Lessons learned from organizing and teaching virtual phylogenetics workshops

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Abstract

In 2020 and 2021, the COVID-19 pandemic led to an abrupt overhaul of many academic practices, including the transition of scientific events, such as workshops, to a fully virtual format. We describe our experiences organizing and teaching online-only statistical phylogenetics workshops and the lessons we learned along the way. We found that online workshops present some specific challenges, but format choices and rigorous planning can alleviate many of the concerns typically associated with a virtual medium. In addition, online workshops have unique advantages such as the flexibility they offer to participants and instructors and their accessibility to non-traditional and underprivileged audiences. We hope that our experience will encourage workshop organizers to consider online-only events as an integral part of potential training opportunities rather than simply a stop-gap solution for unusual circumstances. In addition, we hope to prompt broader discussion about integrating aspects of online workshops into traditional in-person courses to make training opportunities more flexible and inclusive.

1 Introduction

Phylogenetic analysis of biological data often requires a high level of expertise not only in the statistical framework underlying applied models and approaches, but also in the specific software implementations and their wide range of available options. This, in turn, leads to a high barrier to entry for researchers interested in using phylogenetic programs and packages. As a result, developer teams spend considerable effort creating materials and opportunities for new users to learn how to use complex software tools so that they can apply phylogenetic methods to their own data. Workshops are perhaps the most common mechanism used by scientific software developers to expand their user base and provide expert training to empiricists. These events are an opportunity for scientists to directly interact with the developers and obtain deeper insight into the software. At the same time, these short courses also enable developers to learn more about the needs of users working with empirical data. Moreover, many software developers gain valuable experience in teaching and pedagogy as instructors in hands-on workshops. Participants and instructors recognize the value these experiences can have in improving software, building the knowledge base of scientists at all levels, and creating opportunities for networking that often lead to fruitful collaborations.

This work focuses on workshops dedicated to RevBayes (Höhna et al., 2016), a broadly used Bayesian phylogenetic software tool that enables inference of evolutionary parameters under complex, hierarchical models. The RevBayes developer team provides extensive, publicly available documentation and user tutorials for a wide range of analyses and applications via the project website[1]. Since 2013, RevBayes has been featured in over 40

[1]The RevBayes Project Website: http://revbayes.com

workshops[2], either as standalone events, or part of more general courses, such as the Woods Hole Workshop on Molecular Evolution[3] and the Bodega Bay Workshop in Applied Phylogenetics[4].

In early 2020, the onset of the COVID-19 pandemic required instructors to cancel in-person workshops and innovate ways to deliver training materials to practitioners (Lowenthal et al., 2020; Prasad et al., 2020; Andrade de Oliveira et al., 2021). The majority of workshop participants are early career researchers, many of whom attend workshops to deliberately meet planned professional goals, such as attaining skills to complete dissertation research or seeking out postdoctoral research opportunities. Thus, a year without workshop opportunities may be a significant setback to many scientists early in their training. Rather than canceling all of our planned workshops, the RevBayes team opted to transition to fully online events, and we have recently completed two so-called "Stay-at-Home RevBayes" workshops. Our experiences and the feedback from participants have been very positive, and we believe that this format has unique advantages and a few challenges when compared to traditional, in-person workshops.

This paper describes our experience organizing the Stay-at-Home RevBayes online courses, explains the rationale behind some of our choices, and provides suggestions for future workshop organizers. Our goal is to share our experience organizing and teaching a technical software workshop in an online format, as well as demonstrate some of the advantages and challenges of such a course. In particular, we believe that online-only events remain relevant beyond the specific context of the pandemic, and that they should not be dismissed in a rush to get back to previous practices. Furthermore, as we transition back to planning in-person activities, we hope to stimulate discussions among the developers of phylogenetic methods on new approaches for enhancing workshop experiences and inclusivity, while creating broadly accessible learning opportunities.

2 The Stay-at-Home RevBayes Workshops

The primary goal of all RevBayes workshops is to provide participants with a solid foundation in the theory and application of phylogenetic methods—as well as practical knowledge of the software implementation—so that they will be able to analyze their own data using complex models and Bayesian statistics. To achieve this goal, the RevBayes team has developed a rich library of tutorials[5] providing extensive details about various phylogenetic analyses. When presenting this material in an in-person setting, we are often constrained by time and only able to spend a couple of hours on each topic during a five- to seven-day workshop. However, a virtual course offers the opportunity to spread the material over several weeks, enabling participants to work at their own pace and review what they have learned before moving on to the next tutorial. Thus, the format of the Stay-at-Home RevBayes Workshops included a mix of synchronous meetings (using the Zoom video-conference service), detailed tutorials and pre-recorded videos, and real-time discussions via Slack (an online instant messaging platform), all spread out over five to six weeks (we discuss the communication tools used in more detail in Sections 2.2 and 3.3). An overview of the core workshop components is provided in Box 1.

[2]RevBayes Workshops: http://revbayes.com/workshops
[3]Workshop on Molecular Evolution, Woods Hole, MA, USA: https://molevolworkshop.github.io
[4]Workshop in Applied Phylogenetics, Bodega Bay, CA USA: http://treethinkers.org
[5]RevBayes Tutorial Library: http://revbayes.com/tutorials

Box 1: Overview of the main components of the Stay-at-Home RevBayes Workshops

- *Course website*[ab]: The workshop description, application link, schedule, and materials are provided on a public website for each course.
- *Introductory synchronous session (Zoom)*: Participants and instructors introduce themselves, then instructors give an orientation on the workshop format and procedures, offer an overview of RevBayes and the Rev language, and check that all participants succeeded in installing the required software.
- *Introductory lectures*: Participants work through previously published videos providing background on the theory of Bayesian phylogenetics.
- *Asynchronous completion of RevBayes tutorials*: Participants work at their own pace to learn a curated set of methods and analyses in RevBayes (Fig. 1). Each lesson includes:
  - *Detailed online tutorial*: Each online tutorial provides the theory and background for a specific model or statistical method and a step-by-step explanation of how the corresponding analysis is performed in RevBayes.
  - *Video guide*: Each online tutorial links to a series of videos (hosted on YouTube) created by a RevBayes instructor walking the viewer through each section of the lesson and providing additional details.
- *Communication*: Instructors are available to answer participants' questions and engage in group discussions via the course messaging tool (Slack) and regular office hours (on Zoom).
- *Final group synchronous session (Zoom)*: Participants and instructors discuss the course materials, common issues faced during the workshop, and future directions for new methods or applications in Bayesian phylogenetics.
- *One-on-one meetings*: Each participant is paired with an instructor to meet via Zoom and discuss the participant's plan for applying RevBayes to their own data.

[a]Stay-at-Home RevBayes Workshop Summer 2020: http://revbayes.com/workshops/online2020.html
[b]Stay-at-Home RevBayes Workshop Spring 2021: http://revbayes.com/workshops/online2021.html

2.1 Workshop Content

We created a syllabus that included four introductory lectures and eight detailed tutorials. At the start of the workshop, participants learned about the course format, timeline, and content in a synchronous meeting. Additionally, during the first synchronous session, we included a background lecture on RevBayes and the Rev language. Clearly outlining the structure, tools, and course expectations early helps build participant trust and comfort (Zydney et al., 2020), which is key when in an online format or using new tools. It was important to include lectures on basic probability theory and Bayesian phylogenetics—as background knowledge on these topics is required to correctly assess models and inference output in RevBayes—and thus it is fortunate that this material was already available online. In 2018, Paul Lewis recorded a series of lectures entitled "Phylogenetics 101" (or Primer on Phylogenetics)[6] for *Phyloseminar*, an online seminar on phylogenetics topics created by Frederick Matsen in 2009[7]. These lectures begin with topics as fundamental as the definition of conditional probability, and, by building upon that foundation, culminate in the construction of complex phylogenetic models and the assessment of their statistical properties. For the RevBayes virtual workshop, these lectures provided participants with an accessible introduction to (or review of) the core theory in Bayesian phylogenetics.

After completing the introductory material and installing RevBayes, the workshop participants were assigned a series of tutorials. The lessons began with an introduction to Markov chain Monte Carlo (MCMC) in RevBayes and then increased in complexity to include analyses of datasets combining fossil and extant taxa (Gavryushkina

[6]Primer on Phylogenetics (YouTube Playlist): https://www.youtube.com/playlist?list=PLztACvN0g42vSxiQ4tM0sQTddMx-V4OLE
[7]Phyloseminar: http://phyloseminar.org

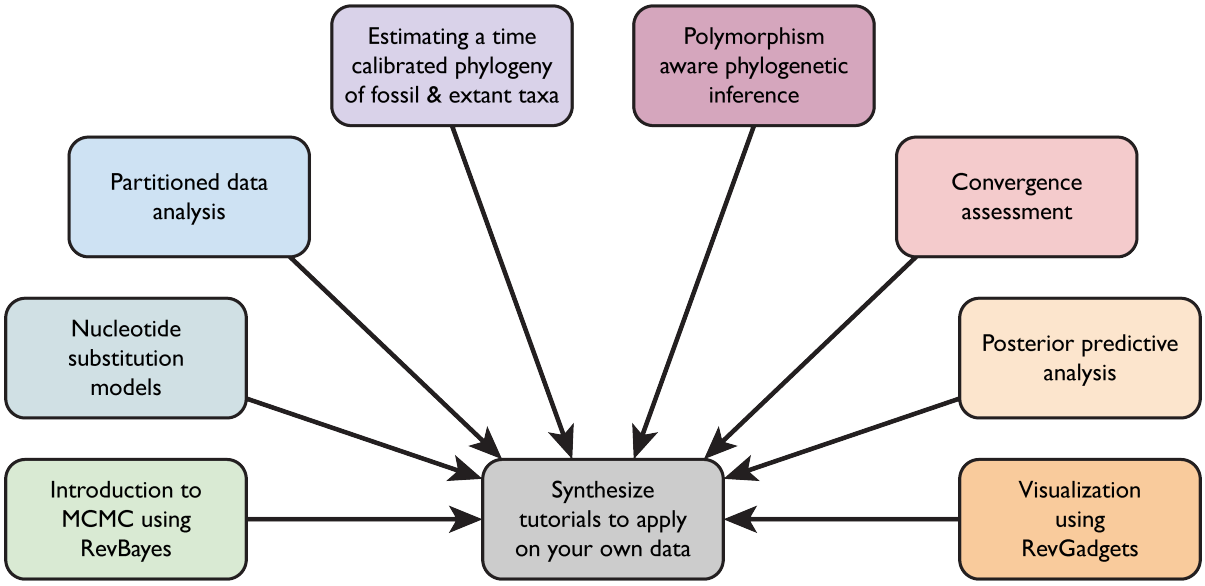

Figure 1: The Stay-at-Home RevBayes Workshop focused on eight core topics, each with a detailed tutorial and accompanying video guide. The goal of the course is to provide enough time for participants to complete the tutorials while considering how the methods will be applicable to their own data and research questions.

et al., 2017; Barido-Sottani et al., 2020), polymorphism aware phylogenetic methods (De Maio et al., 2013, 2015; Borges et al., 2019), and posterior predictive analysis (Höhna et al., 2018) (Fig. 1). For each tutorial, we created a video guide (hosted on YouTube) that walked through each step and concept. The videos were time-stamped or recorded in segments so that video links could be placed at each section heading of the online tutorials. For example, in the "Introduction to Posterior Prediction" tutorial[8], each section links to a YouTube video where the tutorial author describes the contents of that section. The video guides emulate how we often walk participants through a tutorial during an in-person workshop, with features like "pause" and "replay" that are not really possible in a synchronous class. During these demonstrations, we are often able to insert practical tips and other topics that might not fit naturally into the written tutorial and thus enhance the content. For instance, we can remind the audience of the difference between stochastic (*i.e.,* estimated) and constant (*i.e.,* fixed) parameters, which use a different syntax in the Rev language and can be confusing to inexperienced users. The extensive details included in each tutorial may also be somewhat intimidating to new users and the video guides serve as a way to ease learners into the material. Participants were provided with a suggested timeline for completing each component of the course. After completing the set of tutorials curated for the online course, workshop participants were then given time to explore the other tutorials on the RevBayes site or to start analyzing their own data.

The core content created for the Stay-at-Home RevBayes Workshops is accessible to anyone at any time. Thus, researchers are able to work through the tutorials and videos even if they are not part of a workshop. Nevertheless, registering and committing to a course—online or in-person—provides a timeline and structure, as well as access to experts in the field for guidance, and these facilitate completion of learning goals.

[8]Introduction to Posterior Prediction: http://revbayes.com/tutorials/intro_posterior_prediction

2.2 Workshop Interactions

Phylogenetics workshops offer participants the unique opportunity to learn methods and software directly from experts and developers. Moreover, these kinds of courses enable researchers from diverse fields and backgrounds to build connections that can often lead to exciting new collaborations. While online workshops do allow attendees to interact via text chats, such spontaneous interactions may not come as easily in a virtual medium—particularly across multiple time zones—as they would when meeting in person. Traditional activities amenable to, or even fostering, spontaneous discussions, such as breaks or meals, must be rethought and deliberately executed. We therefore used a variety of activities and tools (described in detail in this section) to provide participants direct access to instructors and create ways to engage and network with one another.

Prior to the start of the workshop, all participants and instructors were asked to create an introduction slide that was then shown during our first synchronous session (Fig. 2). All synchronous meetings were held on Zoom[9] and the introductory session provided space for participants and instructors to get to know one another. We used break-out rooms in Zoom to hold small group discussions to enable more casual conversations among participants and instructors. These interactions were also included to help reduce participants' hesitancy to ask questions or request help during the course.

The first synchronous meeting provided a detailed overview of the workshop format and introduced participants to our primary communication tool: Slack[10]. The workshop Slack space included a separate channel for each tutorial, as well as channels for participants to discuss general questions on phylogenetics and Bayesian theory, technical issues (*e.g.,* software installation problems), and the RevBayes interpreted language. Importantly, Slack offered a private communication platform that helped participants feel more comfortable asking questions and a mechanism for sharing links to synchronous Zoom meetings and other course materials. In addition, after the conclusion of each workshop, the associated Slack space remained open for several months, providing the opportunity for participants to refer back to previous answers and discussions, as well as ask follow-up questions.

While the participants worked through the material on their own time, we held regular "office hours" via Zoom (each scheduled for one hour), where they were invited to raise issues and ask questions about the workshop content. In the first edition of the workshop, these meetings were held every week. In the second workshop, synchronous sessions were mirrored because of less time-zone overlap, thus office hours were reduced to every two weeks to avoid overloading instructors.

At the conclusion of the multi-week Stay-at-Home RevBayes course, we held a final synchronous session to address remaining questions about the tutorials and discuss RevBayes and Bayesian phylogenetic inference in general. In the first edition of the workshop, this final session was held over several days. Based on feedback from the participants, this session was reduced to two hours in the second workshop.

We then arranged a one-on-one meeting between each participant and an instructor selected based on the participant's specific interests and dataset. The one-on-one meetings allowed participants to troubleshoot analyses applied to their own data under the guidance of a workshop instructor and collaborate to devise creative

[9]Zoom: https://zoom.us
[10]Slack: https://slack.com

Figure 2: An example of an introduction slide by workshop instructor Carrie Tribble. All instructors and course participants used the same slide template. In the first meeting on Zoom, everyone was able to introduce themselves using their slide.

solutions to unique biological problems. Both participants and instructors found these meetings to be one of the most valuable interactions in the workshop.

In summary, we held scheduled sessions and optional office hours on Zoom and created a Slack space for communication throughout the duration of the course. Additionally, each participant met in a one-on-one meeting with an instructor at the end of the workshop. We believe that all of these elements have important and non-overlapping roles. In our experience, questions raised on the Slack forum tended to be shorter and more narrowly focused on the workshop material, such as technical issues or specific analysis choices in the tutorials. Synchronous sessions attracted broader, more open-ended questions and provided an opportunity for instructors to discuss general guidelines, best practices, or exciting future directions for methods development. Finally, the one-on-one meetings ensured that all participants left the workshop with actionable advice on how to apply the teachings on their own datasets, even if they did not feel comfortable raising questions in front of the whole group.

2.3 Flipping the Workshop Format

In our experience, the intense schedule of most in-person workshops is very tiring for both instructors and participants, making it difficult for some participants to complete all the activities and tutorials. Even when all activities are completed, an extremely heavy schedule can lead to lower understanding and long-term retention of important concepts. Since online workshops are not constrained by the physical presence of participants at the venue, it was easier to extend the workshop schedule to run over several weeks and develop material amenable to a flipped-workshop format.

A flipped-classroom format (King, 1993; Lage et al., 2000; Nahar et al., 2019)—where lectures and tutorials are pre-recorded and synchronous sessions can be used for questions and discussion—was an optimal approach for several reasons. First, it is widely acknowledged that online meetings require more focus and are more

tiring than in-person meetings (leading to so-called "Zoom fatigue"; Bailenson, 2021). Therefore, we limited synchronous sessions to material that could not be covered in other ways. In addition, recording video tutorials and lectures creates a bank of teaching materials that can easily be reused for future workshops, whether virtual or in-person, and made freely accessible online to both participants and non-participants. This ensures that time and effort invested by the instructors has a lasting impact beyond the participants of the current workshop, making it much easier to organize subsequent events, even if the original instructors are unavailable. Finally, a flipped format allows participants to make their own choices about the proposed material, spending more time on topics they find relevant, interesting, or challenging and skipping topics they have already mastered or that do not apply to their research. In turn, this means that instructors are free to offer a wider range of topics, since they need not be relevant to all participants.

Since the flipped format used synchronous meetings for discussion, we encouraged participants to form study groups and work through the material together, much like what might happen at a traditional in-person workshop; however, this rarely happened in our experience. It is possible that such groups connected through other communication channels that were not visible to us, or that participants simply preferred to work through the material with their own local colleagues, whose research interests are closer to their own. This lack of group work likely also reflects limitations intrinsic to online-only, asynchronous communication. Online events may thus be less likely to foster close relationships between participants, although we could not assess whether this impacted the learning process.

Participant engagement can take three forms: learner-to-learner, learner-to-instructor, and learner-to-content; students value all three forms and broad engagement is critical for learning (Martin and Bolliger, 2018). In general, participant engagement during the Stay-at-Home RevBayes Workshops was somewhat varied. This manifested as a core group of learners active on open Slack channels and asking questions during synchronous meetings, a subset of participants communicating primarily via direct messages to instructors and in the one-on-one meeting, and a small number of participants who were unable to fully participate because of unexpected changes to their local circumstances. Aside from the last group, similar patterns happen in on-site workshops. Although we believe the online format was not hugely detrimental to engagement, an online format provides overall less opportunity for participation than an on-site workshop, making it vital that interactions are engaging and meaningful.

In order to remain flexible, we only required attendance at the first and last sessions. Participants were made aware of this requirement before the event and attendance was very good (only 2 or 3 participants were unable to join). While office hours were not mandatory, we saw consistent attendance from many of the participants: the usual participation was around 10 participants (out of 20) in the first workshop, and around 4 for each of the two sessions (out of 25) in the second workshop. Overall, we found that having a formal round of introductions at the start of the workshop, as well as encouraging everyone to keep their camera on if possible during synchronous sessions, helped both participants and instructors to engage in the event.

3 Practical Considerations When Organizing a Virtual Workshop

Although the logistics involved in organizing an online workshop are reduced compared to an on-site event, there are still some key elements that must be considered to ensure that a workshop is accessible and successful.

3.1 Time Zones

At first glance, online events seem extremely accessible no matter where in the world interested participants are located. However, the diversity of participants' and instructors' locations means that holding synchronous activities in an online setting requires working to identify times that work for everyone. Thus, paying careful attention to overlap among the participants' and instructors' time zones is critical for promoting communication and engagement.

Figure 3 shows the geographic distribution of the workshop participants and instructors. All the time zones are described in reference to Coordinated Universal Time (UTC). While the first iteration of the Stay-at-Home RevBayes Workshop attracted applications from all over the world, we restricted our participant selection to applicants residing in a specific time-zone range (from UTC-7 to UTC+3). Since most of the instructors also reside in those time zones, we were able to schedule synchronous meetings during a time that worked well for everyone involved. Because time zones prevented us from including a wider distribution of participants in the first course, the second iteration of the Stay-at-Home RevBayes Workshop specifically targeted applications from researchers based from UTC+4 to UTC+14 (including UTC-10).

In general, the set of time zones involved in the workshop will determine whether a synchronous session can accommodate everyone involved, or if replicate sessions must be offered at different times. For instance, it became clear early on that it would not be possible to find a single time for synchronous meetings during our workshop for participants in Asia and the Pacific, since our instructor team is based in Europe and North America. Thus, we held duplicate sessions that involved different combinations of instructors and participants. In order to ensure continuity across these duplicate sessions, we recorded the sessions or took notes to share the discussion with participants not in attendance.

Ultimately, confusion is difficult to avoid when holding events spanning time zones. To mitigate scheduling complications, we announced session times using UTC and provided links to online time-zone conversion services (*e.g.,* World Time Buddy[11]). Whether single or replicate sessions are chosen, announcing meeting times well in advance is critical, so that participants can plan their attendance around other commitments they may have. Additionally, it is also useful to send a notification about the synchronous session via Slack 30 minutes or an hour ahead of time to ensure that everyone is aware of the upcoming meeting, even if they accidentally miscalculated the time-zone adjustment.

[11] World Time Buddy: https://www.worldtimebuddy.com

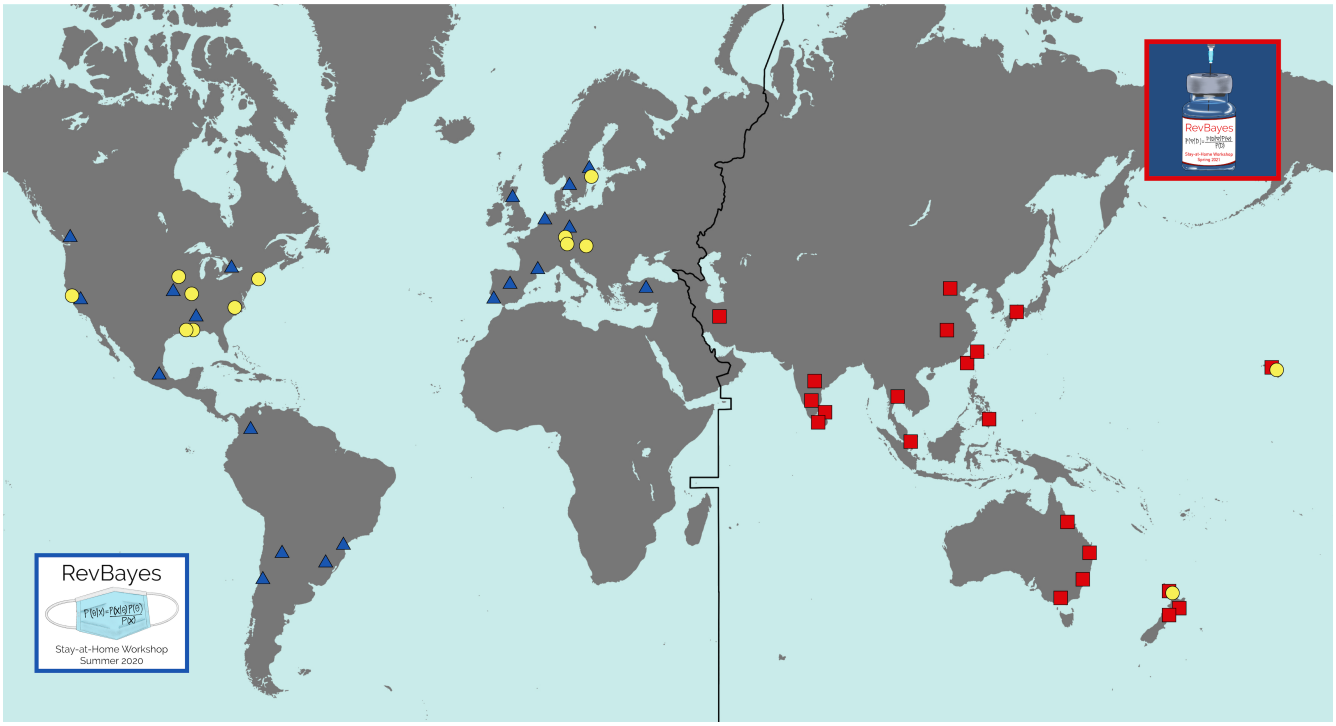

Figure 3: Locations of participants and instructors from both Stay-at-Home RevBayes Workshops. Instructors (yellow circles) primarily reside in the United States and Europe. Participants from the Summer 2020 workshop (blue triangles) were based in North America, South America, and Europe. Participants from the Spring 2021 workshop (red squares) attended from Asia, Australia, New Zealand, and Hawai'i. The black line dividing the map approximately delineates the boundary between UTC+3 and UTC+4 time zones, which determined the selection of participants in the two workshops. We designed logos (shown in the bottom-left and top-right corners) for each workshop that were inspired by current events.

3.2 Participant Recruitment and Selection

We created an application form using the online service Qualtrics[12]. Using this form, we asked applicants to rate their previous knowledge of Bayesian phylogenetics theory and applications and describe their learning goals, research questions, and datasets. Applicants were also required to indicate the time zone in which they would be residing during the workshop. Examples of the application form and participant confirmation form can be found in the Supplementary Materials.

We advertised the workshops using Twitter and the Evolution Directory[13]. For the first Stay-at-Home RevBayes Workshop, we advertised generally and this resulted in over 300 applications from all over the globe. When soliciting applications for the second virtual course, we contacted applicants from the first round who resided in our targeted time zones (UTC+4 to UTC+14) and encouraged them to reapply. Additionally, our advertisements specified that preference would be given to applicants from Asia and Pacific time zones and we received just over 100 applications in the second round. Applicants' responses indicated that they all felt comfortable with the prospect of participating in an online course, which likely contributed to the success of our workshops.

[12]Qualtrics: https://www.qualtrics.com
[13]The Evolution Directory: https://evol.mcmaster.ca/evoldir.html

When organizing an online or in-person workshop, the number of participants and instructors involved is an important consideration. Adding instructors to the team comes at a very low cost for an online event, and we found that having a broad team of instructors, both in terms of geographical location and expertise, was very helpful in spreading the amount of work and ensuring that instructors would be responsive to questions. Since there is similarly little additional cost in adding participants, it can be tempting to expand the number of participants well beyond the usual attendance of on-site workshops. However, we decided to keep the number of participants low (20-25 participants) to guarantee that synchronous sessions could remain interactive and personal. Thus, we chose to provide the materials created for this workshop freely online, to ensure that unselected applicants and future students could still benefit from our efforts.

Selecting just 20-25 participants from the large pools of applications was difficult. We created a list of selected participants that maximized the geographic and institutional representation within the time-zone range for each workshop. Our hope is that by working with researchers from a wide array of institutions, they will be equipped with the knowledge to communicate what they learn to their colleagues and local communities. Although we selected participants at a variety of career stages (graduate students, postdocs, professors), we primarily focused on early career scientists, since they are usually more closely involved in setting up and running analyses and would, in our opinion, benefit the most from getting hands-on experience with the software. Since our workshops focused on learning to apply phylogenetic methods in RevBayes, we also prioritized applicants with datasets ready (or soon-to-be ready) for analysis. Finally, although we provided the *Phyloseminar* lectures for background on phylogenetic theory, our workshop did not focus heavily on this topic. As such, we preferred applicants who already had some knowledge of phylogenetic methods. In general, the specific goals and aims of the workshop should guide the participant selection process.

3.3 Technical Tools

For many university researchers and educators, the sudden switch to virtual learning and collaboration in the spring of 2020 was essentially a crash course on various tools for online communication. Because of our experiences teaching and collaborating remotely, we felt equipped to host a virtual workshop with participants from all around the world. We were fortunate to have access to institutional licenses for Zoom and Qualtrics, otherwise we would have had to opt for alternative services or purchase licenses specifically for the course. The global shutdown in response to the spread of COVID-19 additionally made Zoom a familiar tool for all workshop participants. Thus, this was the ideal service for our synchronous meetings.

In addition to Zoom, we relied heavily on Slack for communication among instructors and participants during the course. This service enables real-time chat that can be organized by topic and is much better suited to a virtual workshop format than email. Our workshop Slack space was created using the free version, which limits access to only the 10,000 most recent messages. Thus, participants and instructors must be made aware that not all of the messages will be accessible and they may have to save discussions they would like to view again.

We used several other tools and services for generating content for these virtual workshops including Google Docs for organizing information and sharing documents, YouTube for hosting recorded videos, and Open Broad-

caster Software (OBS) for recording video tutorial guides. Open Broadcaster Software[14], in particular, is an extremely useful and flexible program for recording (and streaming) technical videos demonstrating software usage. This open-source and free tool is frequently used by video-game enthusiasts to live stream or record screencasts of game play, thus it is ideally suited for creating video tutorials on phylogenetic applications that require interacting with different platforms (*e.g.,* RevBayes, R, text editors, etc.).

3.4 Inclusivity and Accessibility

Online courses have the potential to enable participation from a much larger and diverse pool of scientists than most face-to-face workshops. However, it is important to develop a course timeline and format that enables flexibility and to carefully consider factors that may limit access to materials and communication. There are ways we can improve future virtual courses to make them more inclusive and accessible, however, we gained some key insights that are unique to the online-workshop format.

When recruiting participation from a global audience, it is important that efforts to make a workshop inclusive and accessible are mindful of the availability of required tools and software. This consideration is not limited to scientific software, but also any tool or service used for communication and coordination. For instance, Google services (Docs, Forms, YouTube) are blocked in China, requiring alternative tools or work-arounds to connect participants to materials hosted on Google sites. Announcing the required tools before the start of the workshop is essential so the participants can make the necessary arrangements or contact the organizers if there are issues.

There can be substantial monetary costs associated with in-person workshops that are significantly reduced in a virtual setting. These costs (*e.g.,* renting the venue and audio-visual equipment) are often, in turn, passed on to participants if the workshop organizers do not have access to funding or resources on site. Furthermore, an online format does not require travel and lodging (sometimes totaling several thousand dollars), reducing potentially prohibitive participant costs, particularly for researchers from countries with lower cost of living. Both Stay-at-Home RevBayes Workshops were offered free-of-charge because the instructor team is supported by grants and other sources of funding for which delivering workshops is a stated goal. Additionally, the size of the instructor team and online flipped-workshop format significantly reduced the workload, requiring a lower time commitment from instructors and organizers. For everyone involved, a virtual course additionally eliminates administrative and geographical burdens associated with traveling internationally (obtaining visas can be difficult or impossible depending on an individual's citizenship and the location of the workshop), making it much easier to reach scientists from regions where international travel is heavily restricted.

Ultimately, an online and flipped-format course can operate with much more scheduling flexibility than on-site workshops. Our choice to use a flipped-workshop format in combination with a limited number of synchronous sessions was designed to take advantage of this flexibility and allow both instructors and participants to easily combine workshop attendance and other professional or personal responsibilities. This created an opportunity to include both instructors and participants who might not have been able to leave at-home duties (*e.g.,* caregiving, teaching) for an in-person course. Because of this, our synchronous Zoom meetings occasionally welcomed cameos

[14]Open Broadcaster Software: https://obsproject.com

from small children and other family members.

When delivering content to people in their homes (or local offices or cafes) across multiple continents over several weeks, it should be expected that real-life issues will interfere and take some participants or instructors away from the course. For example, on August 10, 2020, during the first Stay-at-Home RevBayes Workshop, a severe thunderstorm (called a "derecho") hit the Midwestern United States. The storm swept through Iowa in the middle of one of the workshop's synchronous meetings and four workshop instructors lost power to their homes for over 72 hours. In other instances, participants faced unexpected changes to their work responsibilities, family emergencies, or pandemic-related effects in their regions. During our introductory sessions, we discussed the possibility of unplanned issues, letting the participants know that we would work to adapt to such interruptions and make sure all participants were able to meet their learning goals.

3.4.1 Workshop Code of Conduct

In recent years, workshop organizers and venues have worked to develop policies and procedures to ensure that in-person courses are safe and welcoming to all participants. It is critical that these efforts are not neglected for a virtual workshop. For the Stay-at-Home RevBayes courses, we developed a code of conduct[15] that provided a clear policy on harassment and discrimination (the code of conduct is also provided in the Supplementary Materials). This was adapted from the Safe Evolution[16] policies developed by the Society of Systematic Biologists, the American Society of Naturalists, and the Society for the Study of Evolution for virtual and in-person activities. This code applied to all interactions during the workshop, including synchronous sessions, but also the Slack forum as well as private messages between participants and/or instructors. Upon acceptance to the workshop, participants were required to agree to the policies stated in the code of conduct via the attendance confirmation form (see Supplementary Materials). Then, during our introductory meeting, we reintroduced the policies, discussed the procedures for reporting any discriminatory behavior or harassment, and stated that repeated violations of the code would lead to removal from the workshop. A clearly stated code of conduct communicates to participants that they will be treated respectfully during the workshop, creates a more inclusive culture (Foxx et al., 2019; Favaro et al., 2016), and helps to reduce participants' hesitancy to post questions or start discussions during our meetings or on Slack.

4 Perspectives

In total, we received over 400 applications for the Stay-at-Home RevBayes Workshops and it is clear that there is a world-wide demand for accessible training in phylogenetic methods. Assessing the overall success of workshops, whether online or on-site, is generally tricky, particularly since some benefits of the training may not be apparent to participants until they are more advanced in their research projects. However, feedback from our workshop participants (via a formal survey and informal comments during meetings and on Slack) indicated that many workshop attendees felt that they gained a deeper understanding of applications in Bayesian phylogenetics and

[15]RevBayes Virtual Workshop Code of Conduct: http://revbayes.com/workshops/code_of_conduct/virtual_coc
[16]Safe Evolution: https://www.evolutionmeetings.org/safe-evolution.html

RevBayes, and that they would recommend attending future editions of the virtual workshop to colleagues (see the example workshop feedback form in the Supplementary Materials). Furthermore, our instructor team also appreciated the increased flexibility and the lower intensity of the format. All of the instructors from the 2020 team were interested in teaching an online workshop in the future and all who were available returned for the second offering.

While we feel that many of the choices we made in organizing two virtual RevBayes workshops led to successful outcomes, we recognize that there are unique challenges associated with an online setting and several ways we can improve future courses. For example, we plan on expanding the bank of recorded materials to cover more topics so that we can meet the needs of a broader audience of researchers. It will additionally be important to ensure that the videos and tutorials are kept up-to-date as RevBayes is under continued development.

Another area of improvement is apparent from the map in Figure 3. Although we had participation from 24 different countries throughout the two workshops, there are distinct parts of the world that are not represented among our workshop participants. We must do more work to reach scientists residing in Africa, parts of Central and South America, and Asia, to ensure that residents of these regions interested in learning about RevBayes are connected to workshop opportunities. For instance, we need to broaden our approach to advertising future workshops by posting to mailing lists or communication platforms popular in these areas and by directly contacting local scientists and organizations. Moreover, our instructor team is primarily based in Europe and the US, reflecting the composition of the developer team involved in the RevBayes project. This ultimately created scheduling difficulties and limited synchronous interactions during the Asia/Pacific workshop. In the future, expanding the RevBayes developer community will improve these issues and may also help reach participants from currently underrepresented regions.

We also hope to improve on how we assess learning outcomes and facilitate participant engagement, which can be difficult for online courses. Providing a practical education and hands-on assistance is a common challenge for online teaching (Long et al., 2014; Nahar et al., 2019). In an in-person workshop, instructors and teaching assistants are able to walk around the room as participants are working through the material and assess progress or answer questions on the spot; this is not possible in an online format. However, it may be possible to encourage more engagement by actively following-up with participants, or implementing lightweight asynchronous follow-up activities such as journaling (Camfield et al., 2020) after each section of the material. Through Slack, instructors could lead discussions, checking that participants were successful with the activities and encouraging discussion about the analyses. Additionally, we could facilitate participant engagement by integrating more discussion questions into the tutorial activities and encouraging participants to report and interpret their analysis results.

Although we encouraged participants to work in groups, the format and geographic distribution likely prevented this from occurring. These types of groups regularly form at in-person workshops, aiding in both material comprehension and community building. It is possible that participants will be more receptive to forming groups if this is facilitated by the workshop's structure and instructor team. Thus, in the future, we are interested in developing ways to help participants form collaborations early on in the course. Lastly, as a result of increased online instruction, there are many innovative strategies and techniques, such as HyFlex learning or utilizing

cloud computing resources, that could be implemented in future workshops (see Harris et al., 2020; Lowenthal et al., 2020).

As vaccination efforts reach more and more parts of the globe, there is an understandable desire to return to the old "normal" and to put everything associated with the pandemic behind us, including online teaching. However, although in-person workshops offer opportunities for networking and interactions that are difficult to facilitate in an online setting, they also tend to select participants with specific characteristics: the ability to pay for the event and the travel expenses, the ability to travel internationally without a heavy administrative burden, and no medical needs or personal responsibilities requiring their presence at home. Online workshops can reach beyond these traditional audiences and offer training to more diverse populations of scientists with less access to such courses locally.

Online events also help limit carbon-emitting air travel and thus lower the contribution of our scientific community to the climate crisis (Jäckle, 2021; Sarabipour et al., 2021). A geographically dispersed audience for an in-person workshop leads to excessive carbon emissions from travel. Locally based workshops with an emphasis on land-based travel can have a lower environmental impact, but such events are limited to areas with a high concentration of researchers, creating inequality in access to training. Additionally, regional workshops may still require considerable air travel if instructors are not all based in the same area. Thus, online or hybrid workshops have the greatest potential to reduce the carbon footprint of phylogenetics workshops.

The complexity and difficulty of statistical phylogenetics software continues to increase and workshops will remain an extremely important mechanism for researchers to learn how to use analysis tools. In this paper, we have focused on the distinct benefits and challenges of virtual workshops, but it is important to note that no learning format is effective for all people, as can be evidenced by the numerous formats that arose in the evolutionary biology community during the COVID-19 pandemic. The formats range from completely synchronous workshops over that take place over a few days (*e.g.,* Taming the BEAST Online [17] or the Sydney Phylogenetics Workshop [18]) to completely asynchronous where the provided materials are accessed by the participants on their own timelines (*e.g.,* SLiM Workshop [19]). The RevBayes workshop sits between these two extremes by offering both synchronous and asynchronous portions. Any choice of format comes with its own logistical requirements, pedagogical considerations, and impacts the level of accessibility, thus the format should be tailored to the overall goals of each workshop. We felt that the hybrid format provided a balance of independence and autonomy while also giving adequate access to research experts for guidance through the material. Nevertheless, the value of in-person learning and networking is undeniable. Thus, the RevBayes developer community plans to offer both in-person and virtual workshops in the future to strengthen our connections with scientists using statistical phylogenetics to answer biological questions. Many lessons learned from our virtual workshop can be extended to in-person settings. A flipped classroom format allows participants to engage with the material beforehand and seek deeper understanding during synchronous sessions with instructors. We believe this format can help participants achieve learning outcomes and could be adopted for in-person workshops. Additionally,

[17] Taming the BEAST Online: https://bsse.ethz.ch/cevo/taming-the-beast/overview-2021.html
[18] Sydney Phylogenetics Workshop: https://meep.sydney.edu.au/workshops
[19] SLiM Workshop: http://benhaller.com/workshops/workshops.html

having recorded content creates a bank of reference material for both participants and non-participants long after any workshop concludes. The materials developed for online courses thus present exciting opportunities for organizers of in-person workshops to consider alternative pedagogical practices that may enhance learning in a face-to-face course. By diversifying the formats of the workshops we offer, we not only open educational opportunities to a broader range of learners, but we can also improve how we teach concepts and methods across all courses.

In conclusion, we believe that virtual courses on phylogenetic analyses and approaches are more than a workaround for the current circumstances and offer numerous unique advantages. We hope that our experiences will inspire other methods developers in our community to explore this format further and that online workshops will become an integral part of scientific training in the future.

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