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Teaching entomology online: Challenges, benefits and examples of effective hands-on activities

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Abstract

Traditionally, teaching entomology to undergraduate students has relied upon conventional laboratory-style practical classes—where students are taught how to collect, identify and curate specimens, as well as understand the form and function of key insect groups using unsophisticated but specialised equipment. Entomology educators had to promptly adapt their methods of teaching in response to the COVID-19 pandemic, which forced the online delivery of courses that often largely relied on face-to-face teaching. This imposed limitations on what could be effectively taught outside of a lab setting, although in many cases these were mitigated through online technology that introduced opportunities to support entomology students. Here, we assess the learning objectives of a range of current entomology courses taught namely in Australia, Aotearoa New Zealand, the United States and Europe. We found that practical hands-on skills, such as identification and curation, and understanding of insect morphology and diversity, often taught via lab activities, are common across many courses. Given the perceived tension between current moves to online educational delivery and these common practical learning objectives in entomology, we present a series of four activities that can be taught via online or distance approaches. These exercises can be used to effectively teach key concepts and skills such as identification, form and function and ecological research skills related to insects. We also discuss some challenges and benefits associated with the online delivery of entomology courses, emphasising a number of equity and accessibility benefits that online approaches might deliver.

KEYWORDS
distance learning, entomology, insect science, remote instruction, student engagement, university education

INTRODUCTION

Entomology has long been a cornerstone of biological sciences education (Osborn 1911). Traditionally, in-class general entomology courses, particularly the lab components, were designed to provide students with hands-on experience observing, identifying, dissecting and curating insects; these objectives have changed little over the last 100 years (Osborn 1911). Practical research activities in classes also regularly focus on the behaviour, physiology and ecology of insects, giving students both general research skills and entomology-specific training. However, the shift towards online education, accelerated by recent global events, introduces challenges to achieving these learning objectives through a virtual classroom.

In 2020, teachers and learners across the entire global educational sector, from primary to tertiary, were thrust into a dramatic shift. The COVID-19 pandemic forced students to learn at home, away from their teachers and peers, largely in front of a screen (Shim & Lee 2020). At the same time, educators had to rapidly adjust their teaching activities, approaches, strategies, assessments and ways of interacting with and engaging their students—whether they were first graders or postgraduates (Hebert et al. 2022; Ramlo 2021). The initial hurdles were those of delivery—how could they effectively teach these skills and concepts without face-to-face engagement?

At this time, teachers leaned heavily on the online technologies that had been successfully employed by distance education providers for more than a decade (Kentnor 2015). Online learning platforms and recently developed video-conferencing tools, such as Zoom and Microsoft Teams, allowed teachers and students to engage virtually, but many educators discovered a dramatic drop in student engagement (Salta et al. 2022; Walker & Koralesky 2021), making it clear that the challenges of teaching online were not simply technological.

The impact and effectiveness of online teaching has previously been evaluated (e.g., Ozdamli & Karagozlu 2022; Selvaraj et al. 2021) and has led to more informed suggestions on how to deliver material online (Sharma & Saini 2024). However, teachers at the early stages of the pandemic reported that students had reduced attendance, participation and willingness to ask questions compared with in-person courses (Walker & Koralesky 2021; Wyatt 2021), whether the delivery online was synchronous or asynchronous. In addition, studies have reported that the shift to online teaching resulted in reduced feelings of connection between students and faculty, and among students and their peers (Hollister et al. 2022; Marler et al. 2021).

For entomology instructors, as well as for other teachers of subjects within the natural sciences, there are additional challenges that are either unique or appear particularly relevant. The major focus on practical and 'hands-on' skills in many natural science disciplines has meant that teaching those skills online requires major changes to activities, assessments and expectations of students (Davis & Pinedo 2021; Delgado, Bhark, & Donahue 2021; Tripepi 2022). In an emergency teaching context, such as those associated with the beginning of the pandemic, practical activities often consisted of students watching prerecorded videos, or live-streamed footage of instructors completing practical tasks, rather than doing them themselves. This immediate shift to an online delivery format has been reported as a poor substitute to the face-to-face practical teaching students were accustomed to (Means & Neisler 2020; Pagoto et al. 2021) but in an emergency context, at short notice, was the best or only option available to many teachers. The utility of online video approaches also depends on the skills that are considered a primary learning objective of the course. For example, if students are expected to be proficient in their usage of a microscope or in running a PCR, watching someone else do this is unlikely to give them competence in the skill. However, observing and collecting data on animal behaviour might be effectively taught using real-time footage of wild animals.

Most entomology courses include a lab or practical component as a part of their curriculum because it is considered crucial for providing hands-on experiences that allow students to directly observe and work with insect specimens. These experiences are beneficial for developing skills in insect taxonomy, morphology, ecology and physiology. Exercises done in labs can also help students develop skills such as microscopic examination, specimen preparation and data collection, which can be difficult to achieve in lecture-only based courses. Labs may also provide the opportunity to take students into the field to directly observe and collect insects, building important field-based skills, which are associated with positive learning outcomes and higher order thinking (Dresner et al. 2014). Lastly, labs and other practical exercises provide an interactive learning environment that can not only enhance student understanding and retention of complex concepts presented in the lectures, but promote collaborative learning and increased opportunities for social interactions (Chim et al. 2024).

Here, we summarise historical and current learning objectives of in-class entomology courses, particularly the lab components, and discuss how these can be met through innovative activities that can be done in an online setting. A number of recent approaches and many institutions utilise online activities to achieve entomology learning objectives (Cosme, Turchen, & Guedes 2020; Mech et al. 2022). By utilising technological advancements and pedagogical strategies, we discuss a number of activities and provide ways to ensure that entomology students can attain the same level of understanding and practical skills in an online format as they would in a traditional classroom setting.

METHODS

Learning objectives of various undergraduate entomology courses were determined by conducting online searches for 'undergraduate entomology courses' and 'general entomology syllabus'. Each syllabus or course outline was then evaluated and the learning 'objectives' or 'outcomes' were compiled and divided into common themes. We recorded whether the university provided a more in-depth entomology programme—for example, offering a minor and/or major in entomology—or was limited to a standalone general introduction to entomology course. This allowed us to understand how commonplace it was to have an insect collection as part of the course assessment. Universities offering entomology programmes often had dedicated taxonomy or collection-based courses where students would complete an insect collection instead, or as well as, in a more foundational entomology course.

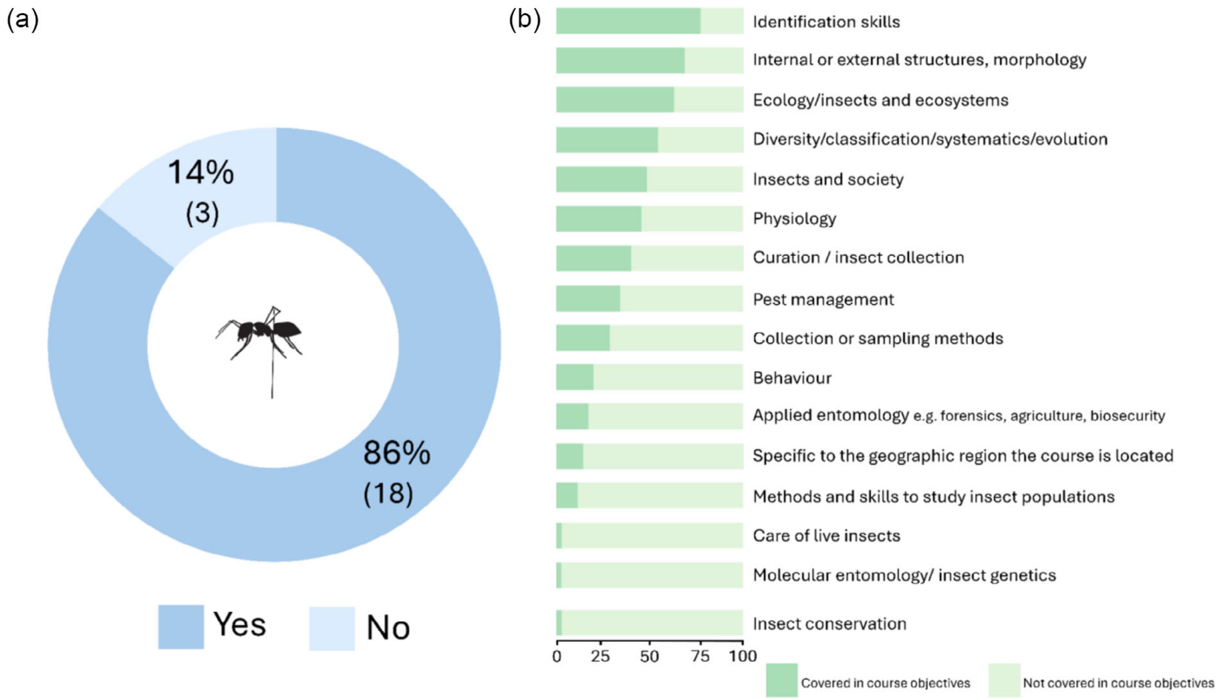

FIGURE 1 (a) Percentage of general entomology courses with an insect collection as a part of assessment or practical learning component. Note that courses from universities that have an extensive undergraduate entomology programme are omitted as an insect collection is likely captured in alternative courses. Numbers in brackets indicate the number of courses for each option; total number of courses reviewed = 21; for two courses, this information was unclear as thus was not included. (b) The proportion of courses that addressed different core learning objectives that were identified by evaluating available online syllabi and course outlines ($n = 35$) for general (foundational) entomology undergraduate courses. Note that this includes general entomology courses that contribute to more extensive entomology programmes.

RESULTS/CASE STUDIES

Primary learning objectives

In total, we evaluated 38 course syllabi or outlines associated with general entomology courses taught at different universities worldwide. Of these, 15 were associated with a more significant entomology programme (e.g., those institutes that offered a minor or major in entomology). For undergraduate courses at universities that did not have larger entomology programmes, we found that 86% required an insect collection as part of the course assessment or practical learning component (Figure 1a). Learning 'objectives' or 'outcomes' were available for 35 of the 38 courses evaluated. These primarily were focused on insect (1) identification skills, (2) morphology, (3) ecology, (4) diversity and (5) physiology (Figure 1b).

In order to demonstrate how these more common learning objectives can be met within the curricula of online or distance-learning entomology courses, we present below four case studies. These represent practical activities that we (the authors) have collectively developed and/or used in our own experience teaching entomology to undergraduate students namely in Australia, Aotearoa New Zealand and the United States. Each of the four activities can be conducted by students at home with online support from teaching staff. They are also 'hands-on' activities, giving the students a suite of entomology and general research skills, and meet the learning objectives we found to be most common in our assessment of current entomology curricula (Figure 1b). Our courses are subject to formal student evaluations, in which students can also provide written feedback on their experiences, including their impressions of the online activities we implemented. In addition, learning objectives/outcomes can be evaluated by graded assignments. However, the use of these data in a publication such as this requires preapproval through the relevant institutional review boards or ethics committees. Given that these activities were introduced during the pandemic, at short notice, preapproval was not possible. As such, we are limited to providing our personal experiences as entomology educators for these activities and our overall impressions of the student experience.

Insect morphology/internal and external structures

Understanding insect form and function provides students with foundational knowledge important to many aspects of entomology as well as broader biological sciences. Knowledge of insect morphology and physiology can provide insights into insect adaptations, such as the raptorial forelegs of praying mantises for capturing prey, or the elongated proboscis of moths for collecting nectar. In addition, it can inform students about ecological roles, evolution and diversity, as well as pest control strategies. For example, understanding the digestive system of pests can help in the development of targeted insecticides. Understanding the external and internal structures of insects is typically learned by doing dissections in in-person labs, but these can be taught in an online class as well.

Activity 1—Fairleigh Dickinson University, United States of America

Due to the pandemic of COVID-19, all courses were taught online at Fairleigh Dickinson University in fall 2020, including the undergraduate Entomology lecture and lab course. As this was known in advance, students were provided with an 'entomology bag' which contained basic entomology equipment, including dissection tools. Each dissection tool kit contained a scalpel, a bottle of ethanol, forceps, dissection scissors and as a large lubber grasshopper of the genus *Romalae* stored in a large glass vial filled with a 90% ethanol solution. These grasshoppers, native to the Southern United States, are commonly used for insect dissection, as they are large and easily available in the United States from commercial suppliers. The migratory locust, *Locusta migratoria*, would also be suitable. Other easily available insects could also be used, such as those provided as feed by a local pet store. Similar to previous in-person dissections, this activity was graded on the accuracy of proper identification of given morphological traits. However, unlike in fall 2020, students were also graded on accurate graphic depiction when they submitted drawings.

Before dissection day, students were asked to familiarise themselves with the dissection tool kit, their lecture notes, as well as the grasshopper in the vial (e.g., what are the names of the dissection tools? what is the sex of the grasshopper?). In addition, students were asked to find a tray as well as a quiet place to conduct their insect dissection, making sure their dissection does not cause additional stress in an already stressful time at home. To create a sense of community on dissection day via Zoom, students shared their family's reactions regarding the upcoming dissection, along with the place of their grasshopper's dissection, which included kitchen tables, basement floors, and their personal rooms.

After a short introduction on how to use the available tools, students were asked to open the vial and observe the external anatomy of the insect, which had been discussed in the preceding lectures. First, they had to identify several morphological characteristics of their specimen including its head, thorax, abdomen, wings, legs, compound eyes, antennae, ocelli and based on the terminalia, its sex. After that, they were asked to take pictures of their specimen (with their cell phone) and label its parts accordingly with an arrow (all students were familiar with how to write/label a picture taken with their phone; other technological problems in this course were often solved by student interactions via the Zoom chatroom). In previous years, during in-person labs, students would submit drawings as part of their assessment. However, given the overall stress these students experienced throughout the pandemic and the additional challenges of doing dissections in their homes, it appeared more appropriate to use photographs instead of drawings. Taking pictures also allowed for a more even pacing among the participating students, as students tend to vary in their abilities to draw efficiently. Thus, no student felt rushed to conduct the dissections, which allowed them to work as one large team and to finish each section at almost the same time. However, if this activity were to be run online regularly, drawings could be incorporated, if that were preferred and could be submitted online as photos.

After external anatomy, we proceeded to investigate the head with all its components, including mouthparts, sutures and compound eyes. After labelling the head, students continued to dissect mouthparts, which again were documented as a labelled picture (Figure 2). We similarly investigated the thorax, legs and abdomen. Each student was asked to paste each of the labelled pictures into a document and submit it online. After the dissections, students cleaned their tools in bathroom sinks ('My mom told me I cannot use the kitchen sink for that!') and discarded the grasshopper remains.

Throughout the activity, students were very engaged, supported each other by explaining how to dissect certain parts, shared pictures with each other and exhibited a great sense of humour throughout—something which is often encountered during in-person dissections. To

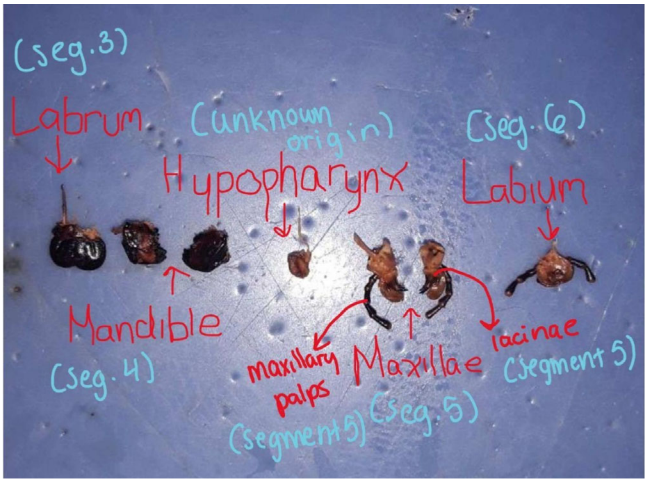

FIGURE 2 Example of an in-home dissected lubber grasshopper head. Students had to submit a picture taken with their mobile phone, find and label the required parts and submit it as an assignment.

increase a sense of belonging and engagement, one might consider adding polls, which can now be easily done with Zoom. For example, asking students how many males and females they have could lead to a discussion on sex ratios, or students could be asked functional questions for relevant body parts. Overall, this activity successfully achieved our learning objectives related to students developing an understanding of the external and internal anatomy of insects.

Insect morphology and identification

Insect morphology is a foundational component of entomology education as it provides the knowledge necessary for identifying and classifying insects, understanding evolutionary relationships (e.g., insect taxonomy and systematics) and comprehending how insects interact with their environment, find food, reproduce and defend themselves. For example, the fossorial forelegs of the mole cricket allow them to navigate underground and the larger mandibles on male stag beetles are for battles for resources or mates. Insect morphology is typically learned through a combination of lectures that may introduce terminology with associated images and labs that typically involve curated specimens that best show the morphological traits being taught. Knowledge of insect morphology has historically been assessed through submitted collections that have students determining insect identifications using dichotomous keys based on morphological characteristics.

Activity 2—University of Maine, United States of America

This activity was created for an undergraduate Introduction to Applied Entomology course, which was taught online during the fall semester of 2020. New technologies, such as iNaturalist, changed the landscape of learning and meant that students no longer needed to learn insect morphology to identify the insects they submitted to get a good grade on a collection—they just needed to take good enough pictures for a phone app to identify it for them. Paying attention to the small details in insect morphology is lost when using apps, which means that many of the soft skills that were formally gained by doing an insect collection, such as patience, organisation, time management, critical thinking and communication, are also lost. To meet these other learning objectives and gain these soft skills, a homework assignment was developed that was an updated version of the traditional insect collection and can be easily implemented in an online format.

Students were asked to complete a digital insect collection where they not only took and submitted pictures of the specimens they collected, but they had to include a label and point out three morphological characteristics (for each family) that were necessary to get to the correct ID, with arrows pointing to those characteristics. This ensured that even if they used an app to reach the family-level identification, they had to show that they understood *why* it was in that family. All students had smartphones that allowed them to take the images, but the assignment could be completed using a hand-held camera if needed. The assignment required fewer specimens than a traditional collection (20 unique adults vs. 50), but a diversity requirement of at least six different orders was still needed. Students were provided with basic instructions on how to trap and collect insects (e.g., how to make a kill jar or pitfall trap or utilise outdoor lights) and then additional supplies, such as aerial nets, were available for students to pick up if they lived close to campus. However, nets were not required because the assignment was designed to be accomplished with basic household items. Given that the assignment only requires images, it could be completed without killing the insects. To slow down insect movement (in order to get good images) without harming them, they can be chilled in a refrigerator (15–60 min depending on size and species) and/or placed on an ice pack. Insects will gradually become active again as they warm up and can be released once the images have been collected.

A student's final 'collection' was submitted as a PowerPoint slide show, where the first slide was an image of the specimen on the label and their justification for the order-level identification. An additional slide with cropped/zoomed-in images followed it with numbered arrows pointing to the diagnostic traits for identification that corresponded to a text box listing the numbered justifications. Students also had to indicate which feeding guild they believed the insect to be in, as a way to think about the habitat it was collected in and its potential ecological niche. Example slides were provided to the students (Figure 3) along with tips for how to make a successful 'collection' and instructions on how to use PowerPoint. Because in-class labs provide ample time for students to work on their collections with the instructor available for assistance, a couple 'drop in' lab days were offered via zoom for students to ask questions, share images and get feedback on their collection before submission. This activity achieves learning objectives related to insect identification and morphology and was well received by the students.

Insect ecology and behaviour

Insects play vital roles in ecosystems, such as through pollination, predation, decomposition, and serving as a food source for other animals. Learning about insect ecology helps students understand these roles and the broader impact insects have on ecosystem health and stability. Observing insect behaviour provides insight into how

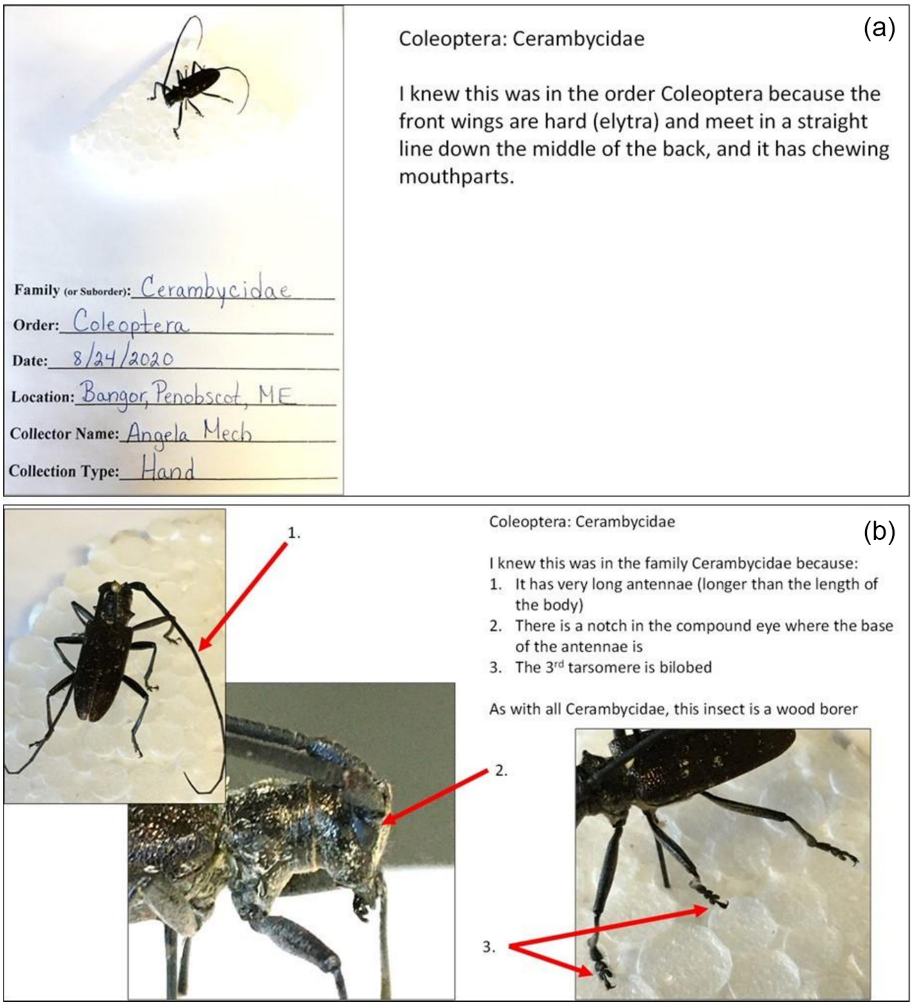

FIGURE 3 Example slides for a digital insect collection. The first slide (a) includes the identification label, and the second slide (b) includes the list of traits and the corresponding arrows pointing to those morphological traits that justify the identification.

insects interact with their environment, other organisms, and each other and equips students with practical skills on collecting data.

Activity 3—University of New England, Australia

This activity, developed for undergraduate entomology students at the University of New England, a leader in distance education for over 70 years, has been designed for students to complete at home and is associated with part of their assessment.

As ants are generally a ubiquitous taxon, occurring in most urban and natural environments, students can choose to conduct this exercise at a locality that is convenient for them, such as their backyard or in a local park or green space. For this activity, students can quickly and easily sample their local ant community using different bait types they are likely to have readily available at their home (e.g., honey, sugar, jam, tuna, pet food or other meat) and develop a simple ecological question to answer using this straightforward baiting setup.

Prior to commencing the activity, students are given a short online presentation to introduce the exercise and a range of related ecological and entomological concepts such as intraspecific and interspecific competition, spatial and temporal partitioning, community assemblage, and food preference and recruitment behaviour of social insects. Based on what concept they find most interesting, students can then develop a question to answer using their baiting setup. For instance, students may decide to test which bait types are most attractive to different ant species by offering various baits (carbohydrate-, protein- or lipid-based) in small stations (a card with a pea-sized offering of each bait type, either in pairs or arrays and replicated several times; Figure 4). They can then observe the bait stations at intervals over the course of 1–3 h to record the numbers of ants/species feeding on the different baits. Alternatively, they may want to explore potential temporal niche partitioning in the ant

FIGURE 4 Example of bait stations set up to examine insect behaviour. Ant communities were sampled using common household items: peanut butter, honey and pet food.

community by offering baits at different times of the day (e.g., early morning, midday, late afternoon and evening) to see if the dominant ant species at bait stations differs in response to time of day.

Although students are unlikely able to accurately identify different ants to species in the absence of a microscope, photographs uploaded to iNaturalist may help with identification or alternatively, they can designate ants to morphospecies. Students may also address some of their questions by observing behavioural and morphological traits (e.g., trail forming ability, body size and number of individuals), which they can then correlate to their observations to understand whether different traits are associated with competitive advantages, or a species' ability to monopolise a resource. As part of the assessment, students share their setup and findings (with a short photo diary) to a dedicated online forum, which encourages engagement and broadens their learning by sharing their research questions and experiences. This activity could be extended by guiding students through appropriate statistical analysis of their results and further assessed as an online research presentation and/or a formal research report formatted as a journal article. Overall, this type of research project addresses learning objectives associated with insect ecology along with broader outcomes based around conducting research projects and writing and presenting results.

Insect diversity, identification and collection

Experiencing the vast diversity of insects first-hand provides students with a comprehensive view of their biological richness and complexity. Learning to make sense of this diversity via the development of identification skills fosters an appreciation of insects but also trains students with skills that are essential for employability in jobs related to conservation, ecosystem health, and pest management.

Activity 4—University of Auckland, Aotearoa New Zealand

This activity was taught online in 2020 amidst the first wave of the COVID-19 pandemic and during the first period when Aotearoa New Zealand was in lockdown. In this course, undergraduate entomology students were asked to create an insect collection of 30 curated specimens. Prior to 2020, when the class was in person, there were many opportunities for interactions between staff and students (and among students), and a strong atmosphere of collaboration and engagement in the collecting, presenting and identification of insects. When students were stuck at home, engagement and interaction suffered. This activity was introduced as a fun way to get students involved in learning the skills necessary for insect identification while maintaining communication and engagement with one another and staff.

Students were asked to search the windows of their homes after dark when internal or external lights were on and attracting moths from surrounding gardens or local environments. For any moths found, students took photos, usually with their mobile phones (sometimes with higher quality cameras), and posted those photos online on the course discussion board in a dedicated channel within the course's online learning platform (Figure 5). At this point, other students in the class would attempt to identify the moth species in each photo and suggest an ID in a thread attached to the image. Additional students could then agree with the proposed ID, or propose their own identification with reasons why they disagreed. Students were asked to submit at least 10 photographs and to attempt to identify moths from at least 10 photographs that others had submitted.

Within Aotearoa New Zealand, the moth fauna is relatively small (<2000 species) and very good online resources exist with high quality photos of all the most common larger Lepidopteran species. In addition, a copy of the book 'Which New Zealand Insect?' by Crowe (2002) was provided to each student—a large number of the most common species are depicted within. Therefore, it was possible to expect that for most moth species that students could photograph in suburban Auckland, they should be able to determine an identification. In other parts of the world with a relatively manageable moth fauna, similar resources may be available. If not, or if the diversity of the moth fauna is prohibitive, a particular family could become the focus, or a short guide to the most common moths could be developed. Alternatively, iNaturalist might provide a decent guide to the most encountered moths in a particular city or region.

FIGURE 5 Examples of photos taken and submitted by students and staff for the online moth identification activity at the University of Auckland. All moths were identifiable to species from these photos using the resources available to students.

We found that regardless of the accuracy of the initial identification provided for each image, the engagement and interaction that followed was seen to be just as important, if not more so, than the identification skills that students practiced. In 2020, a time when student engagement and interaction suffered, this activity led to 100% engagement with all students submitting photographs and identifying moths from others' submissions.

Alongside this activity, students also completed a standard insect collection from home. Students had received the collecting, pinning and labelling gear prior to lockdowns and so were still able to complete this assessment, but in a reduced form (15 species rather than 30). Demonstrations of setting and pinning were given online with recordings provided for asynchronous learning. In addition, online help sessions were provided via zoom to give students feedback on their progress. If a home-based insect collection is to be used as a standard part of an online or distance-based entomology course, collecting and pinning equipment could be posted to students or available for local students to collect from campus at the beginning of semester. Depending on the preference of staff, an insect collection could be used alongside or in place of an activity such as the moth identification activity described above, but the high degree of interaction and engagement among students may be harder to replicate with only an insect collection. However, given that a large number of entomology courses have an insect collection as a major assessment (see Figure 1a), we wish to emphasise that a collection can still be part of an online entomology course, providing the practical skills that achieve many learning objectives associated with insect identification, collection and curation.

DISCUSSION

Benefits of online entomology education

Despite the challenges faced during the COVID-19 pandemic and its period of emergency online teaching, many courses have continued to provide online learning options post-pandemic, including entomology courses. The drivers behind the decisions to continue with online learning are diverse, but several advantages are apparent: (a) increased equity owing to more flexible timeframes of asynchronous learning and the ability to learn from home, (b) the utilisation of technologies that students are already adept and comfortable with and (c) the demonstration that science can be done at home, in local environments and away from laboratories.

Educational programmes that offer distance-based or online options for study allow more equitable access to education (Molinar, Huang, & Narui 2024). The flexibility of asynchronous learning means that students can engage with course material at times that fit with their other responsibilities. For example, online learning may level the playing field for those who have traditionally experienced obstacles to education such as older working adults and those with parenting or other caring responsibilities (Stone 2022). Asynchronous online learning can also improve access for those who live large distances from campus, who have socioeconomic constraints, including the need to work full time or juggle multiple jobs while studying, and for students with physical or cognitive disabilities (Molinar, Huang, & Narui 2024). It is however also important to be aware of inequities that can be exacerbated by online learning, owing to varied access to required technologies or adequate learning environments (Farley & Burbules 2022).

Challenges of online education

The online learning environment also brings with it, a range of challenges. These include (a) technological constraints and significant effort required to modify teaching and learning activities to the online environment, (b) the need to monitor and stimulate engagement in a dispersed and sometimes silent student body and (c) potential equity concerns over access to and familiarity with the required technologies of online learning. Our shared experiences across multiple institutions have largely found these challenges and constraints relatively straightforward to manage. All of the activities described above took a solid amount of planning, development and modification prior to their implementation, but not more so than any face-to-face practical activities we had previously developed. Student engagement required careful monitoring, but the work that students submitted online and the engagement in online discussions allows clear identification of students who are not engaging, and the potential to follow up with direct communication and encouragement. For example, the moth identification activity at the University of Auckland, had a slow start with only a small proportion of students engaging. However, clear communications with the whole class and individual students about the benefits and requirements of engaging, coupled with the fun atmosphere of collegiality in the discussion forum brought about a 100% level of engagement in the activity. On the other hand, synchronous lab activities like the grasshopper dissection did require less prompting when compared with in-person labs, possibly because students could not fully rely on a lab partner. However, distributing the equipment at the beginning of the semester proved to be a challenge at the height of the pandemic and required substantial coordination between student and staff, as well as among students helping each other out, if they were unable to come to campus for the timed pickup. Equitable access to the necessary technologies was assessed early in phases of the pandemic lockdown and addressed if needed. For example, at the University of Auckland, devices and prepaid ‘internet sticks’ (portable modems) were provided and delivered to some students who did not have home access to a device or internet. Overall, while we acknowledge important and sometimes significant challenges to converting and delivering online entomology teaching, we all found in our shared experience, that they could be overcome.

A need for insect collections?

The shift to online teaching during the pandemic also opened the door to discussions regarding the reevaluation of the traditional curriculum associated with a general entomology course. For example, the tried and true method for assessing a student’s ability to identify insects has been for them to submit a curated insect collection—this has been the preferred assessment for over 100 years (Osborn 1911). Previously, identifications for insect collections were made using dichotomous keys based on morphological characteristics, meaning that the correct identification showed a level of skill that the student had. With the increasing popularity of tools that can help users identify organisms with a single picture (e.g., iNaturalist), an insect collection may no longer be an assessment of a student’s ability to successfully work their way through an identification key, but an assessment of their ability to take good pictures. If this is the case, and digital identification tools will continue to improve and become more commonplace, we ought to reevaluate collections as a form of assessment for learning objectives associated with insect identifications and instead utilise them for other course goals.

There is still much value in student insect collections. The curatorial skills learned when handling and preparing insects for a collection are irreplaceable. For example, the handling of specimens allows for a better understanding of insect anatomy and classification, improves fine-motor skills and gives students the opportunity to interact with insects, which would not be possible if only pictures are taken. In addition, the steps required to make an insect collection can result in a reduction of fear or disgust regarding insects that students may have had prior to the course, often due to their limited exposure to the natural world. Although tasking students to collect and curate an insect collection still clearly has merit, and we describe how this could be utilised in conjunction with other activities (see Activity 4), instructors could consider making it an abbreviated activity that meets the objectives just mentioned as well as to assess curation skills (rather than identification skills).

Other reasons to consider altering the larger traditional final collection include ethics and conservation. For example, students may have a keen interest in learning more about insects, but feel morally challenged to collect and kill potentially hundreds of specimens to create a suitable collection for a satisfactory grade. Submitting a photographic collection (see Activity 2) or using a scavenger hunt activity using iNaturalist (e.g., Mech et al. 2022) could be implemented to reduce this concern. This approach would also make entomology courses accessible to neurodivergent students and those with limited fine-motor skills. Lastly, given the dramatic decline of insect populations throughout the world (Wagner et al. 2021), it is becoming difficult to justify annual collections of thousands of insects for each entomology course. This can be especially problematic if students are unintentionally collecting insects that are considered threatened or endangered. However, student collections also present an opportunity to establish or continue natural biodiversity records for local insect fauna, providing a potential means of generating valuable temporal data that could otherwise be difficult to obtain. Many universities have natural history collections to which specimens can be accessioned, meaning student work can contribute in perpetuity to our understanding of biodiversity. That said, alternatives to extensive student collections could be considered. For example, instead of focusing on a wide range of insects to gain curation skills, instructors might consider asking students to collect easily identifiable invasive species or other abundant groups.

The future of online entomology education

Looking into the future, it is reasonable to assume that the delivery of higher education will adapt in response to meet the needs of society and technological advances. The responses of insects to different global change scenarios are poorly understood, but understanding fundamental insect biology is going to be necessary in light of global food security and human health. Entomology education thus is as important now as ever, and with an increasingly online society, developing curricula that can be delivered remotely is an inevitable reality. Although a shift to more online teaching may initially be challenging, there are many opportunities for students to engage and interact with the insect fauna wherever they are based. Global biodiversity databases and repositories can be integrated into online teaching activities that encourage the engagement of students beyond the local fauna and target learning objectives related to systematics, morphology and ecology.

We provide a number of activities that can be implemented in online entomology courses that meet the traditional learning objectives of in-person classes while also adding equity, socioeconomic, ethical and conservation benefits. These offer just a few examples of how students can conduct at-home activities with minimal specialised equipment to develop fundamental skills in entomology. It is our hope that this will inspire other entomology educators to further develop and share additional practical activities that meet core learning objectives and equip future cohorts of entomologists.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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REFERENCES

Chim, H.Q., Dolmans, D.H., Oude Egbrink, M.G. & Savelberg, H.H. (2024) Experiences of face-to-face and online collaborative learning tutorials: A qualitative community of inquiry approach. *Education and Information Technologies*, 29(14), 18561–18589.

Cosme, L., Jr., Turchen, L.M. & Guedes, R.N.C. (2020) Insect world: game-based learning as a strategy for teaching entomology. *The American Biology Teacher*, 82(4), 210–215.

Crowe, A. (2002) *Which New Zealand insect?* Penguin Books.

Davis, C.P. & Pinedo, T. (2021) The challenges of teaching anatomy and physiology laboratory online in the time of COVID-19. *Journal of Microbiology & Biology Education*. 22(1), Available from: https://doi.org/10.1128/jmbe.v22i1.2605

Delgado, T., Bhark, S.-J. & Donahue, J. (2021) Pandemic teaching: creating and teaching cell biology labs online during COVID-19. *Biochemistry and Molecular Biology Education*, 49(1), 32–37. Available from: https://doi.org/10.1002/bmb.21482

Dresner, M., de Riveria, C., Fuccillo, K.K. & Change, H. (2014) Improving higher-order thinking and knowledge retention in environmental science teaching. *Bioscience*, 64(1), 40–48. Available from: https://doi.org/10.1093/biosci/bit005

Farley, I.A. & Burbules, N.C. (2022) Online education viewed through an equity lens: promoting engagement and success for all learners. *Review of Education*, 10(3), e3367. Available from: https://doi.org/10.1002/rev3.3367

Hebert, E., Wood, R., Jeon, K. & Reena, I. (2022) Faculty making the emergency online transition during the COVID-19 pandemic: effects of prior online teaching experience and strategies used to learn to teach online (special edition 2022). *Higher Learning Research Communications*, 12, 59–76. Available from: https://doi.org/10.18870/hlrc.v12i0.1322

Hollister, B., Nair, P., Hill-Lindsay, S. & Chukoskie, L. (2022) Engagement and online learning: student attitudes and behavior during COVID-19. *Frontiers in Education*, 7, 851019. Available from: https://doi.org/10.3389/feduc.2022.851019

Kentnor, H.E. (2015) Distance education and the evolution of online learning in the United States. *Curriculum & Teaching Dialogue*, 17.

Marler, E.K., Bruce, M.J., Abaoud, A., Henrichsen, C., Suksatan, W., Homvisetvongsa, S., et al. (2021) The impact of COVID-19 on university students' academic motivation, social connection, and psychological well-being. *Scholarship of Teaching and Learning in Psychology*, 10(3), 320–330. Available from: https://doi.org/10.1037/stl0000294

Means, B., Neisler, J. & with Langer Research Associates. (2020) *Suddenly online: a national survey of undergraduates during the COVID-19 pandemic*. San Mateo, CA: Digital Promise.

Mech, A., Rosenberger, D., Fanning, P., Riggins, J.J., Aukema, B. & Hartshorn, J. (2022) There's an app for that: teaching entomology in the online age. *Natural Sciences Education*, 51(2), e20081.

Molinar, G.A., Huang, K. & Narui, M. (2024) The three E's of pedagogical effectiveness for online asynchronous learning: engagement, equitability, and examinations. In: *Unlocking learning potential with universal design in online learning environments*. IGI Global, pp. 126–145 https://doi.org/10.4018/979-8-3693-1269-8.ch007

Osborn, H. (1911) The present methods of teaching entomology. *Journal of Economic Entomology*, 4(1), 67–74. Available from: https://doi.org/10.1093/jee/4.1.67

Ozdamli, F. & Karagozlu, D. (2022) Online education during the pandemic: a systematic literature review. *International Journal of Emerging Technologies in Learning (iJET)*, 17(16), 167–193. Available from: https://doi.org/10.3991/ijet.v17i16.32287

Pagoto, S., Lewis, K.A., Groshon, L., Palmer, L., Waring, M.E., Workman, D., et al. (2021) STEM undergraduates' perspectives of instructor and university responses to the COVID-19 pandemic in spring 2020. *PLoS ONE*, 16(8), e0256213. Available from: https://doi.org/10.1371/journal.pone.0256213

Ramlo, S. (2021) The coronavirus and higher education: faculty viewpoints about universities moving online during a worldwide pandemic. *Innovative Higher Education*, 46(3), 241–259. Available from: https://doi.org/10.1007/s10755-020-09532-8

Salta, K., Paschalidou, K., Tsetseri, M. & Koulougliotis, D. (2022) 2022. Shift from a traditional to a distance learning environment during the COVID-19 pandemic. *Science & Education*, 31(1), 93–122. Available from: https://doi.org/10.1007/s11191-021-00234-x

Selvaraj, A., Radhin, V., Ka, N., Benson, N. & Mathew, A.J. (2021) Effect of pandemic based online education on teaching and learning system. *International Journal of Educational Development*, 85, 102444. Available from: https://doi.org/10.1016/j.ijedudev.2021.102444

Sharma, S. & Saini, J.R. (2024) Understanding the impact of online teaching on students' learning and performance: a post-pandemic analysis. *Interactive Learning Environments*, 32(9), 5089–5105. Available from: https://doi.org/10.1080/10494820.2023.2209787

Shim, T.E. & Lee, S.Y. (2020) College students' experience of emergency remote teaching due to COVID-19. *Children and Youth Services Review*, 119, 105578. Available from: https://doi.org/10.1016/j.childyouth.2020.105578

Stone, C. (2022) From the margins to the mainstream: the online learning rethink and its implications for enhancing student equity. *Australasian Journal of Educational Technology*, 38(6), 139–149. Available from: https://doi.org/10.14742/ajet.8136

Tripepi, M. (2022) Microbiology laboratory simulations: from a last-minute resource during the Covid-19 pandemic to a valuable learning tool to retain—a semester microbiology laboratory curriculum that uses Labster as prelaboratory activity. *Journal of Microbiology & Biology Education*, 23(1), e00269-21. Available from: https://doi.org/10.1128/jmbe.00269-21

Wagner, D.L., Grames, E.M., Forister, M.L., Berenbaum, M.R. & Stopak, D. (2021) Insect decline in the Anthropocene: death by a thousand cuts. *Proceedings of the National Academy of Sciences*, 118(2), e2023989118.

Walker, K.A. & Koralesky, L.E. (2021) Student and instructor perceptions of engagement after the repaid online transition of teaching due to COVID-19. *Natural Sciences Education*, 50(1), e20038. Available from: https://doi.org/10.1002/nse2.20038

Wyatt, B. (2021) Insights into student participation in a soil physics course during COVID-19 emergency online learning. *Natural Sciences Education*, 50(1), e20036. Available from: https://doi.org/10.1002/nse2.20036

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