Implementing version control with Git as a learning objective in statistics courses

Matthew D. Beckman
Penn State University
and
Mine Çetinkaya-Rundel
University of Edinburgh, RStudio, Duke University
and
Nicholas J. Horton
Amherst College
and
Colin W. Rundel
University of Edinburgh, Duke University
and
Adam J. Sullivan
Brown University
and
Maria Tackett
Duke University
January 8, 2020

Abstract

Version control is an essential element of a reproducible workflow that deserves due consideration among the learning objectives of statistics courses. This paper describes experiences and implementation decisions of four contributing faculty who are teaching different courses at a variety of institutions. Each of these faculty have set version control as a learning objective and successfully integrated teaching Git into one or more statistics courses. The various approaches described in the paper span different implementation strategies to suit student background, course type, software choices, and assessment practices. By presenting a wide range of approaches to teaching Git, the paper aims to serve as a resource for statistics instructors teaching courses at any level within an undergraduate or graduate curriculum.
Keywords: version control, education, data science, reproducible analysis, workflow, version control, collaborative learning
1 Introduction

With the recent growth in data science, computing has become an increasingly important component of the undergraduate statistics curriculum. Nolan and Temple Lang (2010) included ‘version control’ as a key topic for statistical analysis, particularly when coordinating work across a team. The 2014 American Statistical Association Curriculum Guidelines for Undergraduate Programs includes proficiency with modern statistical software as well as well-documented and reproducible data wrangling skills as a necessary component of the undergraduate curriculum [American Statistical Association (2014), p. 7; 9-10]. The National Academies consensus report on Data Science for Undergraduates (National Academies of Science, Engineering, and Medicine 2018) included workflow and reproducibility as an important component of ‘data acumen’. Version control is an essential element of a reproducible workflow, and therefore deserves due consideration among the learning objectives of statistics courses. In a recent paper, Fiksel et al. (2019) motivate the use of GitHub for version control and describe how they integrated this complex and powerful system into two courses.

This paper follows the same format as Garfield et al. (2011) by describing the experiences and implementation decisions of four contributing faculty—teaching different courses at different institutions—who have successfully integrated Git into one or more statistics courses in order to teach version control as a learning objective. The various courses and implementations highlight different implementation strategies chosen based on student audience, course type, software choices, and assessment practices with a goal of providing a range of implementations across a variety of courses and student populations in order to provide a resource for statistics instructors to interpolate an implementation suitable for use in their own courses at the undergraduate or graduate level.

1.1 Definitions

We begin with some common definitions.

- Git (git-scm.com) is an open source version control software system.
- Git repository (repo) is analogous to a project directory location analogous to a folder.
in Google Drive, Dropbox, etc. It tracks changes to files.

- GitHub is a remote hosting service for Git repositories. See Fiksel et al. (2019) for more details and background on GitHub.
- GitHub Classroom is used to distribute assignments to students. The instructor simply creates a template Git repo that includes starter-code, data sets, document templates, and anything else students may need. A single URL is provided to the class, and then each student is provided their own personal copy of this template repo when they click the URL and accept the assignment. The instructor can also reuse these template repos each time the class is offered.
- RStudio (rstudio.com) is an Integrated Development Environment (IDE), e.g., a front-end, for R that offers integration with GitHub.
- RStudio Server Pro (rstudio.com/products/rstudio-server-pro) is a cloud-based version of RStudio that can be installed by instructors or institutions.
- RStudio Cloud (rstudio.cloud) is a cloud-based version of RStudio on servers provided by RStudio.

2 Method

In order to organize the paper, the contributors first agreed upon a set of organizing prompts to provide direction as they describe their experiences:

- Describe the course/students
- Why use Git?
- What tools do you use for implementing Git implementation in your class?
- How do you introduce Git? Describe your students’ first encounter with Git in the course.
- What role does Git have in the regular day-to-day workflow for your students in the course?
- How do you assess Git proficiency as a learning objective?
- How do you address Family Educational Rights and Privacy Act (FERPA) and related privacy issues?
• Do you have other advice for instructors considering incorporating Git or some other type of version control into a statistics course?

The contributors were then free to address as many of these prompts as they deemed appropriate. Each narrative description was then written independently in an attempt to reduce cross-pollination and promote similarities and differences to emerge naturally. The panel responses have been organized to align roughly with their place in a statistics curriculum at each respective institution: a pair of undergraduate courses beginning in the first semester, a second undergraduate course in statistics, a course in a Master’s in Statistical Science program, and finally a master’s level course in a Biostatistics program.

In addition to the organizing prompts, each contributor populated a matrix of learning outcomes with codes representing the type of exposure typical in the course(s) described. Table 1 presents this matrix using the following symbolic representation for each learning outcome in each course:

- □□□□: None. Not included in course.
- ■□□□: Incidental. May or may not occur in the course.
- ■■□□: Teacher. Instructor shows this to students, but students are not responsible to do for themselves.
- ■■■□: Student. Students are expected to do this for themselves, but may not be assessed on it.
- ■■■■: Assessed. Students are expected to do this for themselves AND will be assessed for proficiency.

3 Teaching R and Git beginning in the first semester (Beckman)

3.1 Background

Prior to academia, I worked as a statistician in the medical device industry where I first learned some basic version control skills. Since medical device manufacturing is a closely
regulated industry, version control was critical to maintain transparency, traceability, and reproducibility while also preserving a workflow that facilitated collaboration. Moreover, as a member of hiring committees recruiting and interviewing candidates for our team of statisticians, I had seen first-hand the benefit and convenience when evaluating an application accompanied by a GitHub ID and GitHub Pages portfolio. The hiring team could then look closely at actual projects completed by the candidate and scrutinize problem solving, critical thinking, code quality, programming style, and version control skills needed on the job but difficult to otherwise assess in an interview. When I began teaching undergraduate

Table 1: Git learning outcomes and assessment across the courses.

| Learning Outcome                                                                 | Sullivan | Rundel | Tackett | Beckman |
|----------------------------------------------------------------------------------|----------|--------|---------|---------|
| **Repositories:**                                                                |          |        |         |         |
| cloning a private repo and pushing a commit                                     | ■■■■     | ■■■■   | ■■■■    | ■■■■    |
| creating a repository                                                            | ■■■■     | ■□□□   | ■□□□    | ■■■■    |
| creating a branch, merging branches                                              | ■■■■     | ■□□□   | □□□□    | □□□□    |
| retrieving an older version of a file                                            | ■■■□     | ■■□□   | ■□□□    | ■□□□    |
| continuous integration or other automation                                       | □□□□     | □□□□   | □□□□    | □□□□    |
| **GitHub Issues:**                                                               |          |        |         |         |
| create, comment on, and or assign an issue                                       | ■■■□     | ■□□□   | ■□□□    | ■□□□    |
| referencing commits in issues                                                    | □□□□     | □□□□   | □□□□    | □□□□    |
| referencing code line numbers in issues                                          | ■□□□     | ■□□□   | ■□□□    | □□□□    |
| **Collaboration:**                                                               |          |        |         |         |
| student teams collaborate in a shared repo                                       | ■■■■     | ■■■■   | ■■■■    | ■■■□    |
| dealing with a merge conflict                                                    | ■■■□     | ■■■□   | ■■■□    | ■■■□    |
| forking and creating a pull request                                              | ■■■■     | ■□□□   | □□□□    | □□□□    |
| merge a pull request                                                             | ■■■□     | ■□□□   | □□□□    | □□□□    |
| reviewing changes and blame                                                       | ■□□□     | ■□□□   | ■□□□    | ■□□□    |
| respond to a review                                                              | □□□□     | □□□□   | □□□□    | □□□□    |
| create gh-pages                                                                  | ■■■□     | ■□□□   | □□□□    | ■■■■    |
statistics and data science students, I wanted to make sure my students understood the potential impact of such a resource and were encouraged to begin curating a portfolio as soon as possible to share with future employers.

If not a learning objective, version control had always been at least an incidental topic in several of my courses. First as a special lecture near the end of the term accompanied by an extra credit incentive awarded to students for submitting their final project as a GitHub Pages website, and later as an extra-curricular enrichment opportunity in the first-year orientation course for students interested in potentially studying statistics as a major. These casual introductions served a few purposes for my students and for me. For students, it provided a low-risk opportunity to dabble with version control tools at my recommendation. On the other hand, it allowed me to take a small step toward exposing students to the benefits of version control while also experimenting with some necessary logistics before I was quite comfortable to feature it among the course learning objectives.

After a year or two, the first statistics course to implement version control as a learning objective was a two credit (i.e., 2 x 50 minute instruction each week for 15 weeks; STAT 184) R programming course modeled after a similar Data Computing Fundamentals course developed by Daniel Kaplan at Macalester College and the accompanying textbook (Kaplan 2015, Kaplan & Beckman 2019). The STAT 184 course was designed as a first-year undergraduate course that welcomed students from any academic program and had no prerequisites at all. The course typically enrolls 30-40 students in each section, and demographics have ranged from sections with exclusively first-semester students (linked to the aforementioned first-year orientation course), to other sections with mixed audiences that may include seniors on the cusp of graduation with or without prior programming experience. Once established in STAT 184, version control was soon added as a learning objective in a subsequent course: (STAT 380) Data Science Through Statistical Reasoning and Computation. STAT 380 is intended for undergraduate students in the statistics or data sciences majors; both STAT 184 and an introductory statistics course (e.g., AP Statistics) are enforced as prerequisites.
3.2 Tools and implementation

In both STAT 184 and STAT 380, students are expected to adopt a workflow built around the RStudio integrated development environment (IDE) with Git integration. In the beginning of STAT 184 all students are expected to use an RStudio Server Pro hosted by the university (the licensing for this setup is free for instructional use). This strategy allows the instructor to rely on consistent configuration and hardware which provides several key benefits:

1. All students and instructor use the same version of R and essential packages; this cuts down on early distractions due to differing versions of R or installed packages.

2. Git installation and integration with RStudio is standardized because everyone is using the same server. Many STAT 184 students find terminal (shell, bash, etc) commands quite intimidating, so it is a significant benefit that the RStudio Server enables the class to walk through a very small number of commands (as few as three) together line by line—within the RStudio IDE—to ensure success. Furthermore, minimum viable instructions are provided as an appendix in the course text (dtkaplan.github.io/DataComputingEbook) with troubleshooting directed to Bryan's *Happy Git and GitHub for the useR* resources (Bryan 2018).

3. Students only need a web browser and an internet connection to access the server. As a result, nearly any computer, Chromebook, or tablet available should be sufficient for full participation, and students can easily switch hardware as needed if using a lab computer during class and a personal computer at home, for example.

Once the class has navigated the overhead of tool configuration, one or more assignments each week are deployed to students through GitHub Classroom (Fiksel et al. 2019). Students submit assignments in the university’s learning management system (LMS) for most assignments, though they are expected to create and submit a GitHub repository (or a website via GitHub Pages) for the semester project in each course.

To be clear, there are several software tools mixing together in the STAT 184 and STAT 380 use case:
For STAT 184 and STAT 380, Git was simply chosen as a matter of instructor familiarity and convenience. RStudio integration with Git allows students to practice version control fundamentals and adopt key steps in the workflow (e.g., diff, commit, pull, push, and more) that minimizes the use of terminal commands after the initial configuration. This feature is actually quite important in our implementation because it allows introductory-level statistics students to fix their attention on course content—including version control fundamentals—while reducing the logistics of Git integration to little more than clicking a different sort of save buttons. Furthermore, GitHub Classroom allows the instructor to keep student work private and retain administrator privileges which has enormous benefit where academic integrity may be a concern. Git/GitHub is built for collaboration, but inappropriate collaboration can easily lead to academic integrity violations without such protections.

3.3 First exposure in class

For the first student encounter with Git and GitHub in STAT 184, typically the instructor creates a public GitHub repo associated with a GitHub Pages website for the class. Students are provided a link to the webpage where they find instructions to (1) create a GitHub profile of their own, (2) create their first Git repo, (3) turn their personal repo into a GitHub Pages website, (3) edit a table in the instructor’s class repo to add their name, GitHub user ID, and a functioning URL for GitHub Pages website they have just created, (4) leave an informative commit message and initiate a pull request to the instructor’s repo. The whole exercise takes students about 30 minutes to introduce version control:

- every student creates a GitHub repo
- every student must make at least two commits and issue a pull request to successfully complete the assignment
- every student collaborates on an outside repo belonging to another GitHub user (the instructor)
- every student creates a public GitHub Pages website as a starting point to begin developing a work portfolio
• the instructor obtains roster with name and GitHub user id associated with each student
• the instructor can demonstrate the process of merging pull requests
• the instructor can demonstrate how merge conflicts are created and resolved

This short activity has the additional benefit that the entire exercise can be completed within the GitHub web interface, which has a significant advantage that students need not use R, the terminal, or even Markdown at any step if they aren’t already comfortable doing so at the beginning of the course. Students begin building schema for version control without confounding it with other unfamiliar tools.

Since students are assumed to have experience with version control in their prerequisite STAT 184 class, their first encounter with Git and GitHub in STAT 380 is simply a GitHub Classroom assignment. STAT 380 tends to have about 50-60 students enrolled, so an approach that streamlines logistics was desirable. The roster of names or email addresses was uploaded to GitHub Classroom in order to populate a roster with GitHub user id for each student. A blended strategy in which a pared down version of the GitHub Pages assignment could certainly be deployed with GitHub Classroom as needed to balance engagement and logistics.

3.4 Regular workflow

Once the class has been initiated to the necessary tools and fundamental concepts, the class norms for the rest of the semester include expectations that students maintain GitHub repos associated with virtually every assignment in the course, although nearly the entire workflow takes place entirely within the RStudio IDE. The only regular (albeit trivial) version control task outside the RStudio IDE is the requirement that students click a link and accept the template repo deployed through GitHub classroom, and then students are taken to a GitHub webpage associated with their personal copy of the assignment repo which they will “clone” to associate the repo with an RStudio project. In total, this transaction takes less than a minute. From that point on, students can make commits, push, pull, diff, etc. using a graphical user interface (GUI) within the RStudio IDE and few if any terminal commands are required (see Figure 1).
Some of these Git repos are associated with an activity that is launched, completed, and submitted in the space of a week or less, other Git repos are used on a regular basis throughout nearly the entire academic term, and a few repos are associated with cooperative assignments for which all students (often a pair) must contribute to the work and add to the commit record for the assignment. Currently, the final product of most assignments is still submitted to the class LMS (e.g., Canvas, Moodle) for grading, however, students are expected to make regular commits in each repo and several assignments do grade the commit record evident in the associated GitHub repos.

### 3.5 Assessment

As instructors, students will value what we assess so it is important to assess all learning objectives (GAISE College Report Revision Committee 2016). The transition from incidental topic to learning objective was made complete once version control had become integrated into assessment practices (e.g., homework, projects, exams). For early assignments, success was set at a fairly low threshold: objective evidence that students have simply created a repo of their own or edited a repo provided to them. As the workflow has time to mature, assignments may include direct scrutiny of a commit record or similar activity documented.
within a repo. For example, STAT 184 and STAT 380 students are expected to maintain
a single repo for all weekly problem sets assigned from the textbook, and this repo then is
graded as a distinct homework score at the end of the semester based on verification that
all assignments are present and associated with a minimum of two commits per assignment.
Also in STAT 380, students are assigned a semester project to be completed with a partner,
for which they must create and maintain a GitHub repo and establish a clear record of con-
tributions to the final product by each teammate. Students then submit the repo itself to
be graded according to a rubric that evaluates reproducibility–i.e., can the instructor run
the submitted code without modification and reproduce the entire analysis–and scrutinizes
the commit record.

Lastly, both STAT 184 and STAT 380 students are made aware that procedural ques-
tions about version control or the mechanics of a workflow that includes version control
are in scope for in-class exams. For example, this might include a few selected-response
questions (e.g., True/False) about details such as whether a “git pull” updates files (a) in
the directory on their local computer, (b) on the GitHub Remote Server, (c) both, (d)
neither, or another task might show students a screenshot of a merge conflict and then ask
them to explain what caused the conflict and how it might be resolved.

3.6 Other remarks

If version control is to be taken seriously as a learning objective for a course, then it should
be made clear to students early and often. Students should find mention in the course
syllabus, students should expect to see it on exams, and students should feel that it is
among the class norms for regular assignments. The instructor may also add credibility to
the workflow if students see incidental evidence of the utility of version control. This can
perhaps be as simple as using “git pull” while presenting on a projector at the beginning
of class. Another useful tactic might involve allowing Git/GitHub records to remedy a
student mistake. For example, STAT 184 and STAT 380 both penalize late work, but
the late penalty can be waived one-time for each student if the work had been completed
and committed to their GitHub repo prior to the deadline. This provides recourse for a
student who might suffer failed Internet access just before the deadline, an undetected issue
uploading a file to the LMS, or perhaps submitted the wrong document to the LMS by accident. Since there is no way a student could back-date a Git record, the instructor can simply view the repo, navigate to the last commit before the due date, and then either grade the work present at that time or use diff to verify that no substantive changes occurred between the version completed on time and a later version. If the student has appropriately integrated version control into their workflow the late penalty is waived and version control is reinforced as a valuable member of the workflow. If not, the student is no worse off and perhaps the missed opportunity can start a productive conversation to resolve obstacles that may have prevented them from adopting the recommended workflow.

4 Teaching Git in the second statistics course (Tackett)

4.1 Background

With the rise of increasingly large and complex data, computing has become an important component of the undergraduate statistics curriculum. As noted previously, recent national curricular documents have stressed the importance of computation and statistical software as a necessary component of the undergraduate curriculum. As many professors do, I strive to teach students the skills they need to pursue statistics outside the classroom; this was my primary motivation for including proficiency using Git through RStudio and GitHub as a learning objective in my undergraduate regression analysis course. By the end of the semester, students have not only enhanced their statistical analysis skills, but they’ve also developed workflows for conducting analyses individually and collaboratively. With the widespread use of GitHub in academia and industry, students will be able to apply these skills in internships, research programs, and their future careers. More immediately, they will be able to use these computing tools as they work on analyses and projects in subsequent courses.

Another motivation for implementing Git in the course is to encourage students think about statistical analysis, specifically regression analysis, as an iterative process. While working on a given assignment, students “submit” their work multiple by knitting their R Markdown file, writing a commit message to document the changes, and pushing the
updated work to their assignment repository on GitHub. This helps reinforce the notion that a regression analysis typically requires multiple revisions, as students can review their commits to see all the updates they’ve made to their work. Additionally, because students are periodically “submitting” their assignment as they work on it, there is less pressure of the final deadline where everything must be submitted in its final form. By the time the deadline approaches, students have generally submitted a majority of their work; this has reduced issues around late submissions.

With these motivations in mind, I have implemented Git in an undergraduate regression analysis course. The infrastructure using RStudio and GitHub and pedagogy was based on (Çetinkaya-Rundel & Rundel 2018) and (Data Science in a Box 2019).

4.2 Course description

STA 210: Regression Analysis, is an intermediate-level course in the Department of Statistical Science at Duke University. About 75 students take the course each semester, representing a variety of majors across campus. The course is one of the core requirements for the statistical science major and minor, so a large proportion of the students have either declared or intend to declare a statistical science major or minor. The only prerequisite is an introductory statistics or probability course, so students come into the course with a range of previous experience using R and Git. As an example, in the most recent semester, a majority of students used R and RStudio in a previous course, while less than half had any previous exposure to Git and GitHub. Given the wide range of previous experiences with these computing tools, some of the challenges of teaching Git in this course are similar to those experienced in a first semester statistics course.

4.3 Tools and implementation

The primary computing tools used in STA210 are RStudio and GitHub. Students use RStudio Cloud, a cloud-based version of RStudio accessible through a web browser that requires no infrastructure on the instructor or institution-level. This cloud-based version of RStudio has several attractive features. By having students use RStudio Cloud, rather than installing it on their own devices, students are able to use it immediately, as soon as the
first day of class (Çetinkaya-Rundel & Rundel 2018). Secondly, since RStudio is accessible through a web browser, students can use it on multiple types of devices including laptops, desktops, and tablets, among others. Next, by using the cloud-based platform, all students use the same version of RStudio and its packages; as the instructor, I am able to easily install or update packages throughout the semester. This eliminates complications that arise from students using multiple versions of R or differences based on the type of device, which is important given the size of the course enrollment. Finally, Git is already configured on RStudio Cloud, so students are able to integrate Git into their workflow as soon as the first assignment.

On GitHub, the course is set up as a GitHub organization with the educational benefits through GitHub Classroom. By having the educational benefits, students have free private repositories, so their work remains in compliance with the FERPA (2019) and is only accessible to them, the instructor, and the teaching assistants. The professor and teaching assistants are “Owners” in the organization, and the students are “Members”. As “Owners”, the professor and teaching assistants are able to see any repository created within in the course organization and thus see all students’ work. As “Members”, students are only able to view and access the individual or group repositories assigned to them; they cannot view or access the repos for any other students. They can also view any repos within the organization that have been made public, such as those containing supplemental notes and extra materials for the course.

Students use Git commands through the Git pane in RStudio. By interfacing with Git through this pane, students can make use of the basic functionality of Git without working using “point-and-click” commands rather than through the command line. For students new to these computing tools, this reduces the cognitive load, since they are not tasked with learning how to use the command line in addition to learning RStudio and Git. The Git pane in RStudio also provides visual cues that are helpful for students to recall the purpose of each command. For example, there is a down arrow to “Pull” and an up arrow to “Push” as seen in Figure 1.

All administrative activities involving GitHub are done using the ghclass R package (Rundel et al. 2019). These activities include adding the students to the GitHub organiza-
tion at the beginning of the semester, creating teams on GitHub, making and replicating assignment repos, and cloning the repos for grading. These processes are described in more detail in Section 4.5.

4.4 First exposure in class

Students are introduced to Git from the very beginning of the semester. On the first day of class, students create GitHub accounts with guidance from Bryan et al (2018) on choosing a username. Because a lot of students are new to using these computing tools, during the first week of class, a portion of lecture is spent discussing version control and reproducibility, why they are important, and how RStudio and Git will help us achieve those objectives.

During the first two weeks of class, students work on the first computing assignment focused on using RStudio and Git. This assignment serves as a review for students already familiar with these tools and an abbreviated introduction for those who are newer to these tools. For all students, this is their first exposure to the workflow that they will use throughout the rest of the course. Students write their responses in an R Markdown file (.Rmd), knit the file to produce a Markdown document (.md), and push their work to GitHub for submission. Periodically throughout the assignment instructions are instructions to “knit, commit, and push”: knit the R Markdown file to produce the Markdown document, commit the changes, write an informative commit message, and push the work to GitHub. The mantra “knit, commit, and push” is used throughout the semester to remind students how to connect the work they’re doing in RStudio to their assignment repo in GitHub. In addition to reminders about when to knit, commit, and push, examples of informative commit messages are also included throughout the assignment instructions. At the end of the assignment instructions is students to view their work in their assignment repo on GitHub to ensure it is the final version they want considered for grading.

Students work on one to two assignments individually before completing their first group assignment. This gives them an opportunity to become familiar with RStudio and Git and become comfortable with this workflow before introducing the additional layer of collaborating in GitHub. In the instructions for the first group assignment, in addition to the aforementioned workflow cues, students also receive cues to “pull” so they have the
most updated version of the group document and to rotate which group member types the responses. These workflow cues, along with the ones for individual assignments, are eventually removed as the semester progresses and the workflow is more routine for students.

### 4.5 Regular workflow

There are two basic workflows in the course: one for general assignments and one for the project.

Throughout the semester, students work on both individual and group assignments. The workflow steps described below are the same for both types of assignments.

- The professor creates a starter repo. The starter repo includes a link to the assignment instructions, an R Markdown file template, and a folder for the data (if needed). In the beginning of the semester, the dataset is already included in the starter repo. As the semester progresses, students download the data from the assignment instructions and upload it through RStudio.

- A copy of the starter repo is created for each student (or group) using (Rundel et al. 2019). For individual assignments, the repos are named using the template Assignment-\[Username\], where \[Username\] is the student’s GitHub username. For group assignments, the repos are named Assignment-\[Group Name\], where \[Group Name\] is the GitHub team name for a group. For example, the first individual homework assignment is named HW01-\[Username\].

- Students start a new project in RStudio Cloud by cloning their assignment repo. They configure the RStudio project with the GitHub repo by using the `use_this_config()` function in the usethis R package (Wickham & Bryan 2017–2019). Students complete the assignments in RStudio, periodically knitting, committing and pushing their work to their assignment repo on GitHub. They write up their responses in an R Markdown document and knit to produce a Markdown (.md) file.

- Once the assignment deadline has passed, the professor clones the students’ assignment repos using functions in (Rundel et al. 2019).

- The instructor uploads the Markdown files containing the student responses into (Gradescope 2019), an online rubric and grading system. Gradescope is connected
to Duke University’s course management system (Sakai 2019) along with the course management system at many other universities, so grades are securely stored within the university’s system.

In addition to regular individual and group assignments, students complete a final project in groups of three or four during the second half of the semester. The workflow for the project is generally similar to the one described above, with the exception on how they receive feedback throughout the project. At various checkpoints in the project, students receive feedback through the “issues” in their project repo on GitHub. Students can respond by commenting on the issue, which gives them an opportunity to ask questions to the professor and teaching assistants as they work on the project. This feedback system is used for the project to more closely mimic how students may exchange ideas and feedback with collaborators in GitHub outside of the classroom.

4.6 Assessment

Developing a proficiency using RStudio and Git is a learning objective for the course, so students are assessed on how they use the tools on a vast majority of the assignments in the course. Students are required to submit their work through their GitHub repo to be considered for grading, so they must learn how to “push” to GitHub in order to complete individual assignments and both “push” and “pull” for group assignments.

Each assignment includes a category called “Overall” that includes points for how students use Git. Typically three to five points are allocated for having a multiple commits throughout the assignment (usually a minimum of three commits) and informative commit messages. On group assignments, there are also points allocated for having a least one commit from each group member. This is used to hold team members accountable for contributing and to encourage groups make use of the collaborative nature of GitHub.

4.7 Other remarks

One of the most important lessons I’ve learned about using Git in a course is that student buy-in is essential. As mentioned previously, I dedicate a portion of lecture in the beginning
of the semester to introducing students to the concepts of reproducibility, version control, and how GitHub and RStudio will be used to help achieve those objectives. One semester I opted to let students read about these concepts on their own rather than discuss them in class. That semester, I observed more frustration among students as they learned how to use GitHub and more skepticism about why it was worth learning at all. Given the steep learning curve for GitHub, it is important that students understand and have bought in to the value of learning this computing skill in addition to the regular statistical content in the course.

Another lesson I have learned is to only introduce a small number of Git commands to students. There are a vast number of commands in Git, and learning too many can become overwhelming for students. Therefore, I only teach students the Git functionality they need to complete the assignments in the course. This includes how to push, pull, commit, and address merge conflicts. Additionally, having students run Git commands through the Git pane in RStudio has helped students more easily conquer the learning curve; the user interface in RStudio makes Git more accessible for students not familiar with running commands in the command line. With this approach, students develop basic proficiency in using GitHub without detracting from the primary learning objectives of the course.

Finally, if group work is part of a course, it is best for students to work on a few individual assignments before collaborating in GitHub. This provides students the opportunity to become more comfortable with the workflow using RStudio and GitHub for version control before introducing the additional functionality and considerations required for successful collaboration.
5 Teaching Statistical Programming and Git at the Master’s level (Rundel)

5.1 Background

In the Summer of 2016 I was asked to teach the first version of a new Statistical Programming course that was to be offered in the following Fall semester as part of the new Master’s in Statistical Science (MSS) program at Duke University. I was given a great deal of latitude to design the course and its content from scratch and the course was constructed around three core pillars: focus on reproducible methods, emphasize programming skills over statistics, and teach skills that are relevant. While this paper focuses on the first of these, all three are worth discussing briefly to provide the larger context of this course and the courses that have since been derived from it.

Focus on reproducible methods - modern statistics is a fundamentally computational discipline and as such effective communication of statistical results depends on having confidence in the validity of the results as well as being able to describe how the results were derived. This is not an issue that is unique to statistics but it is something that our curricula have been slow to address, but modern tooling and workflows make it easier to address than ever before. With this in mind, my courses have focused on two key aspects of reproducibility: literate programming and version control.

Emphasize programming skills over statistics - this course was only one of the 8 to 12 statistics courses the student will take as part of the MSS program, there are sufficient other opportunities for the student to learn the necessary theoretical and applied topics to become successful statisticians. This course represented the sole required course which exclusively focuses on teaching computation and hence teaching the students to be better programmers and software engineers should be the focus. This is particularly important as the students entering the program come from a wide variety of backgrounds with a significant (if shrinking) percentage having never programmed before.

Teach skills that are relevant - the reality of this and most other master’s programs is that they are expensive and the majority of the graduates are unlikely to pursue admission to a Ph.D. program, and are instead more likely to seek a job in industry. As such, one
of our obligations is to be sure that we are preparing these students for the jobs they are likely to pursue. With the rise and continuing evolution of data science this has become a moving target but it is clear that topics like data munging, databases, SQL, etc. have become far more important in recent years and it is important that that be reflected in our curricula.

5.2 Course history and related courses

This specific course has been offered every Fall since 2016 and has consistently had an enrollment of around 40 students per semester. In 2017, it was decided to add an undergraduate equivalent to the course, Sta 323, which has been offered in the Spring semester each year since and has also had enrollment of approximately 40 per semester. Finally, this year I have joined the University of Edinburgh and have had the opportunity to teach a similar Master’s level Statistical Programming course, Math 11176, which has an enrollment of around 180 students. Despite the different course levels and institutions, the composition of the students is similar, most students have little or no prior coding experience (although this is improving) with only about 10-20% having intermediate or above experience with R or other programming languages. Similarly, most students have never used or had minimal experience with Git and GitHub or any other version control system.

5.3 Infrastructure

This course and its descendants have all focused on teaching R programming, as such we have focused on introducing students to the RStudio integrated development environment. In particular, we have adopted the use of RStudio Server Pro to provide a web browser accessible computing environment that is maintainable, consistent and more powerful / scalable than students working on their own laptops.

The latter paradigm was actually used during the very first iteration of the course, in 2016, where we relied on students installing R and RStudio on their own laptops. While this approach was not a complete disaster, many hours of instruction time were lost to support and troubleshooting individual student’s laptops and software environments. Since adopting the web based interface for students there has been a significant reduction in the
support burden for both myself and university / departmental IT staff as well as a reduction in student frustration, particularly at the start of the course. Additional details on the infrastructure used for these courses is covered in Çetinkaya-Rundel & Rundel (2018).

5.4 Regular workflow throughout class

As mentioned previously, Reproducible Computing is a central pillar of the course and as such we have woven it in the core structure of the course. Specifically, the course(s) are designed around between four to eight team assignments and two individual projects, all of which are required to be completely reproducible. This is achieved by requiring that the assignments be completed using RMarkdown and turned in via GitHub as a raw / uncompiled Rmd document. This requirement is simple to state but it requires significant scaffolding and support to be successfully deployed within the classroom - particularly to get student buy in and to maintain a reasonable workload for the instructors and teaching assistants.

The initially foundation for each course is a single GitHub organization which is used as the central course management system for all course content as well as distribution and collection of student work. At the beginning of each semester students are invited to the organization and progressively given access to their team and individual repositories as work is assigned. The organization is also used to house repositories for the course website (published via GitHub Pages) and supplementary resources like the solutions to in-class exercises or the code resulting from in class live coding sessions.

For each assignment a template repository is created, which is structured using an RStudio project and contains the files necessary for the assignment. Typically, this includes a README.md which contains a detailed description of the assignment, a templated Rmd which will contain their solutions and write up, and any additional necessary support files (e.g. data, scripts, etc). These template repositories can easily be shared with teaching assistants for feedback and or training purposes, and can also be moved from previous years into new organizations for each new offering of a course. The work is assigned to the students by mirroring the template repository to either the student or their team’s private repository, using a consistent naming scheme e.g., hw01-team01, which gives them access
to their own copy of all the necessary files for the assignment and can be directly imported into RStudio from GitHub using the **New Project** GUI.

Students are then able to work on the assignment within RStudio and turn-in/collaborate by committing and pushing their code back to GitHub. Earlier versions of the course(s) focused on teaching both the RStudio Git GUI as well as the command line Git interface, but the vast majority of students preferred the former and so I have mostly dropped the latter in favor of adding other content to the course(s). At the deadline for each assignment it is simply a matter of cloning all of the assignment repositories from the organization to obtain a local copy of all of the students’ work.

In grading each student or team’s work we make a point of recompiling their Rmd to ensure the reproducibility of the work. In early versions of the course this was coupled with a course policy that work that failed to compile would receive a zero, which turned out to be almost impossible to enforce in practice. Most of the time students’ code would fail to run for relatively small issues (e.g., use of `setwd()` or loading an obscure library I did not have installed) that could be easily fixed yet caused a compilation error. It was possible to have a back and forth with the students about the errors and have them correct them but this proved too inefficient and frustrating for both the students and myself.

The solution to this has been to implement automatic feedback for the students on the basic processes of their assignment. This is done by checking their Rmds and repositories using continuous integration tools available via GitHub. Specifically, these are tools that we can deploy that will take the student’s code and run basic sanity checks: does your Rmd knit, do you only have the files we want in your repository, every time they push their code to GitHub. Previously I have used a service called Wercker for this purpose but more recently I have moved to GitHub actions to implement these checks. Implementing these tools gives students a small badge in their repository **README** that shows either green or red depending on whether the check passed or not. Additionally, they can click on these badges to get specific feedback in the case a check failed. This becomes a simple necessary but not sufficient condition for the students to examine when completing an assignment. Examples of the current GitHub action based workflows are available at the ghclass actions GitHub repository ([Rundel 2019](#)).
5.5 Implementation for the instructor

The creation, distribution, and collection of assignments on GitHub is possible in a variety of ways. In the early versions of the course much of this work was done manually or via simple shell scripts, but over time a number of tools have made this process much easier. I have used GitHub Classroom for the automation of some of this process, but have not been completely happy with its limitations - in particular how it handles the creation of team assignments. However, I have found that its roster feature is a useful way to connect students university id with their GitHub account names at the beginning of each course.

Given my own needs and the power and availability of the GitHub API, I have spent a significant amount of time developing an R package called ghclass (Rundel et al. 2019) which I use for automating almost all of my interactions with GitHub for course management. There is far more functionality than can be explored in this paper, but the core use case is for automating the creation of team and individual assignment repositories. Using the template repository based workflow described above the package is able to create new repositories, create teams, add teams or users to the repositories, and then copy the template’s contents with a single function (org_create_assignment()).

One other significant feature of the package is its ability to interact with existing repositories, particularly when it comes to adding or modifying files. This is invaluable as I regularly discover that after distributing an assignment that the provided template includes a typo, or the repository has the wrong version of a file. Rather than having to send out an email announcing the issue, ghclass allows for pushing the correction out to all of the students’ repositories in a way that is merged with any existing work, since everything is managed via Git. Additionally, given the work that has gone into implementing the necessary low level functionality we have been able to begin experimenting with the automation of higher level processes like code formatting feedback and peer review.

5.6 Implementation for the students

As stated previously the expectation is that students will use Git and GitHub for all of their assignments within the class starting from day one. In order to ease the initial learning curve for these tools, as well as RStudio, I have explicitly included at least one hour long
lecture in the first week to cover these topics. Typically, this takes the form of a very brief introduction to the idea and history of version control and Git specifically and then the remainder of the time is dedicated to a live demonstration of the tools.

At this time I have created the first assignment, which is distributed via a GitHub Classroom link - students follow the link, connect their GitHub account to a unique identifier in the roster, and then gain access to their own private repository copy of the assignment template repository. As part of the live demo I take students through this process and how to locate and interact with the repository on GitHub. This then leads to cloning, and bringing the repository into RStudio and then the basic usage of the Git Pane interface. The basic Git concepts of staging, committing, pushing and pulling are covered and we usually conclude by purposefully introducing a merge conflict and go through the process of resolving it.

Generally, this is a large amount of material for the students to absorb in a short period of time but I have found that recording the session (either via screen recording or lecture capture), providing in-person support, and having an initial individual assignment that is focused on reinforcing the workflow is sufficient to get most students up to speed. The number of Git related questions during workshops and in office hours is significant during the initial weeks of each semester, but I usually find that by the third assignment they have almost completely disappeared.

Usage of Git and GitHub has never been an explicitly assessed component of these course, however it is inherently tied to the students work as it is the only available method of obtaining and turning in their work. I have not made any specific efforts to encourage specific workflows with Git / GitHub (i.e., branching, issues, etc.) but it has been interesting to observe some of the emergent behaviors that student teams have developed for collaboration.

5.7 Acknowledgments

I think it is necessary that I acknowledge the importance of Jenny Bryan and her Stat 545 course (Bryan 2019) at the University of British Columbia as a direct inspiration for these courses. It was invaluable to see that such a course already existed and had been successful
over a number of years and the open publishing of the course materials directly influenced many of my early lectures. If I had not had a clear model of a course that was successfully using GitHub it is unlikely that I would have been willing to try it myself.

6 Computing with R and Git for Biostatistics Master’s Students (Sullivan)

6.1 Background

My first data analysis ended up being more of a learning experience than I could have ever imagined. At the time, I was new to statistics, R and programming in general. Without any formal training, I did even know that I should comment code let alone consider any kind of version control. By the time I was asked to make revisions on one of the papers, it had been almost a year since I performed the analysis. No revisions were major but my coding skills had grown and I could no longer read or understand my code. Without comments, I could not understand why observations had been excluded or the reason I recoded certain variables. Without version control I was not able to see the path that led to my final results. I had to re-write all of my code and analysis to make the necessary revisions.

Fast forwarding to being tasked with creating a graduate level programming course for Biostatistics Masters students. I realized that I needed to instill good habits in them to avoid the mistakes I had made. I also wanted to make sure that they could function in the world of reproducible research and data science.

The course started out with 15 students in Biostatistics and now is in its fifth offering and maintains closer to 50-60 students a semester. In fact due to logistical constraints 20 students had to be turned away from the course this year. It now serves students undergraduate to PhD level in multiple departments across Brown. Numerous alumni from the course work as statistical programmers in pharmaceutical or data science companies.
6.2 Course description

PHP 2560 is a Statistical Programming in R course. It is designed as a first programming course for masters students in Biostatistics. The course is in a flipped format where the students watch videos and work on exercises before class. The videos and basic exercises are on the DataCamp (2019) platform and there are more rigorous exercises that are instructor created/modified to bring the students to a higher level. Students access the more rigorous work from GitHub repositories. Many students have used R for things like data analysis in the past but none have used R to write functions, design packages and create shiny apps like this course does.

6.3 Tools and implementation

Students utilize their own computers and have the choice between installing both R and RStudio directly or utilizing RStudio Cloud (RStudio Cloud 2019). Each student creates a GitHub account and connects this to their RStudio use. Pre-class and in-class coding exercises are all placed into GitHub repositories which acts as started code for assignments created utilizing GitHub Classroom. When students accept the assignment, they use RStudio's tools in order to create a new project from their cloned GitHub repository. They are guided to utilize the “commit-pull-push” process frequently as they complete their work. GitHub classroom provides a great platform for creating and creating private GitHub repos for students. The options are easy to control and you can even assign groups if you wish.

6.4 First exposure in class

This course is about statistical programming in R, however the first couple of classes are dedicated to learning Git. Prior to any instruction in R, the students work through the basics of Git. Before the first class students work through GitHub Learning Lab (GitHub Learning Lab 2019) first days of Git and make sure they have Git, R and RStudio on their computer. During the first class, the course page which is a github.io page has a link to a starter assignment and they create an R project with this link. Then they work through typing assignments and the ‘commit-pull-push’ process. More GitHub lab assignments are
given and students spend the entire first class working with Git and RStudio.

6.5 Regular workflow

The rest of the course consists of DataCamp (DataCamp 2019) assignments and pre-class coding exercises. The pre-class work is all in one repository which students add to throughout the semester. The course github.io page contains links to either GitHub repositories for students to grab files from or an assigned project from GitHub classroom (GitHub Classroom 2019). The class consists of a 15 minute overview and review of pre-class work. Then students begin a project by cloning their assigned project in RStudio. Each class they first commit their pre-class work into the group repository, they then review and comment on each others code and commit-pull-push those comments and feedback. At this point, they begin working on group coding projects. They typically create their own scrap work file and then together decided on which code is displayed on the groups’ final results.

When they encounter their first merge error (conflict), they are instructed to work through this with the help of the instructor as well as GitHub Lab’s merge conflict tutorial. This is where it is again instilled in them to commit only the files which they have changed and worked on as well as do not commit the RStudio project file. The Git process is slow going and often frustrating at first, but it does not take long before they have very few conflicts or problems with their repos.

6.6 Assessment

The instructor and teaching assistants create feedback.md files in each repo and comment the code based on a published rubric that all students see on the course site. The use of commits, history and commit messages are some of the rubric, as well as commenting and coding structure in R. The feedback is then pushed to the student repos and they are instructed to pull from time to time in order to see the feedback.

Privacy is protected through utilization or private repos which are obtained for free through GitHub Classrooms education discounts. No one outside of course staff and the specific students in a group can see coding or information. This prevents anyone from seeing student work outside of the typical course team.
6.7  Tips for Other Instructors

Make sure you are familiar with how to get Git and RStudio implemented on various computers. Students run into problems with installations and you need to feel comfortable helping them diagnose issues. Utilize students who have things working on their computer to help others troubleshoot. This creates teamwork but also allows for more students to receive support at a time.

Invest the time to teach them up front about the workflow with Git and about which files to include in their commit. Having them avoid committing files which they did not actually change, like the RStudio project file, will minimize the merge conflicts that they have. In addition, making sure the develop habits like having their own scrap work file that only they edit, helps with both merge conflicts but also accidentally overwriting someone else’s work.

Be prepared for frustration on both the instructor and student end of this. It does not always go smoothly and sometimes it can be hard to diagnose the problem they are having. However, you will find their ability to code in teams and track their work begins to outweigh any issues.

7  Discussion (Çetinkaya-Rundel and Horton)

While there are a number of commonalities to these instructor stories, there are also some differences. In this section we provide a high level overview of some of the issues raised.

7.1  Industry (and academic) preparedness

As noted by all of the instructors, the ability to use version control systems is a highly desired skill in any industry where writing code is part of the job and the need to teach it has been recognized in the literature (Haaranen & Lehtinen 2015). Git is a widely used tool in industry for version control and code sharing. In a 2017 survey of data scientists conducted by Kaggle, over 58% of 6,000 survey respondents remarked that Git was the main system used for version control and code sharing in their workplace (Kaggle 2017). Additionally, knowing how to use GitHub is considered an essential skill in the tech field,
just as important as software development and technical writing (Zagalsky et al. 2015). In an era where many of our statistics and data science students are heading into the jobs where they will be writing code and working alongside software engineers and developers, it is essential that we equip them with these skills. Introducing Git and GitHub early, like many of the authors in the paper suggested, is a great way to ensure that by the time students finish their undergraduate curriculum.

7.2 Students need to see value of these expert-friendly tools

As instructors it can sometimes be frustrating to teach foundational tools and approaches since students often want to jump directly to fancy models or visualization.

How can we help to motivate students to think about the importance of workflow and develop internal motivation? Peter Norvig from Google (personal communication) notes that what students need most is meticulous attention to detail. Are there ways that we can help them develop and strengthen this capacity by demonstrating that source code control is a tool that can be useful to tracking their work and to help them be less error-prone? We saw multiple examples of instructor scaffolding to provide a guided introduction to the power and value of GitHub (to track and document their work) without getting lost in the details.

7.3 Start slowly and keep it simple

A key takeaway of the approaches described in the paper are how instructors have started slow and build up gradually. The instructors have adopted a “less is more” approach to avoid cognitive overload. Depending on the course, level, and mix of students, there are different expectations for what is necessary for the students. For an intro data science course with no prerequisites we certainly want students to use GitHub, but we might expect their grasp to be much less than for a capstone course. That being said, if the intro data science course included a substantive group project students will need most of what they need for a capstone).

Git takes time to get used to, it’s great to start early so by the time students graduate they may be closer to competent Git users – the goal of an intro course introducing Git is
not mastery, but as the name suggests, intro. Hence, it’s perfectly reasonable to keep the focus narrow in terms of Git actions students are exposed to.

Other more advanced features of Git are quite valuable (e.g., branching, pull requests, rebasing, HEAD). But such details might be appropriate to leave until later. Having students learn to use relatively straightforward Git workflows early on is a major win and a big step on their path to developing good habits for workflow and collaboration.

7.4 The benefits and limits of RStudio, RStudio Server, and RStudio Cloud

A common theme for our instructors is their leveraging of RStudio’s Git pane: we can’t imagine introducing Git in introductory courses without this functionality. That being said, it isn’t perfect. Students who run into merge conflicts, who need to use the `git stash` or similar commands, or who want to revert to a previous version still need to use shell commands.

7.5 Not one single path

One striking take-home observation from the instructors’ stories is that different groups follow different models with different pedagogical goals. Some of the ways students and instructors use GitHub include: 1) a pull request model, 2) full write access to individual or group project repos, 3) one repo per student per assignment model with the use of the ghclass package, or 4) same model with the use of GitHub Classroom.

There are also various approaches to assessing student work and providing feedback on GitHub. Use of issues to provide feedback is a popular approach, and it is possible to make this process more efficient and streamlined with the use of issue templates. Automated feedback using continuous integration tools like GitHub Actions is another approach that can either replace or supplement the manual feedback process via issues. Writing automated tests to fully evaluate data science assessments (that not only contain code and output but also interpretations) is difficult, and perhaps impossible, so it’s difficult to imagine how automated checkes can fully replace manual grading, but development on this front are exciting to see as statistics and data science classes grow in size. Another approach is peer
review, which has the benefit of exposing students to each others’ work and also prepares them for industry settings where code review is commonplace.

A key implication of these various approaches is that we don’t want to be too prescriptive in terms of a specific workflow. We might consider an analogy to code style: there are multiple reasonable ones, and we can (and do) engage in sometimes religious arguments about what is “right” but the key aspect is that you need to “fit in”. The same approach is important when thinking about teaching GitHub and version control.

It’s worth mentioning that there are plenty of viable alternatives to the RStudio IDE (e.g., Atom, JupyterHub, Vim) or Git for version control (e.g., Subversion, Mercurial). Several of these tools have similarly efficient integration, and it should be clear that no attempt was made to compare and contrast alternative implementations in this paper.

7.6 Why GitHub (and not GitLab, Bitbucket, etc.)?

There are a number of web-hosting platforms for projects version controlled with Git. The three most popular of these platforms are GitHub, GitLab, and Bitbucket. And among these, GitHub is recognized as the industry standard platform for hosting and collaborating on version controlled files via Git with an estimated more than 2.1 million businesses and organizations use GitHub (GitHub 2019), compared to estimated number of 1 million users on Bitbucket (Bitbucket 2019) and more than 100,000 organizations on GitLab (GitLab 2019).

In addition, GitHub provides a much richer API than the other version control systems, which allow for tools like GitHub Classroom and ghclass. For example, the ghclass package offers functionality for peer review by moving files around between GitHub repositories of students. Additionally, features like GitHub Actions can be used for immediate feedback and auto-grading of files by triggering certain code to run in the background every time students push to their repositories.

One potential difficulty with using GitHub is the fact that the student code, even if in private repositories, is hosted on GitHub servers, which means student data leaves the university. This is especially important for institutions outside of the US since there may be laws around student data leaving the country and being stored on US servers,
e.g., the European Union’s General Data Protection Regulation (GDPR). One remedy to this is for the university to enter a data protection agreement with GitHub for GDPR compliance. Another possibility is for the university to host their own GitHub server. The software associated with this, GitHub Enterprise, is freely available for academic teaching use. However the university needs to supply the hardware (server) as well as IT resources to set up the server and student authentication. Note that the latter is a much more resource intensive solution.

There is, however, an important potential danger of building curricula solely around GitHub. Until 2018, GitHub was a start-up. That year it was acquired by Microsoft. It’s impossible to tell what is next for the company. The company seems like (and states that) they are dedicated to continuing offering free private repositories for educational use, and we have no reason to doubt this. However, one wonders if building all this infrastructure around the free offerings of a for-profit company is wise? It is certainly a risk, but we note that, if you’re teaching data science, and want to stay current, instructors should be willing to take a certain amount of risk, in a calculated way such that the students don’t end up suffering consequences harshly. Staying up to date in this way can be a lot of work. Many educators and developers are investing time in building infrastructure and tooling to help others stay current with their data science pedagogy and tooling. Instructors who are not interested in the development of such tools should track what is being developed, and benefit from tools others are building and keeping updated.

7.7 Creating portfolios

Educators often mention students ending up with a GitHub profile based on their coursework to be a plus associated with teaching with GitHub. However this is not an automatic win as coursework needs to be stored in private repositories and it’s not obvious how to expose this work while conforming to FERPA, GDPR, etc.

One approach is to only allow students to convert their final project repository to be public, and let them know of specific assignments from class that are approved for reproducing in public repositories. These are usually assignments with low risk of plagiarism and/or high personalization, e.g., an assignment that is basically “choose a fun package and
do something with it”.

It is important for instructors to keep summative or overly critical feedback and any grades out of repositories that students might convert to public repositories later. Any team work also needs to be handled with care: all team members need to agree that work can be made public.

It should also be noted that it can take time for students to get their class projects into something that is portfolio worthy. Often times, a repository with just some code doesn’t make a great portfolio entry. Students need to create an informative but brief write-up that features highlights from their work, so that those browsing their portfolio know where to start looking, or more importantly, why this repository is worth looking into. One quick solution for this is a rich README. An additional step is to publish the repository as a webpage simply by turning on GitHub pages (ghpages), which will turn the README of a repo into a webpage. This process can be an official part of an assignment or provided to students as a parting gift to help increase their visibility on the web.

7.8 Automation and workflow

More advanced users (and many instructors) will benefit from the use of automation tools. For the instructor, this might facilitate auto-pulling local files, simplify returning feedback to students (e.g., a script to open all repos to the issues page, a script to pull files, add a file feedback.md that includes comments, commit, and push for many repos). The use of continuous integration tools to check for compilation may be particularly helpful as students work on more complex tools and approaches that go beyond what they can be computing on their laptops. This is an area where many new approaches are available in the research community that have not yet been widely integrated in the curriculum.

7.9 Closing thoughts

One limitation of this article is that it only provides the educator’s point of view to using Git and GitHub. It would be valuable to also collect data from students in statistics and data science courses that use Git and GitHub in order to explore how the implementation of GitHub in the classroom is associated with students’ classroom experiences, similar to
Hsing & Gennarelli (2019), which discusses such a study conducted on students in computer science courses. Future research could help inform a publication akin to Hesterberg (2015) entitled “What every statistics and data science instructor should know about version control”.
References

American Statistical Association (2014), ‘Curriculum guidelines for undergraduate programs in statistical science’, Retrieved from http://www.amstat.org/education/curriculumguidelines.cfm.

Bitbucket (2019), https://bitbucket.org. Accessed: 2019-12-14.

Bryan, J. (2018), Happy git and github for the useR, GitHub. URL: https://happygitwithr.com

Bryan, J. (2019), ‘Stat 545 website’, https://stat545.com.

Çetinkaya-Rundel, M. & Rundel, C. (2018), ‘Infrastructure and tools for teaching computing throughout the statistical curriculum’, The American Statistician 72(1), 58–65. URL: https://doi.org/10.1080/00031305.2017.1397549

DataCamp (2019), https://datacamp.com. Accessed: 2019-12-19.

Data Science in a Box (2019), https://datasciencebox.org. Accessed: 2019-12-19.

Federal Educational Rights and Privacy Act (FERPA) (2019), https://www2.ed.gov/policy/gen/guid/fpco/ferpa/index.html. Accessed: 2019-12-15.

Fiksel, J., Jager, L. R., Hardin, J. S. & Taub, M. A. (2019), ‘Using github classroom to teach statistics’, Journal of Statistics Education 27(2), 100–119.

GAISE College Report Revision Committee (2016), Guidelines for Assessment and Instruction in Statistics Education College Report. URL: http://www.amstat.org/education/gaise

Garfield, J., Zieffler, A., Kaplan, D., Cobb, G. W., Chance, B. L. & Holcomb, J. P. (2011), ‘Rethinking assessment of student learning in statistics course’, The American Statistician 65(1), 1–10.

GitHub (2019), https://github.com. Accessed: 2019-12-14.

GitHub Classroom (2019), https://classroom.github.com. Accessed: 2019-12-19.
GitHub Learning Lab (2019), https://lab.github.com. Accessed: 2019-12-19.

GitLab (2019), https://about.gitlab.com/company. Accessed: 2019-12-14.

Gradescope (2019), https://www.gradescope.com. Accessed: 2019-12-15.

Haaranen, L. & Lehtinen, T. (2015), Teaching git on the side: Version control system as a course platform, in ‘Proceedings of the 2015 ACM Conference on Innovation and Technology in Computer Science Education’, ITiCSE ’15, ACM, New York, NY, USA, pp. 87–92.

URL: http://doi.acm.org/10.1145/2729094.2742608

Hesterberg, T. C. (2015), ‘What teachers should know about the bootstrap: resampling in the undergraduate statistics curriculum’, The American Statistician 69(4), 371–386.

Hsing, C. & Gennarelli, V. (2019), Using github in the classroom predicts student learning outcomes and classroom experiences: Findings from a survey of students and teachers, in ‘Proceedings of the 50th ACM Technical Symposium on Computer Science Education’, SIGCSE ’19, ACM, New York, NY, USA, pp. 672–678.

URL: http://doi.acm.org/10.1145/3287324.3287460

Kaggle (2017), ‘Kaggle machine learning & data science survey 2017’.

URL: https://www.kaggle.com/kaggle/kaggle-survey-2017

Kaplan, D. T. (2015), Data Computing: An introduction to wrangling and visualization with R, Project Mosaic.

Kaplan, D. T. & Beckman, M. D. (2019), Data Computing, 2 edn.

URL: https://dtkaplan.github.io/DataComputingEbook

National Academies of Science, Engineering, and Medicine (2018), Data Science for Undergraduates: Opportunities and Options.

URL: https://nas.edu/envisioningds

Nolan, D. & Temple Lang, D. (2010), ‘Computing in the statistics curriculum’, The American Statistician 64(2), 97–107.
RStudio Cloud (2019), https://rstudio.cloud. Accessed: 2019-12-19.

Rundel, C. (2019), ‘ghclass actions’.

URL: https://github.com/rundel/ghclass-actions/

Rundel, C., Çetinkaya-Rundel, M. & Anders, T. (2019), ‘ghclass: tools for managing classes with GitHub’, http://github.com/rundel/ghclass.

Sakai (2019), https://www.sakailms.org. Accessed: 2019-12-15.

Wickham, H. & Bryan, J. (2017–2019), ‘usethis: Automate package and project setup’, https://github.com/r-lib/usethis.

Zagalsky, A., Feliciano, J., Storey, M.-A., Zhao, Y. & Wang, W. (2015), The emergence of github as a collaborative platform for education, in ‘Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work &#38; Social Computing’, CSCW ’15, ACM, New York, NY, USA, pp. 1906–1917.

URL: http://doi.acm.org/10.1145/2675133.2675284