Learning in a Crisis: Online Skill Building Workshop Addresses Immediate Pandemic Needs and Offers Possibilities for Future Trainings

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Abstract

The COVID-19 pandemic led to the suspension of many summer research opportunities for STEM students. In response, the IRIS Education and Outreach program, in collaboration with Miami University, offered a free online Seismology Skill Building Workshop to increase undergraduates' knowledge, skills, self-efficacy, and interest in observational seismology and scientific computing. Registrations were received from 760 undergraduates representing 60 different countries. U.S. participants consisted of 59% women and 29% from populations traditionally underrepresented in the geosciences. The workshop design consisted of a tailored Linux virtual machine, regular webinars, a Slack workspace, tutorial-style active e-learning assignments, and an optional final project. Every other week for 12 weeks, a module with ~6 assignments was released to build skills with Linux, GMT, SAC, webservices, seismic network processing, Python, ObsPy, and Jupyter notebooks. A final module focused on competitiveness for graduate school, summer internships, and professional jobs. Evaluation of the workshop relied on registration data, pre-/post- surveys, and performance data from the learning management system. 440 completed at least one assignment, 224 completed at least 80% of the assignments, and 191 completed all 35 assignments, significantly higher than most comparable large-scale, open-access courses. Participants invested ~6 hours per week and averaged a score of 88% on assignments. We identified >60% normalized gain in scientific computing skills. There is evidence the inclusive design of the workshop was able to attract and retain a diverse population. However, some additional investigation is needed to ensure benefits were evenly experienced. Regardless of the degree of completion, participants perceived the workshop quite positively: on average 96% described it as high to very high quality, 83% satisfied to very satisfied with their experience, and 70% very likely to recommend to peers. We identify future directions for running a second iteration of the workshop, including strategies to continue broadening participation and improving retention.

1. Introduction

1.1. Setting and Motivation.

Undergraduate research opportunities, like the Research Experience for Undergraduates (REU) program run by the Incorporated Research Institutions for Seismology (IRIS), have become critical stepping stones in the career development of future seismologists, like most other geoscience and STEM fields (Mogk, 1993; Lopatto, 2007). Since 1998, IRIS's summer internship program has facilitated opportunities for 220 undergraduate students to conduct seismological research and produce research products worthy of presentation and recognition at large professional conferences. Alumni of this program have described the program as highly influential on their educational career trajectories (Hubenthal, 2018). This aligns well with the body of literature on undergraduate research opportunities (UROs), which suggests that participating in it can improve retention of students in STEM majors and increase students' interest in pursuing STEM graduate programs, contribute to students' understanding of disciplinary knowledge and practices, and integrate students into the scientific culture (NASEM, 2017). More recent comparative work has shown that when controlling for a number of factors, REU participants are more likely to pursue a PhD program and produce valuable research products such as conference presentations and refereed publications, when compared to their STEM peers that did not participate in REU programs (Wilson et al., 2018).

During the spring and summer of 2020, the COVID-19 pandemic created significant uncertainty within the academic research community, significantly limiting these UROs. As a result, thousands of students within the United States (U.S.) and around the globe faced both personal (e.g. unemployment, illness or death, loss of insurance, etc.) and professional/academic (e.g. loss of on-campus supports, limited access to technology, scant opportunities to develop skills they had hoped to include on their resumes for graduate schools or employment) challenges (Sloan et al., 2020). Even distributed REU sites like IRIS's, where in normal years students regularly use virtual tools to collaborate and build cohorts while distributed at multiple sites across the country (Hubenthal and Judge, 2013), were impacted as IRIS ultimately suspended their REU program for the summer of 2020.

The decision to suspend the IRIS internship program left many struggling with the question of how best to support the needs of the students who would have participated, which many other similar programs faced as well (Sloan et al., 2020). The Education and Public Outreach program within IRIS developed a pandemic response for the multiple communities it serves (including undergraduates), beginning with a rapid assessment of needs within each community as well as reallocation of staff time and financial resources (Hubenthal et al., 2020). A critical component of the needs assessment for undergraduates was an organic discussion on a public social media forum. Here students interested in seismology and geophysics were discussing lost opportunities. Their discussion articulated and highlighted what alumni of the IRIS program perceived as the most valuable aspects of an IRIS internship: learning scientific computing skills in the context of seismology. In response, staff sought to provide this same learning, but in the form of an online workshop. To accelerate the development of this new Seismology Skill Building Workshop (SSBW) and increase chances for success, the workshop was built upon the foundation of existing introductory, tutorial-based, active e-learning materials (Sit and Brudzinski, 2017). These materials had been used to deliver introductory training on Linux, shell scripting, Generic Mapping Tools (GMT), and Seismic Analysis Code (SAC) as part of the USArray Short Course, an intense week-long workshop primarily for graduate students from 2009 to 2017 (IRIS, 2020), and they currently serve as part of the orientation for IRIS's internship program (Taber et al., 2015).

These existing tutorial-based, active e-learning materials would provide the pedagogical model and content starting point for a more extensive, fully online, no-cost summer workshop for undergraduates. The goals for the workshop were to increase:

1. Students' knowledge, skills, and interest in seismology and scientific computing,
2. Self-efficacy in using seismic data, and
3. Competitiveness in the application process for graduate school, summer internships, or professional jobs.

1.2. Workshop Design.

The SSBW was staffed by two lead instructors, Brudzinski and Hubenthal, who were responsible for the curriculum, instruction and assessment, and two Teaching Assistants (TAs) (Fasola and Schnorr) who supported technical aspects of the online platform and assisted participant learning in the discussion space. The SSBW officially ran from June 1 to August 31, 2020, with an expected student time investment of 5 to 6 hours per week during this period. However, students could work at their own pace and some have continued to work on the materials well after the official SSBW end date. We decided not to offer credit through Miami University because the SSBW was replacing a summer REU internship that has not offered academic credit. Instead, we offered to send a detailed performance report (Figure 1) to serve as a completion certificate common in noncredit education yet also provide enough information that students could use it to seek credit at their own institutions (Clark, 2005; D'Amico et al., 2020).

All scientific computing during the workshop occurred locally on participant computers. This was facilitated through a Linux virtual machine, with pre-installed software needed for the assignments, that participants had to download at the outset of the workshop. This virtual disk was a critical element of the workshop as it ensured a common operating environment necessary for instructors to anticipate the exact products and errors that might be produced by students as they worked.

The second core element of the SSBW were webinars facilitated over Zoom. The workshop was divided into seven 2-week blocks. Each block featured two hour-long webinars, typically Monday and Friday of the first week. All webinars were recorded and made available to support asynchronous participation and review. Webinars introduced seismological and computational concepts that would be the focus of that block’s module, while also emphasizing how a seismologist might think about and approach the dataset or methodology at hand. Additionally, webinars also introduced other research skills and topics likely to increase students' success in the workshop and beyond. These included topics such as how to read scientific literature, productive coding habits, seeking the mentoring you need, incorporating workshop learning into a resume or graduate school application, networking and developing elevator speeches. Additionally, two supplemental webinars were facilitated outside of the regular schedule. The first introduced and explored the pathway and process to transition from an undergraduate to a graduate student focusing on topics like deciding where to apply, the application and selection process, funding and grant opportunities, meeting advisors, and making final decisions. The second was a career showcase where seven alumni of the IRIS Undergraduate Internship program, representing a spectrum of career options in geophysics and seismology, described their work and workplaces and answered participant questions about educational and career pathways.

Performance Report for: Example Participant

This free workshop was offered as a fully online, asynchronous opportunity for undergraduates to enhance their skills in scientific computing, while increasing their understanding of seismology concepts. The workshop consisted of a one−hour weekly webinar, interactive learning assignments, and a Slack workspace for discussion among workshop participants and staff. A total of 6 learning modules were assigned to students and each consisted of 5 to 7 assignments, plus a 7th module on career preparation with no official assignments. Participants invested approximately 12 hours per module for the first 6 modules and approximately 2 hours for the final module.

Module 1 − Introduction to **Linux** command line, shell scripting, and basic plot generation with Generic Mapping Tools (GMT) that enables exploration of earthquake patterns in space, time, and magnitude, and Earth's internal structure based on seismic wave travel times.
7 of 7 assignments completed (100% before the due date)
95.6% average score (91.9% workshop average)

Module 2 − Introduction to Seismic Analysis Code (**SAC**) for viewing seismograms as both waveforms and spectrograms, and conducting time series analysis, filtering, and component rotation that enables detection, characterization, and interpretation of seismic wave patterns.
6 of 6 assignments completed (100% before the due date)
93.8% average score (87.4% workshop average)

Module 3 − Use the myriad of IRIS **DMC** waveform, metadata, and earthquake catalog request tools (e.g., web services, earthquake browser, Wilbur, MUSTANG, etc.) to check data availability and access data that enables exploration of relationships between earthquakes and plate boundaries and earthquake frequency and magnitude.
6 of 6 assignments completed (100% before the due date)
89.7% average score (87.1% workshop average)

Module 4 − Use various methods to visualize a **Network** of seismic waveforms for a given earthquake and software for forward modeling and inversion that enables both estimation of subsurface velocity structures and earthquake hypocenter and fault plane solutions.
5 of 5 assignments completed (100% before the due date)
86.4% average score (88.9% workshop average)

Module 5 − Introduction to **Python** and commonly used libraries (e.g., NumPy, Matplotlib, Pandas, and ObsPy) for retrieving, processing, and plotting of data tables and times series that enables rapid scientific analysis of earthquake catalogs and seismic waveforms.
6 of 6 assignments completed (100% before the due date)
85.5% average score (87.3% workshop average)

Module 6 − Use existing and create new **Jupyter** Notebooks with Python to explain and share code with other scientists that enables advanced seismogram processing including removing an instrument response, calculating a spectrogram, and estimating temporal changes in cultural noise.
5 of 5 assignments completed (100% before the due date)
86.4% average score (85.1% workshop average)

Module 7 − Wrap−up, review, and next steps for pursuing a career in seismology, including a webinar with alumni of the IRIS Undergraduate Internship Program.

Figure 1. *Example performance report listing student learning outcomes for the 7 modules of the SSBW. This report illustrates that this participant completed all assignments, their average score for each module, and the assignments were completed both before and after the nominal deadline once the due date requirement was relaxed.*

The third core element of the SSBW were the seven modules that anchored each 2-week block (Figure 1). The content of these modules was selected based on the authors' previous experiences teaching scientific computing and upper level seismology classes, and feedback from graduate students about what they identified as important. The goal was to introduce a spectrum of observational seismology concepts that participants would be most likely to encounter in graduate school and integrate those with computational skills. Each module consisted of 5-7 interactive, self-paced assignments delivered through the Miami University-hosted Moodle learning management system (LMS). Initially, assignments were closed at the end of each 2-week module, but this was relaxed during the third module due to increasing requests from participants for flexibility given the pandemic. The final performance reports provided students' scores for each module and indicated whether assignments were completed before or after the deadline (Figure 1).

The assignments that made up each module were constructed within the Moodle LMS using a tutorial-based, active e-learning approach (Sit and Brudzinski, 2017) (Figure 2). These interactive assignments provided participants with step-by-step instructions and justifications for performing real-world scientific computing tasks in the virtual disk. Tasks were crafted to illustrate a variety of earthquake source and earth structure concepts and encourage students to consider scenarios similar to a practicing seismologist. Thus, participants practiced key syntax and parameter options for software used to process different types of data and metadata common in seismology. Participants' understanding of these tasks and their applications to seismological concepts were assessed using questions embedded regularly throughout each task. Questions included a mix of multiple-choice, multiple-answer, numerical, and short answer. Both the interactive assignment design and the scientific computing tasks sought to inspire critical thinking when evaluating coding outputs and when reflecting on the application of seismological concepts, with participants applying numeracy and spatial reasoning skills to assess code outputs. See example tutorial assignment in the Supplementary Material.

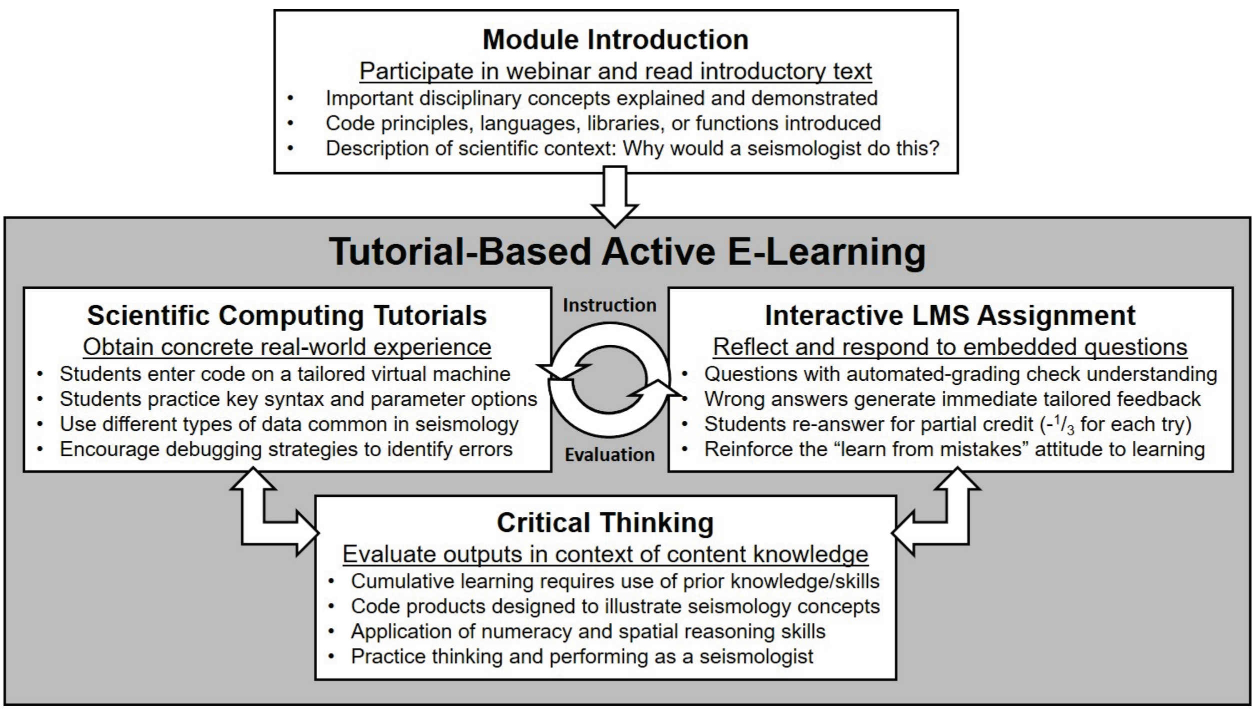

Figure 2. *The SSBW employed a tutorial-based, active e-learning approach where interactive assignments within the learning management system (LMS) provided instructions for performing scientific computing tasks that were regularly evaluated using embedded questions. The design sought to inspire critical thinking when evaluating coding outputs and when responding to seismological questions. Participants were prepped for the active e-learning with webinars and introductory reading.*

This tutorial-based, active e-learning approach (Figure 2) is grounded in constructivism, or 'an approach to learning that holds that people actively construct or make their own knowledge and that reality is determined by the experiences of the learner' (Elliott et al., 2000, p. 256). This implies that for learning to occur, participants in the workshop must actively engage in the learning process through meaningful work and reflect on that work (Prince, 2004). When compared to traditional instruction, we see that active learning courses are significantly more effective in promoting conceptual understanding (e.g., Hake, 1998; Freeman et al., 2014). In the SSBW, the tutorial fosters learning by doing. Participants do not simply learn about scientific computing or the novel syntax of a coding language. Rather, they apply coding syntax and structure as they work with seismological data in processes that illustrate seismological constructs. Together in this way, the process represents a meaningful experience for participants with an interest in geoscience broadly and seismology and geophysics specifically.

Participant reflection, the second component of active learning, is fostered through the interactive assignments. As participants work through each tutorial, the interactive assignment regularly asks them to retrieve information and reflect on the work they are engaging in. This approach of regular retrieval of information, called the testing effect, has been shown to increase the long-term retention of the information across many different conditions (e.g., Dunlosky et al., 2013; Rowland, 2014; Schwieren, Barenberg and Dutke, 2017). Importantly, the testing effect can be further enhanced through the delivery of feedback (e.g., Butler, Karpicke, and Roediger, 2008; Rowland, 2014; Schwieren, Barenberg and Dutke, 2017). Thus, the interactive assignments were designed to provide students with feedback via automated grading within the LMS (Sit and Brudzinski, 2017), consistent with research that indicates feedback should be supportive, timely, and specific to a student's response (e.g., Shute, 2008). Technological developments, such as the LMS housing the interactive assignments, have played an important role in enabling effective automated corrective feedback (e.g., Scheeler and Lee, 2002), such that the interactive assignments of the SSBW provide students with immediate feedback tailored to each answer choice in addition to a summary at the end. When choosing an incorrect response, the feedback signals a gap between a student's understanding and that desired, motivating higher levels of effort. More specific feedback is more effective at correcting misconceptions or procedural errors. Assignments provided chances to re-answer questions for diminishing partial credit (-1/3 for each incorrect attempt), placing an emphasis on skill development by reinforcing learning from mistakes or misunderstandings and providing guidance when participants need support. Automated grading of assignments that encourage practicing have been shown to improve behavioral engagement and lower dropout rates, and increased use of the automated features are shown to correlate with higher course performance (Sancho-Vinuesa et al., 2013).

To supplement and support the learning from the interactive assignments and webinars, a Slack workspace was set up. This element created space for conversations about the workshop content and assignments that would be driven primarily by the participants as questions arose organically. Most instructor posts in Slack were either administrative or brought technical or content expertise to ongoing peer-to-peer discussions and questions rather than driving the discussion. Participants received training on the use of Slack and its threaded structure, which allows organized reply threads to posts within each topic channel. Initially, conversations were organized into 12 channels or topics based on anticipated discussion needs: Administration, Module (1-7), Webinars, Support, Random, Grad School/Careers. However, as the workshop went on and participants worked on an increasing number of different modules and assignments simultaneously, additional, more granular channels were created to make it easier for participants to follow discussions related to a specific assignment. In addition, we recommended a tagging system (e.g., M4T2Q36) that specified which module (M4), tutorial assignment (T2), and question (Q36) that the participant was referring to in a post, and provided students with guidance on how to ask G.O.O.D questions when seeking help (Give a clear description of the problem/context, Outline things you have already tried, Offer your best guess as to what the problem might be, Demo what is happening by including code and sample data if necessary). This combination of adjustments appeared to improve the user experience.

Over the course of the workshop, participation in Slack averaged ~125 active daily users with ~80 messages sent per day. This represents the full spectrum of engagement, ranging from most users who posted ~10 messages during the SSBW, to a small group of self-selected peer mentors who each posted more than 100 messages, with some posting more than 300 messages. The faculty and TAs posted an average of ~200 responses each on topics ranging from administrative announcements and reminders to detailed troubleshooting and technical support. Between these super-users and the workshop TAs, all distributed across multiple time zones, it was rare for student questions or comments in Slack to go unanswered for more than a few hours.

Towards the end of the SSBW, the organizers identified that a final project could present a useful opportunity for participants to showcase their newly developed skills. We decided to make this optional, as we did not want to discourage students by requiring additional work that they had not anticipated. We encouraged participants to create and submit something like a Jupyter Notebook that can demonstrate both code and an outcome of that code, preferably with some explanation. They were advised to consider choosing seismic recordings somewhere in the world, and then use code to request and process the data. The final product would annotate the process of how and why you chose the station(s) or seismicity, along with what they learned from the processing. Ideally, the projects would generate several plots to illustrate findings and justify the conclusions drawn from them. Participants were given an extra month after the nominal end of the SSBW to submit the files, which would be shared with the seismology community, including prospective graduate advisors and employers.

1.3. Workshop Evaluation

To explore the efficacy of the SSBW, collect information to improve its effectiveness, and inform decisions about possible future iterations of the workshop, the following three key evaluation questions were defined for this study:

1. Who does the Seismology Skill Building Workshop recruit to participate and why?
2. How and to what degree does the Seismology Skill Building Workshop retain students to completion?
3. How and to what extent does the Seismology Skill Building Workshop achieve the intended outcomes?

These questions were used to drive the development of a suite of evaluation tools to systematically collect information about the activities, characteristics, and outcomes of the

SSBW. Information about who was interested in participating in the workshop was collected through the workshop registration process and a pre-survey. The pre-survey was sent to all participants that were registered before the first day (n=747). This survey obtained their consent to participate in the workshop evaluation, and for those who did consent, to collect additional information about demographics, background, and reasons for registering for the workshop. Consent was received from 336 registrants for a response rate of 45.0%. Following the workshop, all who had consented to participate in the evaluation received one of three post-workshop surveys. The version they received depended on the degree to which they completed the workshop. For example, participants who did not complete any of the assignments were sent a very short post-survey to explore why they did not start the workshop. Similarly, participants who completed at least one, but not all assignments received a post-survey to explore their perceptions of the workshop and to better understand why they did not complete the entire workshop. Finally, students who completed all assignments were sent a post-survey exploring their perceptions of the workshop and the impact it had on them. These post-surveys were returned by 24.0% (n=6), 46.7% (n=84), and 77.1% (n=84) of recipients, respectively. Some items on the returned pre and post surveys contained missing values. To maximize the data available for analysis, we employed an available-case approach which uses all available samples for each item (Schafer & Graham, 2002). As a result, the number of responses for individual items may vary slightly from others on the same survey.

Both the pre- and post-surveys included closed and open-ended items. Descriptive statistics were calculated in R for closed-response items with the average score on the scales and the standard deviation within the sample reported. Considering the influence of individual survey items on those of similar content (Carifio and Perla, 2007), items measuring related content were combined and totals for each broad category (e.g., computing proficiency, interest, and preparedness) are the focus of our reporting and analysis. A paired-samples t-test was conducted for broad categories, in R, to compare pre and post responses. Remarkably, each of the comparisons reported in this study showed a statistically significant difference between pre and post at the $p<0.001$ level. Given the clear significance in these cases, we focused our attention on normalized gains. Individual participant gains were calculated for each of the broad categories and then averaged across all respondents to estimate the effectiveness of the SSBW in inducing a change (Hake, 1998). Gains (g) were calculated individually for paired pre and post data using the following formula:

$$g = (post - pre)/(max - pre)$$

where *pre* represents the score on the pre-survey, *post* represents the score on the post-survey, and *max* represents the maximum score on the scale given. This is a useful measure as it is independent of learners' pre-test scores which can result in ceiling effects. Once calculated for each participant individually, the gains were then averaged across all students and reported. Normalized gains can be thought of as similar to effect size, and ranges are commonly interpreted as small ($g < 30\%$), medium ($30\% < g < 70\%$), and large ($g > 70\%$) (Hake, 1999).

Open-ended items and 'Other' responses for close-ended items were analyzed using a thematic analysis approach (Braun and Clarke, 2006). Here, responses were repeatedly read and re-read by the authors until major clusters were identified that represented the data set without losing the detailed nuance of the individual responses. Based on these clusters, categories were developed and refined until incremental improvements did not add substantial information or detail, nor did it alter the data narrative.

Participant performance on assignments was collected from the LMS, including completion, score, and duration. Assignment score includes the opportunity to retake each assignment a second time, in which case the reported score is the average of both attempts. On average, a second attempt of an assignment was completed 22% of the time, with the average score of an assignment being boosted 2.3% by this feature. To provide some measure of a participant's "time on task", we used the LMS logs to estimate how much time participants spent on each assignment. The reported duration on an assignment was derived from timestamps of submitted answers to individual questions, ignoring time gaps of greater than 15 minutes which were assumed to be "time off task". We summed the durations between timestamps considered time on task, and then reported total duration only for first attempts at an assignment and only when the entire assignment was completed.

2. Workshop Population

The SSBW was broadly announced through a variety of means. These included a variety of geoscience focused mailing lists (e.g. IRIS Bulkmail, National Association of Geoscience Teachers, etc.) as well as a social media campaign. Since the plight of students was broadly recognized during the pandemic, many colleagues and peer organizations widely shared and rebroadcast the SSBW announcements with students and colleagues alike. All advertisements were in English and indicated that English would be the primary language for the workshop.

Registration for the SSBW was open from May 15th through May 30th, but we honored additional requests for admission afterwards. Surpassing all our initial registration estimates, 1048 unique applications were received during the two-week period. Most (n=760) were from undergraduate students. However, both graduate students and professionals also registered. Most of this later group were referred to the organizers of the ROSES workshop (THIS ISSUE), which was designed for more advanced students. All undergraduate registrants were admitted into the SSBW which now had all the essential elements of a Massive Open Online Course (MOOC). MOOCs provide a flexible learner schedule and improved access to educational resources, but they typically require large initial investments from instructors and often lead to high attrition rates (e.g., Leontyev and Baranov, 2013; Kolowich, 2013; Jordan, 2015).

Data collected from SSBW registrations and the pre-survey was analyzed to describe who registered for the SSBW. While undergraduates from the U.S. made up more than half of the registrants (n=408), the workshop did engage a global community of learners. IP addresses indicated that 60 countries were represented by at least one registrant (Figure 3). Several countries, including Indonesia, Columbia, Nigeria, Canada, and the United Kingdom had more than 20 registrants each. Mirroring the IP address data, 54% of the pre-survey respondents (n=308) identified English as their primary language. Of those reporting other primary languages, most (n=111) indicated that they were either “very” or “extremely familiar” with English.

Figure 3. *The 760 undergraduate registrations received for the summer 2020 Seismology Skill Building Workshop represented 60 countries based on the registrant's IP address.*

In addition to geographic diversity, the pre-survey also indicated that workshop registrants were demographically diverse. For example, 47% of respondents (n=307) described their gender as female and 2% described their gender as non-binary. Ages ranged from 19 to 66 with 66% falling within the "traditional student" range of 19 and 23 years of age. Further, 41% of respondents (n=304) identified with a race or ethnicity that has been traditionally underrepresented in the geosciences within the U.S. Nearly half of the underrepresented minority (URM) respondents hailed from 11 Latin American countries (n=61) and over a third resided in the U.S. (n=45). Of course, care should be taken when interpreting these demographic results as this survey was administered to an international audience who may interpret constructs of race, ethnicity, and gender differently than a US-based population. When considering only respondents from the U.S. (n=153), we found the participation of women (59%) and URMs (29%) in the SSBW exceeded our expectations, as these values are greater than the national percentage of undergraduate geoscience degrees awarded to women in 2019 (~46%) and more than double the percentage awarded to URMs in 2016 (~15%) (Gonzales and Keane, 2020). This suggests that inclusive, open-access practices like the free SSBW may have the potential to contribute to diversifying the field of seismology.

Registrants' majors spanned a wide range of academic disciplines, though most were Geology (n=246), Geophysics (n=161), and Earth Science (n=137) majors. The most common non-geoscience majors attracted included Engineering (n= 43), Physics (n=32), and Computer Science (n=25). Although more than 70% of the registrants were pursuing geoscience degrees, many had little or no experience/training in the primary content of the SSBW. For example, 55% of registrants had taken a seismology or geophysics course, but only 15% had either part-time or full-time research experience in seismology or geophysics, and small percentages reported being at least reasonably familiar with course software: Linux/Unix (14%), Python (28%), SAC (5%).

While students may not have had much experience with course material, some registrants may have had some predisposition to online learning. Over 62% of pre-survey respondents (n=326) had previously taken at least one online course, and 66% of those indicated that they would recommend an online course to other students. Perhaps bolstered by previous successful experiences, registrants for the SSBW saw the workshop as something they intended to complete. For example, when asked which of the following reasons best describes why they signed up for the SSBW, 85% of respondents (n=336) indicated that they were "Planning on completing enough course activities to earn a certificate." Only 7% indicated an intention to complete some but not all of the workshop, while an additional 5% had not yet decided how much of the workshop they intended to complete. The large percentage of SSBW registrants intending to complete the course from the outset is notable as it significantly exceeds what has been found for other courses. For example, when asking the identical question to registrants (n=79,525) of nine HarvardX courses, Reich (2014) found that, on average, only 56% of students intended to complete the course.

To probe beyond the certificate as a goal, registrants were asked to identify factors, from a provided list of ten reasons, that interested them in the workshop. Participants could select all that applied or select "Other" and write in additional factors. As illustrated in Figure 4, the most frequently identified factors were closely aligned with the SSBW's goals. The other option was only selected by six respondents, suggesting that the survey adequately captured students' motivations.

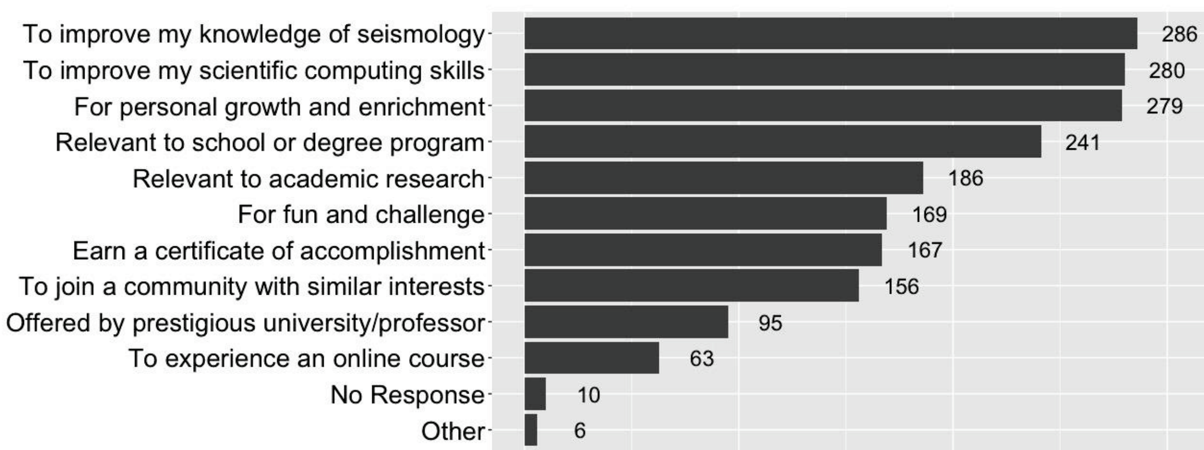

Figure 4: *Reasons participants (n=336) registered for the SSBW and the frequency with which they were selected. Participants could select more than one reason and/or select "Other" and write in their own reasons.*

3. Evaluation Results

3.1. Time Spent on the SSBW

Time engaged with educational content is an important part of any learning experience. Studies of student interactions with the LMS of online courses show the time spent on task and frequency of participation are important for successful online learning (Morris et al., 2005; You, 2016). To assess this in our dataset, we compared participant estimates of the time per week they spent on the SSBW with estimates of time spent on assignments from timestamps of work completed on the LMS server. Of the 82 respondents who completed all assignments, 57% estimated spending 4-6 hours/week, 30% reported 7-9 hours/week, 7% reported 10 or more hours/week, and 4% reported 1-3 hours per week. Using weighted averages from participant responses, we estimated students spent, on average, 6.2 hours per week on the SSBW. This is similar to but slightly more than the 5-6 hours per week that was planned and advertised.

Figure 5 shows the LMS server estimates of time spent on each interactive tutorial assignment that comprised the first 6 modules. While the average time spent on an assignment was ~80 minutes, there was considerable variability based on the standard deviations on each assignment and when we compared assignments from different modules. In fact, participant feedback via Slack about the duration of assignments during the fourth module caused the instructors to shorten that module to only 5 assignments. When the average duration of each assignment was summed for the whole SSBW and we considered the time spent on second attempts, we estimated participants spent ~50 hours on the interactive tutorial assignments. When we added the average time spent on assignments to the two hours per module for webinars and an hour per week for Slack over the entire workshop, this yielded a server-based estimate of 78 total hours. The estimated 5.6 hours per week is similar but slightly less than the 6.2 hours per week weighted averages from participant estimates. However, the LMS-derived durations are likely underestimated because they excluded individual question durations longer than 15 minutes that were assumed to be time off-task but could have been time spent in independent learning.

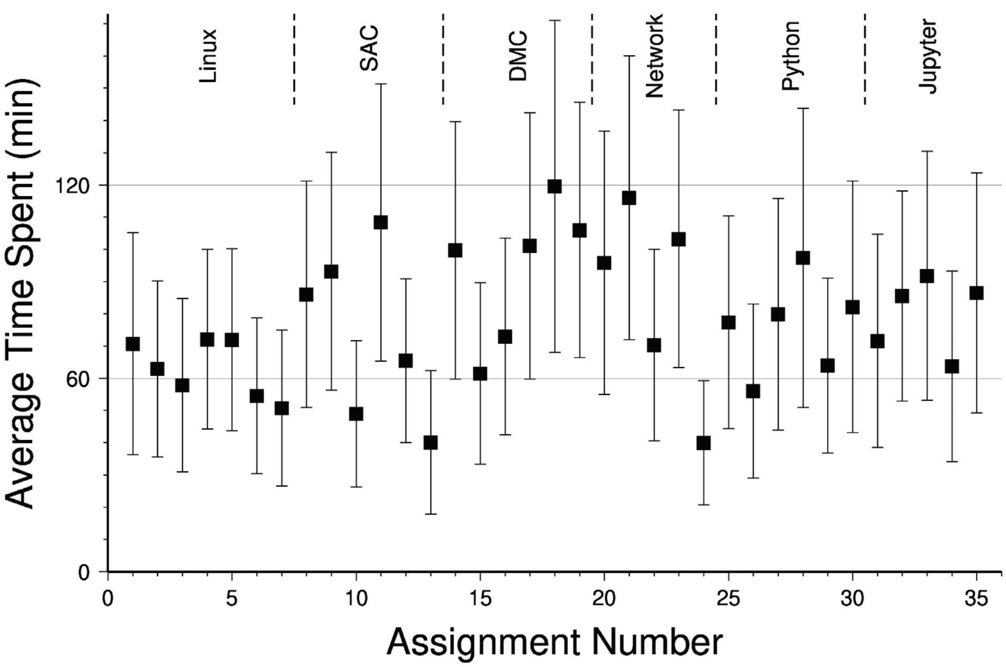

Figure 5*. Mean and standard deviation of the amount of time participants spent on each completed assignment, based on LMS server estimates. Assignments are separated into topic modules that have been labeled and separated by dashed lines (see Figure 1 for Module descriptions).*

3.2. Persistence in the SSBW

Of the 760 undergraduate registrants, 610 logged into the LMS, 440 completed at least one assignment, 224 completed at least 80% of the assignments, and 191 completed all 35 assignments. We interpret the 150 registrants that never logged into the system as those who registered, but whose plans changed such that they decided not to pursue the workshop. For the 170 registrants that logged in without completing any assignments, it seemed more likely these registrants chose not to participate based on the format or workload after viewing the details of the workshop. However, survey responses from these groups were extremely low, so we can only speculate about these cases. Examining the LMS logs, it appears 94% of these registrants attempted to download the virtual machine but only 11% attempted an assignment. Thus it appears ~140 of these registrants may have had difficulty accessing, installing, or using the virtual machine. This conclusion is supported by the large number of Slack messages discussing the virtual machine during the first week of the SSBW.

Figure 6 shows the number of participants completing each assignment, illustrating both overall completion rates and rates of attrition during the workshop. We were encouraged that 25% of all registrants completed the entire SSBW, which means that nearly 43% of those who completed the first assignment were able to complete the whole SSBW. This significantly outperformed our expectations given that the SSBW was free and no university credits or stipends were awarded. While completing each assignment in its entirety is certainly ideal from an instructor's standpoint, our experience working with undergraduates in regular university courses during the pandemic suggests that many students finish a course with a satisfactory grade despite less than 100% completion. Based on these experiences, completing 80% of the assignments was chosen as a criterion to identify a pool of participants who can be considered as having been successful in the workshop. 30% of SSBW registrants met this criterion.

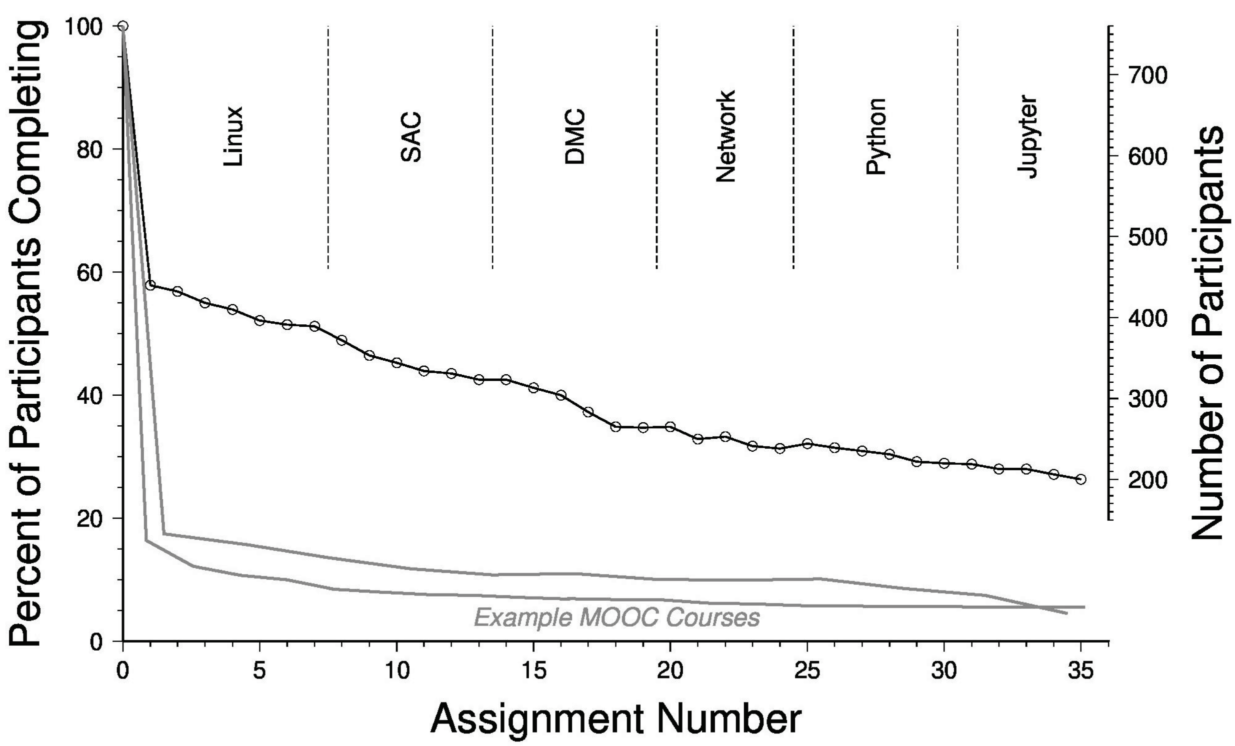

Figure 6. *Number of participants that completed each assignment in the 6 topic modules of the SSBW (labeled and separated by dashed lines), starting from the total number of registrations. Gray lines show attrition rates from a pair of comparable MOOCs (Reich et al., 2014), scaled by total number of registrations and number of assignments.*

Examining other MOOC completion rates further supports this criterion, as MOOCs typically report completion rates as a percentage of registrants that passed the course (Jordan, 2020). In any case, the SSBW rates of completion substantially outperform MOOCs that typically have less than 10% completion rates (Khalil and Ebner, 2014; Jordan, 2015). For example, data provided by Jordan (2020) show MOOCs comparable to the SSBW format (12 to 14 week duration, automated grading, certificate granting) had 5% completion rates on average. Figure 6 includes attrition data from a pair of comparable MOOCs normalized to the number of participants and number of assignments (Reich et al., 2014), which shows that the low completion rate is primarily due to less than 20% of registrants completing any assignments. In comparison, 58% of the SSBW registrants completed an assignment. Some of this difference may be due to 87% of SSBW registrants indicating they were planning to earn a certificate, compared to 56% in comparable MOOCs (Reich, 2014). However, there is also evidence that MOOCs with a more interactive design had completion and attrition rates more similar to ours (Onah et al., 2014; Jordan, 2020), suggesting that the tutorial-based active learning instructional design of the SSBW contributed to the high completion rates. We also note larger rates of attrition associated with assignments that had larger durations (e.g., assignment 18) (c.f., Figures 5 and 6). This suggests that more consistent assignment duration may aid in retention in an asynchronous online educational setting.

Cross-referencing completion status with the registration information, we found that 50% of the participants who were successful in the workshop (≥80% complete) were from the U.S. This is consistent with the percentage of U.S. registrants (54%), indicating country of origin did not play a dominant role in likelihood of success. We also found that 65% of successful SSBW participants had taken a geophysics/seismology course, indicating that prior coursework may play a role in likelihood of success. When considering participants' declared major, Geophysics (29%) and Physics (7%) were slightly overrepresented in the pool of successful participants when compared to the registrant pool (21% and 4%, respectively). Geology (29%), Engineering (4%), and Computer Science (1%) were slightly underrepresented in the successful pool when compared to the registrant pool (33%, 6%, and 3%, respectively). Differences in completion rates between Geophysics vs. Geology and Physics vs. Computer Science majors suggest that there may be variability in how well the SSBW met the needs for different majors.

Cross-referencing successful participants, with pre-survey responses yielded a pool of 140. Examining only the U.S students' (n=59), demographic responses revealed that 61% identified as women and 20% as URM. Thus, women are slightly overrepresented in the successful completion pool compared to the make-up of the pre-survey population (59%), while URMs are underrepresented in the completion pool using the same comparison (29%). For non-U.S. participants (n=74), women comprised 41% of the completion pool while URMs represent 55% of successful participants, which is the opposite of the U.S. participant pattern. When considering all participants (n=133), the percentage of women in the completion pool was 50% and the percentage of URM was 40%. These numbers are similar but slightly different than the original percentages of 47% women and 41% URM. We are encouraged that the percentages of women and URM completing the SSBW are greater than those receiving geoscience degrees annually in the U.S. (Gonzales and Keane, 2020). However, the URM completion rate for U.S. students indicates that additional investigation would help ensure the SSBW supports the needs of all demographic populations evenly.

To better understand factors influencing completion status, the post-survey included a list of possible challenges participants may have encountered. Respondents who did not complete the SSBW were asked to select all that applied from this list or write-in their own. Ninety-one responses were received. The top two most frequently cited reasons were that the course required more time than the participant was able to dedicate to the course and personal reasons (Figure 7). Write-ins were provided by 41 of the respondents which were coded by the authors and, when appropriate, were combined into the existing framework of reasons. Based on these write-ins, it appears that the construct of personal reasons and time commonly overlapped. For example, one participant got a new job during the summer and described no longer having the time to complete the course. They coded this as not enough time, personal reasons, and other (where they detailed what had occurred). Thus, it is reasonable to view the primary reason that registrants did not complete the SSBW as the many factors that compete for one's time. One major new theme did emerge from the coding process that had not been previously included. This theme was “Other technical difficulties" and consisted primarily of hardware failures such as computer crashes and loss of internet for various lengths of time.

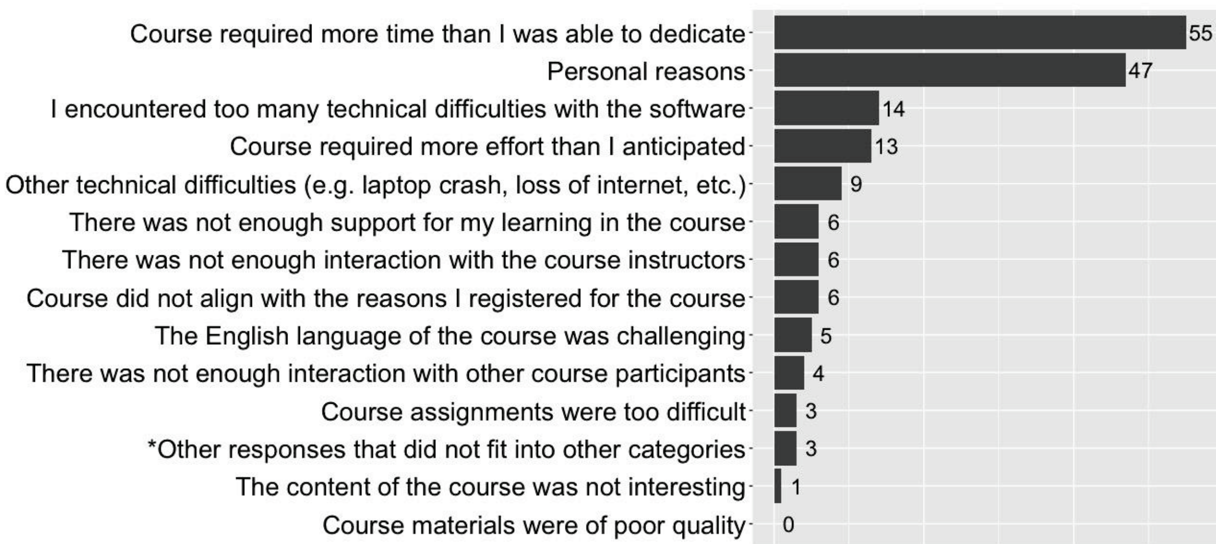

Figure 7: *Reasons participants (n=84) did not complete the SSBW and the frequency with which they were selected. Participants could select more than one reason and/or select “Other” and write in their own reasons. Other reasons described were reviewed, and in all but three cases (*) either fit into existing reasons or represented a new category.*

3.3. Learning from the SSBW

An important goal of the SSBW was to increase students' knowledge and skills in a number of areas. Measuring student learning from an intervention can be quite challenging as various approaches can have biases which influence the results. To address this, we identified two key measures each assessing students’ knowledge and skills from a different perspective. First, student learning was examined by exploring student performance scores per module for all students who completed all items contained in that module. These scores are based on questions developed by the instructors to measure student learning of the outcomes of each module. Since only some of the registered students completed each module, the number of students completing each module will vary. As illustrated in Figure 8, students performed very well with an average score per module of 88% and a standard deviation of 10%. We were able to compare these scores with those from the very similar Linux and SAC assignments used previously for the IRIS Internship orientation (undergraduates, online), the USArray Short Course (graduate students, mix of in person and online), and courses at Miami University (mix of undergraduate and graduate students, in person). Average scores were similar to the scores from the other groups, but 1-2% higher for the SSBW.

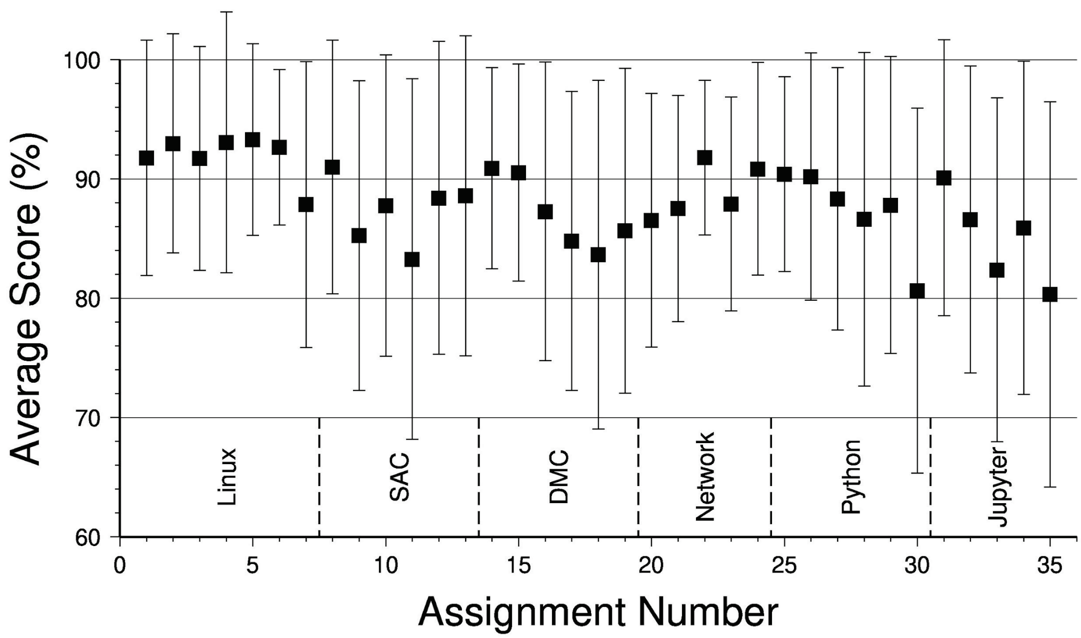

Figure 8. *Mean and standard deviation of participants' scores on each completed assignment.*

Looking at the overall pattern in scores across all of the SSBW assignments, we suspected there might be a gradual change due to the gradual decline in the number of students completing the assignments (cf. Figure 6), but we did not find this trend in the observed performance. Instead, we note that the modules with the highest average scores and lowest deviation were Linux and Python, which were the areas where students appeared to come in knowing the most based on their self-assessments in Table 1.

Participants were also surveyed at the end of the SSBW to explore their own perceptions of learning. Participants were asked to assess how much they learned from this workshop generally and assess their own proficiency for various scientific computing topics using a retrospective pretest design (Howard, 1980). This design is important when asking participants to estimate pre-training knowledge and skills as people often don't know what we don't know prior to training (e.g., Howard, 1980; Rockwell and Kohn, 1989; Pratt et al, 2000; Lam and Bengo, 2003). For example, participants may enter the SSBW believing that they are quite skilled at using Unix, but they may be basing this assessment on their limited knowledge of the uses of Unix. The retrospective pretest design avoids this by asking participants to assess their skills and knowledge both before the workshop and at the end of the workshop when they would employ the same frame of understanding.

Results correlate well with the participant scores on the modules described above. For example, of the 82 survey respondents, 85.4% reported learning “a great deal” (n=31) or “a lot” (n=39) from the SSBW. The remaining 12 respondents reported learning “A moderate amount”. Further, as illustrated in Table 1, respondents reported statistically significant gains across the range of scientific computing skills measured, suggesting a common ability was achieved considering the range of respondents' self-ratings narrowed. This change represents a normalized gain of 60.4%. This is well above gains found in traditionally taught courses (~20%) and at the upper end of the range of gains found in classes employing interactive engagement (30% - 60%) (Coletta et al., 2007). For clarity, Hake (1998) defines interactive engagement as "methods as those designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors."

Table 1: *Participants’ familiarity with various scientific computing topics before and after the SSBW using a retrospective pre-test design on a scale from 1 to 5 where 1=Never used, 2=Vaguely familiar, 3=Occasionally modified or used, 4=Reasonably familiar, 5=Written several applications. Survey items measuring related content were combined into broad categories for calculating average of participant gains considering the influence of individual items on those of similar content (Carifio and Perla, 2007). *Statistically significant difference between before and after at the <.001 level.*

	Before			After			Gains		
	N	**Mean**	**SD**	**N**	**Mean**	**SD**	**n**	**Mean**	**Effect**
File Systems	81	2.9	1.4	76	4.3	0.6	-	-	-
Linux/Unix	82	2.2	1.3	78	4.0	0.6	-	-	-
GMT	82	1.5	1.1	78	3.5	0.8	-	-	-
SAC	82	1.5	1.0	78	3.7	0.8	-	-	-
IRIS Web Services	81	1.3	0.7	78	3.7	0.7	-	-	-
Python	82	2.7	1.5	78	3.8	0.9	-	-	-
Jupyter Notebooks	81	2.2	1.4	76	3.8	0.8	-	-	-
Total Computing Skills	**80**	**14.3***	**5.7**	**76**	**26.8***	**3.8**	**76**	**60.4%**	**Medium**

Although not formally assessed, the optional final project served as an opportunity for participants to showcase their learning. 22 participants submitted final projects that were made publicly available on the SSBW website (https://www.iris.edu/hq/workshops/2020/06/ssb, Showcase tab). All of the submissions had the Jupyter notebook format, likely because the details of the final project idea was shared with participants during Module 6 that focuses on Jupyter notebooks. A positive outcome of participants choosing the Jupyter notebook format was that we could use the nbviewer web application to render that notebooks as a static HTML web page based on the submitted file URL. Five of the submissions included supplementary files that would be used by the notebooks, while the rest used code to obtain data or information. The majority of projects (77%) focused on earthquake seismicity patterns, but others focused on signal processing, volcanic signals, and instrumentation.

3.4. Perceptions of the SSBW

All participants, regardless of the degree of completion, had very favorable perceptions of the SSBW (Table 2). In the full completion pool, 99% described the SSBW as of “high quality” (n=29) or “very high quality” (64%, n=54). In addition, 96% were “Satisfied” (n=25) or “Very satisfied” (67%, n=56) with their experience in the workshop, with a few “Neither satisfied nor dissatisfied” (n=2) or “Very dissatisfied” (n=1). When asked how likely it was they would recommend the SSBW to their peers on a scale of 1 to 10, 76% were promoters (selecting a rating of 9-10), 23% were passives (ratings of 7-8), and only 1% were detractors (ratings of 6 or less), based on the Net Promoter Score (Reichheld, 2003).

Similarly, 92% of respondents who completed an assignment but not the entire SSBW described the quality of the workshop as of “high quality” (n=38) or “very high quality” (n=39), and 71% were “Satisfied” (n=30) or “Very Satisfied” (n=30) with their experience in the workshop. An additional 20% were “Neither satisfied nor dissatisfied”, while 2% were “Dissatisfied” and 6% were “Very dissatisfied” with their SSBW experience. This group was also quite likely to recommend the SSBW to their peers as 63% were promoters (selecting a rating of 9-10), 29% were passives (ratings of 7-8), and 8% were detractors (ratings of 6 or less). These results are surprising as one would expect those who did not complete the workshop to be dissatisfied with their experience. This reinforces the finding discussed previously, that the primary factors influencing participants' failure to complete the entire workshop were external to the design and experience in the SSBW.

Table 2. *Respondents’ perceptions of the workshop aggregated by degree of workshop completion.*

	Assignments Completed	
	All (n=84)	**Partial (n=84)**
Described the SSBW as high quality or very high quality	99.0%	91.7%
Satisfied or very satisfied with their experience in SSBW	96.4%	71.4%
Promoters (highly likely to recommend SSBW to peers)	76.2%	63.1%

3.5. Interest and Preparedness Resulting From the SSBW

Participation in REUs and UROs is often championed as an effective method for increasing interest and preparedness in STEM graduate school and career aspirations (Mogk, 1993; Lopatto, 2007; NASEM, 2017). Studies have shown that students who participated in REUs have stronger graduate school aspirations than those who did not participate (Eagan et al., 2013). However, these differences may have existed prior to the experience, as detailed pre-/post-REU comparisons have revealed small (<20%) increases in graduate school aspirations despite improved self-perceptions of disciplinary knowledge (Russell et al., 2007; Craney et al., 2011; Willis et al., 2013). Confirmation of pre-existing interest in graduate school and careers have been more commonly reported, suggesting the influence of research experiences on career aspirations could be a more indirect effect (Lopatto, 2007; Hunter et al., 2007; Adedokun et al., 2012). In a direct comparison of REU participants and applicants who did not have the REU experience, Wilson et al. (2018) find that the REU experience has a positive effect on the pursuit of a PhD is not a function of self-selecting populations. Although rare in REU studies, decreases in graduate school aspirations have been associated with a lack of mentorship or poor design (Thiry et al., 2011; NASEM, 2017). While the SSBW did not offer an REU experience, we sought to investigate whether the exposure to seismology and scientific computing in this way would have a positive influence on participants' disciplinary interest and perceived preparedness for graduate school or careers with our pre/post survey instruments.

Survey responses show participants' interest in seismology, scientific computing, graduate school increased as a result of the SSBW (Table 3). Interest in all three topics has a normalized gain of 47%. Participants' interest in scientific computing showed the largest increase following in the workshop, although this topic had the lowest score prior to the workshop. The survey responses also indicate the SSBW increased participants’ perceived preparedness to apply to graduate school in seismology and to seek employment, with a normalized gain in perceived preparedness of 37%. The significant gains in interest and perceived preparedness from the SSBW are noteworthy with respect to previous studies of REUs. We interpret these substantial increases as likely related to the high levels of satisfaction with the SSBW (Table 2). Nevertheless, these findings suggest that a fully online skill building workshop may be an effective tool for promoting STEM career paths.

Table 3: *Participants’ interested and perceived preparedness before and after the SSBW using a retrospective pre-test design on a scale from 1 to 5 where 1=Not at all interested/prepared, 2=Not so interested/prepared, 3=Somewhat interested/prepared, 4=Very interested/prepared, 5=Extremely int*erested/prepared. **Statistically significant difference between before and after at the <.001 level.*

	Before			**After**			**Gains**		
	N	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**Effect**
Interest in seismology	81	3.8	1.0	75	4.3	0.7	-	-	-
Interest in scientific computing	81	3.2	1.2	75	4.1	0.8	-	-	-
Interest in seismology graduate school	81	3.5	1.3	75	4.0	1.1	-	-	-
Total Interest Scores	**81**	**10.6***	**2.7**	**75**	**12.5***	**2.1**	**71**	**46.9%**	**Medium**
Preparedness to apply to graduate school in seismology	81	2.5	1.1	80	3.5	0.8	-	-	-
Preparedness to seek employment	80	2.4	1.0	79	3.3	0.8	-	-	-
Total Preparedness	**80**	**4.9***	**1.7**	**79**	**6.8***	**1.3**	**79**	**37.4%**	**Medium**

4. Future directions for the SSBW

The SSBW was developed and implemented as a rapid response to support undergraduates during the summer of 2020 when in-person research opportunities were extremely limited due to the pandemic. The inclusive design of the workshop as a free and open-access opportunity has yielded a response from a very diverse population of undergraduates that exceeded our expectations. In addition, the impact of the SSBW on participants' knowledge, skills, and interests is extremely encouraging. This combination of reach and impact suggests community-wide undergraduate workshops could have an important place in developing the next generation of seismologists alongside typical REU programs that hosts 8-10 students (NSF, 2019). Combined with ongoing interest from seismology faculty, the authors have been inspired to run a second SSBW, again through the SAGE facility, during the summer of 2021. The second SSBW will use the same tutorial-style active e-learning pedagogy successfully implemented in 2020. However, we anticipate making several key adjustments to increase participant retention and success, especially for URM participants in light of the lack of long-term success in increasing the percentages of geoscience PhDs awarded to this population (Bernard and Cooperdock, 2018). The key adjustments we will target are:

- Start and finish the registration process sooner to allow students to better prepare their technological and personal circumstances.
- Expand the target population to include both current undergraduate students and incoming (Fall 2021) graduate students.
- Further investigate our collected dataset, including qualitative responses to identify factors that may have influenced student performance and attrition. This could provide new insights for to develop strategies that could increase the retention rates, particularly for URM participants.
- Employ technological solutions to enable more participants to successfully download, install, and execute the virtual machine prior to the start of the workshop (e.g. offering more robust servers to support the download of the virtual machine, working to reduce the size, and spreading the download period across a larger time window).
- Leverage the documentation of commonly encountered issues from 2020 to further streamline future participants experiences (e.g. keyboard configurations for an international audience).
- Refine assignments with larger than expected durations to help ensure a more consistent weekly time investment in line with the 5-6 hour/week target desired.
- Remove all hard deadlines for assignments to allow participants to work at their own pace for the entirety of the workshop. However, to encourage continued progress, completion dates will continue to be reported on the performance report.
- Preserve the final project as optional, but introduce it from the beginning of the workshop, so that more students consider pursuing it. Interactions with participants identified several that were going beyond the assignments during the early parts of the workshop that could have been encouraged to make them into final projects without much extra work beyond what they had already done independently.

Offered through the SAGE facility, the SSBW is intended to be a community resource that can benefit the academic seismology community broadly. However, we recognize that the current format of the modules is not a format that is easily used and adapted (See example tutorial assignment in Supplementary Material). Therefore, we are still exploring the best way to make the resources available in a way that best serves both individual and community needs, yet maintains the integrity of the assignments (e.g., answers are protected). We anticipate that the development of and outcomes from 2021 SSBW will inform the development of a plan for long-term sustainability of this training style within the community.

Although efforts were made to ensure that the content (both scientific computing and seismological) were inclusive and representative of the breadth of seismological disciplines in the first iteration, the authors recognize that more could be done in this vein. Thus, an additional element of the SSBW in 2021 will be the facilitation of a multi-day community workshop (in person or virtual depending on the situation) targeting practicing seismologists, if possible, given the pandemic. Participants would be trained in the tutorial-style active e-learning pedagogies developed for the SSBW and then given time and space to develop assignments encompassing specializations within seismology that are not currently represented in the workshop. The long-term goal of creating these additional assignments would be to develop a system where students could participate in a "core curriculum" of the SSBW and then supplement that learning with additional asynchronous modules focused on special techniques, based on personal interests or advising from faculty. Announcements for the community workshop to develop these tutorial-style assignments will be disseminated in Spring of 2021.

Data and Resources

The data was collected as part of IRB 2428. An example tutorial-based assignment from the third module is provided in the Supplementary Materials. This text file is in the GIFT (General Import Format Template) format, which is a markup language for describing question and answer sets, typically associated with the Moodle learning management system.

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