counting how many of 25 intersections within each of the four 0.25-m^2 quadrat photographs per 1-m^2 quadrat were covered by red, green, or brown algae, or a diatom mat. The second student group used the same method for determining percent barnacle cover per quadrat, plus counted the number of barnacles of each species present. Some 1-m^2 quadrats had tens of thousands of barnacles, so the students used a random number table to select 10-cm squares within the quadrat to count barnacles within until a minimum of 1000 barnacles were counted in the square meter. This count was multiplied by the total number of squares in the square meter divided by the number counted to estimate total barnacle cover in the full square meter quadrat. A third student group identified and counted the other invertebrates present within each quadrat and calculated species richness. Notes and supplemental close-up photographs taken during photography of the quadrats called this group's attention to hard-to-see species. Students used Excel and R to plot their results and R to statistically compare high versus low intertidal and trampled versus control sites. Each student group collaboratively wrote a detailed report of their

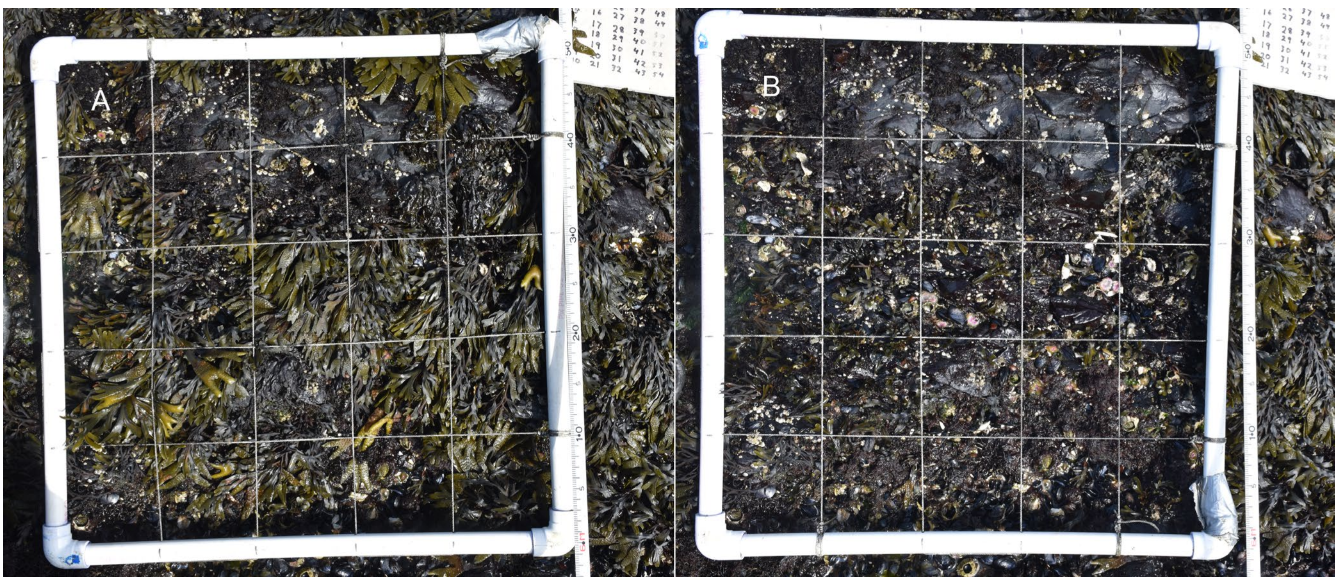

FIGURE 2 **A.** View of a 0.25-m^2 quadrat before removing the algae. The cords are 10 cm apart. The transect tape is on the right and the orienting tile, which is always placed in the center of the square meter, is visible in the top-right corner, indicating that this photograph is of the bottom-left (southwest) quadrant of the full quadrat. **B.** View of the same quadrat after removing the algae in order to count barnacles and invertebrates. Original photographs were of high resolution so that students could zoom in to inspect the quadrat closely

research, including statistical comparison of the high and low intertidal communities at the two locations. The report was formatted as a standard scientific paper. Each group also made a formal virtual 15-min oral presentation of their research and answered questions at the end, following the format used at scientific meetings.

3 | RESULTS AND DISCUSSION

3.1 | Materials for the course

Having each student obtain their own dichotomous key (Kozloff, 1996) worked well. Almost all the students quickly learned the logic of keying and became proficient at it. This proficiency was reinforced periodically by examinations during the quarter, which included having students produce their own dichotomous key to groups they had recently studied. In addition, as part of the final practical examination, the instructor scheduled a private virtual meeting with each student during which the student presented three species of their choice (two of which were in one of their specialty groups) which they had successfully keyed. They led the instructor step by step through the key, using photographs taken from earlier class keying sessions, to illustrate how they knew what the species was. After they finished, the instructor presented them with live samples of two additional species to key. Students were informed before this session that they should choose species with varying levels of keying difficulty but that if they could not select one with some keying challenges the instructor would choose for them, and may also present species they had not yet encountered. Almost all students were successful at this exercise and expressed strong satisfaction at their newly acquired keying skills.

Some students were not able to obtain the printed key at the beginning of the quarter and initially used the key present in the *Invertebrates of the Salish Sea* (Cowles, 2021) website instead. The website key is the same as Kozloff's key (1996) with updates and modifications, and is used on the website by permission of University of Washington Press. However, it does not fully substitute for the printed key because it only contains keys to the species that are included in the website.

3.2 | Field experiences for students

The live, 4G-connected field sessions early in the course were effective in stimulating student interest and dialog in the course. We recognized during the experiences, however, that some elements could detract from the experience if not handled carefully. Viewing a field trip through a screen is not the same as being there. Activities such as donning boots, long searches through the eelgrass, or long stretches between finding new species may retain interest of students experiencing the trip on site, but can lead to screen fatigue and drifting interest by remote students. Live, real-time trips such as these should be carefully planned in advance to minimize lag times and keep interest strong. One must also check reception ahead of time if the site is around cliffs or ravines to be sure cell reception remains strong.

The remote field trips using a GoPro camera also worked well. The chest mount was most useful because it offered a direct view of objects being held, while also producing a more stable scene while walking. The chest mount also allowed visual checking of the settings to verify that recording was taking place and in the correct mode. The head mount was more flexible in surveying an area since it allowed surveying a scene from side to side without turning one's whole body, but required more practice to avoid distracting, jerky output. Some of this instability may be improved by using gimbals or a more advanced GoPro model. To provide the ambiance of the different intertidal settings, short time-lapse sequences were taken of the access to and movements around the site. Time-lapse speeds of 2× and 3× on the GoPro camera worked well for these sequences, whereas speeds of 5× and faster were too jerky and hard to watch. Examinations of specific habitats and species along with any narration were conducted at normal speed.

The resolution and quality of the GoPro videos was reasonable for general surveys but needed supplementation by the digital SLR when viewing objects closely. The GoPro is not designed to provide macro views of objects and was not used for views closer than about 25 cm. Even at further distances the GoPro sometimes focused on the intertidal background even when an object was held prominently centered in front of it so some sequences had to be discarded. In these cases, and for all close-ups, the still photographs taken by the SLR and accessory lenses were very useful.

The light, two-chambered mop bucket was an invaluable aid which could be carried miles into remote locations and provided a dry and stable platform for camera work. The SLR camera, extra lenses, reference materials, and collecting permits were carried in a day pack when long distances were traversed but kept in the dry side of the bucket when they were being frequently accessed.

An initial precaution when planning video sequences was to make sure all segments from different sources, such as the Panopto-generated introduction and the GoPro sequences, were filmed at the same resolution. Also, it may be wise to use a lower resolution than the equipment is capable of, especially if time and equipment are limited. Our initial videos were taken at 1080p resolution, but we discovered that these full high-definition (HD) resolution images were difficult to work with. They quickly produced files multiple gigabytes in size which caused multiple software failures in the simple editing programs we tried. The Microsoft Video Editor program that was eventually used was more stable than several other inexpensive editors available online but sometimes had long pauses when working with large videos. Also, even after a video sequence was laid out in the editor, an HD video of 15-min length could take 3 hr of computer processing time to render and upload to Panopto.com (a resource for online posting of videos for education or business purposes) for viewing by the students. Dropping our video resolution to 720p HD resolution when filming produced videos that were still sharp but less than half the size and caused fewer software issues. Use of high-end computers with fast processing speed and high-end video processing software, if available, may help with this. Be careful to use standard formats with the GoPro camera and test them beforehand because the camera is capable of several video formats that our video editing programs could not read.

The initial planning for the course, which took place before the COVID-19 pandemic, included scheduling to have as many minus tides as possible incorporated within the course hours. Once the change to online took place, however, this turned out to be a disadvantage for all field experiences except the early ones which were conducted live. If a field experience is to be recorded beforehand and shared later, it is better for the instructor to visit and film at the field site during a time when other formal class activities are not taking place back at the classroom. Alternatively, online prerecorded lectures or other activities can be scheduled during the times when the instructor needs to be in the field taking advantage of the minus tides.

3.3 | Detailed, close-up examination of invertebrates

The video workstation for working interactively with students while introducing them to the local invertebrate species exceeded expectations, with a few caveats. It was easy to switch back and forth for different views via the OBS software and allowed excellent, real-time dialog with the whole class about the invertebrates being examined. Students quickly overcame their hesitation and engaged in discussion about the focal species and it was easy to have any student lead the group in the dichotomous keying. After the first few sessions it was easier to have participants use their own copies of Kozloff's (1996) key rather than focusing on the copy at the workstation unless the instructor was pointing out some feature in the key. Having students consult their own keys also allowed the instructor to keep the workstation focus on views of the species being keyed rather than switching back and forth between the specimen and the key. Nonetheless, having a separate camera which could be dedicated to viewing the key was frequently a useful feature.

The first version of the workstation used autofocus webcams. However, it appears that webcams are usually optimized to focus on faces and do not do well focusing on books or on nearby invertebrates. Several models of autofocus webcams that we tried frequently shifted focus in and out instead of remaining focused on the invertebrate or on Kozloff's key (1996). They also tended to adjust exposure back and forth or leave parts of the specimen overexposed. Once we switched to the Vcloo HD manual-focus webcam, we were able to maintain steady focus on the object of interest even at a range closer than 10 cm and had less problem with overexposure as well. Exposures were often better when the light source was reflected off a diffuse white screen than when it was focused directly on the specimen. Having a movable light source was also important to prevent strong reflection from the water or wet animal surfaces.

The close-up focus of the webcams coupled with the even closer focus of the dissecting microscope typically covered the range of magnifications needed for examining the specimens. However, the closest effective field of view using the webcams was about an order of magnitude greater than the widest field of view of the microscope. To bridge this gap photographs were occasionally made with a simple USB mini-microscope camera and provided to the students after the session.

The HDMI video capture card we initially used, the Epiphan AV.io 4 K ESP1360 HDMI to USB 4 K Capture Card, is quite expensive ($499 on Amazon [amazon.com] as of January 24, 2020). Midway through the class a VABSCE HDMI to USB Video Audio Capture Card was found to also work, presenting a nearly 30-fold cheaper option ($17.59 on Amazon as of November 29, 2020). The VABSCE video capture card appears to be a generic USB card, with many apparently identical video capture cards appearing on Amazon simultaneously with brand names such as GOODAN, MavisLink, Auscoumer, BlueAVS, and Tengchi, any of which would likely work for this function. Together, the only items we needed to purchase for this system beyond standard laboratory equipment were the capture card and webcams, which totaled only $165 at the time of manuscript submission.

3.4 | Research project

In the research project, the students applied the skills they had learned in class to contribute directly to solving a real problem faced by the Deception Pass State Park. The study revealed that, although algal cover increased similarly at lower tide levels at both Urchin Rocks and Northwest Island, most lower algae at Urchin Rocks (the trampled site) were diatom mats rather than macroalgae. Barnacles were more abundant at Urchin Rocks than at Northwest Island, especially near the trail, but were primarily small individuals. Many invertebrates were found at both sites but species richness was about 50% higher at Northwest Island, and Urchin Rocks had few predatory snails, mussels, and large anemones. Seastars were present at Urchin Rocks but at lower abundance and in lower zones than at untrampled Northwest Island. A tentative comparison was also made to a similar study of the same transects conducted in 2002 as part of a marine class taught by one of the authors (D. Cowles), but the comparison had to be mainly limited to algal and barnacle cover. The other invertebrates and their diversity could not be fairly compared to the earlier study because the earlier study had been *in situ*, with students carefully picking through the algae to find motile invertebrates. The 2020 photograph study, by contrast, required removing the algae before photographing the invertebrates so many of the most motile invertebrates, especially crustaceans, ran away before the photograph was taken.

With prior coaching, practice, and critiquing of rough drafts, all student groups were successful in their data analysis and presentation of their reports. After the course was finished, the instructor carried out a more detailed analysis and presented a technical report on the project to Deception Pass State Park.

The articles in this special issue of *Invertebrate Biology* provide many innovative ideas of how to teach about invertebrates under different circumstances. Some articles, such as Lindsay (2021) and Nova et al., 2021) provide ideas for situations in which the students retain some access to campus or to specialized equipment. Others, such as Eugene et al. (2021), Middlebrooks and Salewski (2021), and Schulze et al. (2021) work well for situations in which students cannot access campus but retain some access to the field sites being studied. Verdes et al. (2021), The Virtual Field Project (https://thevirtualfield.org/), and this article present ways that students without access to campus, to specialized equipment, or to the field sites can nonetheless experience important aspects of research and field studies. Specifically, the methods presented here were successful in providing remote, online students with field experiences, with detailed study of a wide variety of local macroinvertebrates, and with participation as a collaborative team in a genuine research project. Nearly all the students did well in the course, and by the end at least one senior had decided to apply to graduate school with an interest in marine studies. Students generally prefer actual field experiences over virtual ones (Spicer & Stratford, 2001), and hopefully none of us will ever again need to teach a field-oriented marine invertebrates course in this way. If we do, however, some techniques we tried here will we hope provide useful starting points for bringing active, hands-on marine studies and research to future remote students, regardless of the circumstances that prevent meeting in-person.

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REFERENCES

Brusca, R. C., Shuster, S. M., & Moore, W. (2016). *Invertebrates* (3rd ed.). Sinauer Associates.

Cowles, D. (2021). *Invertebrates of the Salish Sea*. Retrieved January 25, 2021, from https://inverts.wallawalla.edu/

Eugene, A., Burke, R. L., & Williams, J. D. (2021). Of mudsnails, terrapins, and flukes: Use of trematodes as a field-based participatory science project in parasitology research. *Invertebrate Biology*, *140*, in press.

Kozloff, E. N. (1996). *Marine invertebrates of the Pacific Northwest*. University of Washington Press.

Kozloff, E. N. (2000). *Seashore life of the northern Pacific coast: An illustrated guide to northern California, Oregon, Washington, and British Columbia*. University of Washington Press.

Lindsay, S. (2021). Integrating microscopy, art, and humanities to power STEAM learning in biology. *Invertebrate Biology*, *140*, in press.

Middlebrooks, M. L., & Salewski, E. (2021). Self-guided field trips take invertebrate zoology students away from their screens and into the environment for hands on learning. *Invertebrate Biology*, *140*, in press.

Nova, M., Sanchez, N., Gutierrez, M., Canovas, R. G., Pardos, F., Trigo, D., & Diaz Cosin, D. (2021). The Lab InA box: A take-away practical for invertebrate (non-arthropods) biology course online. *Invertebrate Biology*, *140*, in press.

Pennisi, E. (2020). Courses bring field sites and labs to the small screen. *Science*, *369*, 239–240. https://doi.org/10.1126/science.369.6501.239

Schulze, A., Hajduk, M. M., Hannon, M. C., & Hubbard, E. A. (2021). Invertebrate film festival: Science, creativity, and flexibility in a virtual teaching environment. *Invertebrate Biology*, *140*, in press.

Spicer, J. I., & Stratford, J. (2001). Student perceptions of a virtual field trip to replace a real field trip. *Journal of Computer Assisted Learning*, *17*, 345–354. https://doi.org/10.1046/j.0266-4909.2001.00191.x.

Verdes, A., Navarro, C., & Alvarez-Campos, P. (2021). Mobile learning applications to improve invertebrate zoology online teaching. *Invertebrate Biology*, *140*, in press.

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