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Teaching Data Reproducibility through Service Learning

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Abstract

Data reproducibility is becoming increasingly important in the social sciences, but it has yet to be incorporated into many undergraduate sociology programs. This note describes a service–learning activity that can be added to an introductory statistics course. Students partner with a nonprofit and analyze quantitative data to answer questions selected by the agency. Reproducibility is the central mechanism of communication between the nonprofit, the students, and the course instructor. An assessment of the project suggests that students achieve an understanding of how to create reproducible data. They also come to see its value as a method of communication about data decisions.

Key Words

data reproducibility, service learning, quantitative methods, statistics

One of the joys of teaching undergraduates is the opportunity to introduce them to new ideas and trends in our field. Today, data reproducibility has emerged as an important new area of focus for sociologists and other social scientists. The term "reproducibility" refers to the creation of detailed records of all the steps taken to prepare and analyze quantitative data. These records allow others to reanalyze the data, increasing confidence in the conclusions. This is why journals often require that reproducible data be made publicly available. Reproducibility is also beneficial for researchers who returns to data after a period of time and need to recreate their previous work (like the undergraduate who decides to continue with their senior honors topic in graduate school). Finally, reproducibility facilitates communication about the handling of data within research teams and between undergraduates and their faculty mentors. For all of these reasons, it is time for sociologists to think about whether and how we teach reproducibility principles to our students.

This note describes a service-learning project based on a partnership between a nonprofit agency and an introductory statistics class. The agency provides the students with research questions and data and the students conduct the analysis necessary to answer the questions. What is unique about this project, however, is that reproducibility becomes the central method of record-keeping and communication between all the parties (the students, the agency, and the instructor). In the sections that follow, we describe this project and then briefly assess its impact on student learning. Readers should note that the authors have made all the reproducibility files for this assessment available (in SPSS). These files can serve as an example for instructors interested in introducing reproducibility in their classes.

WHAT IS REPRODUCIBILITY?

The terms replicability and reproducibility are often used interchangeably but, in this project, we use the term "reproducibility" to refer to the command files that allow others to exactly recreate a quantitative analysis all the way from the original data to the final conclusions. In other words, reproducibility involves the creation of files containing the computer code that was used in both processing and analyzing the data. Importantly, reproducibility requires a researcher to document all the ways the data are modified throughout the project. For example, a record is kept every time a variable is recoded. We use the Tier Protocol, a data reproducibility system developed especially for social scientists (https://www.projecttier.org/). This protocol clearly spells out how to organize data in a way that makes it easy for others to rerun the analysis.

The term "replicability" is broader than reproducibility. It refers to the recreation of an entire experiment, not just the data analysis. For example, to replicate the famous Milgram authority experiment, one would need an extremely clear description of everything from the instructions given to participants to the conditions in the lab. While replicability is certainly important, most sociologists do not conduct experiments. We are more likely to use survey data, making reproducibility a more central issue in our work. Readers who are interested in reading about replicability and reproducibility in sociology should refer to Freese and Peterson's comprehensive article in the *Annual Review of Sociology* (2017). They argue that sociology has been slow to engage in the debate around these topics. Instead, psychologists, political scientists, and economists have taken the lead. Freese and Peterson summarize the developments in these other fields and urge sociologists to create policies appropriate for our own discipline.

LITERATURE REVIEW

At least three bodies of literature bear directly on this project: one considers the pedagogical impact of service learning, the second explores effective ways to teach statistics and other quantitative concepts, and the final literature discusses why and how to introduce reproducibility to students. First, it should be said that there is some debate in the literature about the meaning of the term "service learning." For example, it is not always clear how service learning differs from other forms of community-based or experiential learning. Drawing on several seminal works on service learning, this paper uses the term to refer to class activities that require students to work with community members (or with a community organization) to design some type of intervention based on a shared understanding of a problem. This shared understanding is attained through discussion as well as through the application of concepts learned in class. Reflection and cooperation are hallmarks of service learning (Blau et al. 1999; Eyler and Giles 1999; Huisman 2010).

There is compelling evidence to suggest that service learning is well suited to teaching a wide range of sociological concepts. For example, Huisman (2010) successfully taught the sociological imagination through an interview project with immigrants. Students in Rooks and Winkler's class (2012) worked with a local homeless agency to develop an interview–based research project. This project helped them develop an understanding of the causes of poverty. Service learning has also been found to increase students' civic engagement, to humanize the "other," and to enable students to develop critical consciousness and self–awareness (Nurse and Krain 2006; Prentice 2007; Rondini 2015).

A great deal of research has been conducted on effective ways to teach statistics. We know that many social science students enter quantitative methods classes fearful and difficult to reach through a traditional lecture format (Paxton 2006). Research indicates that interactive

learning is more effective pedagogically (Garfield and Ben-Zvi 2007; Hakeem 2001; Potter, Caffrey, and Plante 2003; Smith 1998). For example, Caulfield and Persell (2006) found that collaborative research projects improve social science reasoning as well as quantitative skills. Pfeffer and Rogalin (2012) argued that students learn more effectively through active learning and through exposure to the challenges and benefits of real–world data analysis. Similarly, in a review of peer-reviewed writing on social research methods pedagogies, Kilburn, Nind, and Wiles (2014) found that, between 2007-2013, the most common published strategies involved active and project-based learning. Tying together the findings of the service learning and statistics pedagogy literatures, Bach and Weinimmer (2011) found that students who partnered with community agencies to create and carry out a research project reported that they increased their methodological understanding and also came to appreciate the importance of research to community agencies.

The literature on teaching reproducibility to students is in its infancy, but it spans a number of disciplines. For example, Marshall and Underwood (2019) recommend including an empirical research project in a "writing in economics" upper level course. Reproducibility is central to the organization and documentation of the project. Frank and Saxe (2012) describe how students in psychology lab courses can be taught methods through reproducing other scholars' work. Ball and Medeiros (2012) describe the Tier Protocol and how to introduce it to economics students. Although mostly drawn from fields outside of sociology, there is also a repository of syllabi for courses that teach reproducibility or replicability at https://osf.io/vkhbt/. The literature on teaching reproducibility and the available syllabi contain many useful suggestions but, unfortunately, may not be an easy fit into a sociology curriculum. The project

described below is specifically intended for a sociological social statistics class and it draws on the pedagogical benefits of service learning to teach quantitative content to undergraduates.

THE PROJECT

Our project is a collaboration between an introductory social statistics class and a local drug and alcohol rehabilitation facility. Instructors thinking about implementing this project, however, could partner with any type of nonprofit as long as they have quantitative data and are knowledgeable enough to answer questions about the coding of the variables. It is not necessary that agency staff members have a high level of statistical knowledge because the students are required to present their findings in a way that a layperson can understand. To identify a partner, instructors can cold-call nearby nonprofits, but it may be more fruitful to contact their university's community outreach or experiential learning office. These groups have already established relationships with local agencies and may be able to suggest one that already has a good relationship with the university and who has worked effectively with students in the past.

Ideally, service learning benefits both students and nonprofits, but research indicates that nonprofits often receive only limited benefits. This is particularly common when the agency is not consulted about the design of the project (Blouin and Perry 2009). To ensure that our nonprofit partner benefits, we ask that they create the research questions. The class instructor does need to check carefully to make sure that 1. these questions can be answered using the statistical techniques the students have learned and 2. the data provided by the agency are completely de-identified (see the discussion of the protection of human subjects below). When the students do not have enough knowledge to answer the questions (for example, when the agency asks for a multivariate analysis of a dichotomous dependent variable), the instructor works with the nonprofit to modify the questions.

The questions we work with in our class are intended to help the nonprofit improve their services. For example, the agency has a goal of increasing rates of sobriety in the community by reducing the number of "no–shows" for appointments. This goal is based on research suggesting that treatment has a greater likelihood of success when a client attends at least four appointments (NIATx 2019). To achieve this end, the agency asks our students to analyze factors (like age group and marital status) that may predict the number of appointments attended. They then use the information to target their outreach and support efforts. Another research question asks students to analyze which of the nonprofit's various services has the highest rate of retention (for example outpatient services compared with different types of inpatient services). These data help the agency to decide where to concentrate their staff training efforts.

Our statistics class usually enrolls about 25 students, but we have successfully run the project with as many as 32 and as few as eight. During the course of the semester, we cover descriptive and basic inferential statistics. The service–learning project is most fruitful if students are able to conduct at least some inferential statistical procedures (our students most often use chi square and t-tests). Students also need to have access to SPSS (or an equivalent program) and have a basic understanding of how to operate it (for example, it is helpful if they come into the project knowing how to recode variables and run the basic descriptive and inferential operations).

We start the service-learning project about halfway through the semester with a staff member from the nonprofit coming to class to introduce themselves, the agency, and the project. They talk about why they have selected the particular research questions and the purposes to which our analyses will be put. We have found that this is also a good time for an initial discussion of how the data were entered and coded. The class instructor then assigns groups of

four to six students to work together on a subset of the questions. Students start with an exploration of the literature pertaining to their questions and then develop hypotheses based on that literature. While we have always chosen to give the groups different questions, instructors could instead choose to have all the groups work on the same set of questions. It is likely that the groups would make different decisions about processing and analyzing the data, leading to interesting class discussion. One common set of questions would also lessen the workload of the instructor.

During the period of time that the students are reading the literature outside of class, the course instructor teaches the basics of data reproducibility in class. We generally set aside one or two fifty-minute class periods for this discussion. The full Tier protocol calls for the creation of three command files (with comments that explain the code), a file with the original data and any documentation that comes with it, a file with the cleaned-up final data that was used in the analyses, and a file for the actual analyses and for the data appendix (which is like a codebook of the variables used in the analyses). We recommend that students set up their files on the Open Science Framework (a free collaborative work space for research that does not require an academic affiliation see https://osf.io/). This way, the students, the nonprofit, and the instructor can all access the files.

We should note here that instructors may find that the full Tier protocol is too complicated to teach in an introductory class. Fortunately, instructors can simplify the protocol to fit the available time. For example, students can create just one command file, rather than three. An instructor might also choose to forgo the creation of a data appendix and a readme file. To simplify things further, we recommend that instructors allow students to copy and paste the syntax from the statistical package into the command files rather than doing any actual coding

themselves (SPSS makes this easy by providing the code in the output file and other programs have a way to do this as well). Finally, rather than requiring students to set a working directory and relative paths as the full protocol recommends, instructors can allow students to simply open their data file and run the syntax files from there. Instructors who have more time should consider teaching the full protocol however. One way to make room for this is to create a partial credit lab that is associated with the statistics class.

Regardless of how much time an instructor has, there are some elements of the protocol that should not be skipped. At the most basic level, students must be taught what code is and that it can be run from a syntax (command) file rather than from the drop–down menus. Instructors should demonstrate cutting and pasting code from an output window and re–running it. For example, we often show our class how to run a simple frequency distribution and then locate the code in the output window. We copy and paste the code into a new syntax file and show the students how to run it. They can then see that the frequency distribution appears for a second time in the output window. In addition to understanding what code is and how to use it, students must learn to comment their code. Comments in the code allow students say in plain English what each piece of code does (For example with the frequency distribution described above, a student might type the following into the syntax file, **This code runs a frequency distribution of the age variable.* Note that the asterisk and period are how SPSS denotes comments). Finally, students need to understand that all data decisions and analyses must be recorded in a syntax file. This includes, for example, all recoding of variables or the removal of outliers.

One of the challenges students face in this project is that they quickly discover errors in the nonprofit's data. This happens because multiple social workers and administrators enter it very quickly. While annoying, we find the messiness of the data to be a useful teaching tool.

First, it forces students to carefully clean the data before they begin analysis. This is a good practice and it also makes them more familiar with the data as they think about each variable. Second, the messiness of the data reinforces the value of reproducibility as students see how many decisions have to be made about recoding (for example, what do you do with a person whose age was accidentally recorded as 124?). Recoding variables can be a difficult concept for students to grasp at first. For this reason, we generally talk them through recoding one or two of the variables during class time, describing how we might make recoding decisions (for example, if students have a seven-category education variable, we talk about the theoretical and practical considerations that they could use to reduce the number of categories). Because the nonprofit needs to use the data and findings later, the students come to understand how important it is to record all their decisions.

While we ask our students to do most of the work on the project outside of class, we also schedule two class sessions where the groups work together while the instructor is present. We also make it a point to hire two teaching assistants who have participated in the activity in a prior semester. Because the nonprofit is very busy, we ask that our students do not send questions to them individually, rather the instructor gathers the questions and sends them in one batch, making sure that there is no repetition.

The final part of the project occurs when the students present their findings to the agency. We use this presentation in lieu of a course final, but it could also be done during regular class time. The presentation includes both basic descriptive statistics related to their questions (What percent of clients showed up for four or more appointments?) as well as inferential statistics (Do the average number of sessions vary by age group?). The presentation is interactive and allows both the agency and the students to reflect on the project as they discuss the findings and ask

each other questions (see Mooney and Edwards 2001 for a discussion of the importance of structured reflection). The final deliverable to the agency includes the presentation slides as well as the reproducibility files.

ASSESSMENT

To assess the impact of this project on student learning, we distributed a survey at the end of the semester to our class as well as to a control group of students from a psychology class. The survey assessed student attitudes toward reproducibility, plans to use it in the future, knowledge of its mechanics, and confidence in that knowledge. As Sweet and Cardwell (2016) point out in their review of assessment in *Teaching Sociology*, the use of attitudinal measures alone is common but is not a particularly powerful form of assessment. They also point out that student confidence tends to be under–assessed in the pedagogical literature.

The survey's knowledge items involved the meaning of reproducibility and the steps that are necessary to create reproducible files. These items required write–in responses. The behavioral items were closed–choice and asked whether the students planned to use (or had already used) reproducibility in their senior thesis (all seniors at our institution are required to collect data or conduct secondary analysis of a pre-existing dataset in order to graduate). Finally, the attitudinal items asked students for their opinions about the amount of ownership researchers should have over data, how much trust should be placed in researchers, and how important it is to be able to reanalyze data. There was also an item asking how confident students feel about their ability to create a reproducible project. Finally, the experimental group received two extra questions asking how much the service–learning project enhanced their understanding of reproducibility.

While the instructors of the control and experimental groups were different, both covered the same statistical techniques (including chi square, ANOVA, t–testing, and regression). Both classes were also predominantly composed of upper–division majors. The psychology instructor covered data reproducibility during lectures but did not require students to practice it. There are a number of ways in which the control and experimental group were different from each other. For example, the students had different majors, indicating somewhat different interests and outlooks. Psychology students are also required to take more quantitative methods lab courses than are sociology majors, so it is likely that they had a higher level of preexisting knowledge about reproducibility. The control group was also slightly older than the experimental group. Just over 20 percent of the students in the psychology class were seniors, while the sociology students were either juniors (78 percent) or sophomores. Fortunately, these differences favor the psychology students, so if we find that sociology students are more knowledgeable about reproducibility, it is likely not an artifact of preexisting differences.

The data presented in Table 1 indicates that there are not significant differences between the control and experimental group in terms of attitudes. Additionally, both groups were about equally confident in their ability to create a reproducible project. Remember that readers who would like to check these analyses can rerun them using the data and SPSS command files provided (start with the readme file).

Insert Table 1 here

In order to analyze whether the service–learning project has an impact on behavior, we had to restrict ourselves to data about the plans of juniors and sophomores (who had not yet started their senior thesis) because there were no senior sociology students. This comparison indicates that the groups are indistinguishable (with 91 percent of the experimental group and 93

percent of the control group responding that they plan to use reproducible methods in their upcoming senior projects).

It appears that adding a service-learning project to a statistics class does not change attitudes, confidence, or planned behaviors over and above the impact of simply hearing lectures about reproducibility. Where stark differences appear, however, are in students' knowledge of what reproducibility is and how one achieves it. The experimental group was able to describe, in detail, the different elements a journal might require for reproducibility (command files and a data appendix for example). The control group could not give specific examples. For example, one student in the control condition said, "Probably just a detailed report of all methods and results—all your data." Of 23 responses from the experimental group, 22 gave specific examples of items that would need to be provided to the journal. The few students in the control group who gave a specific response said they would provide "detailed methods" rather than the data or command files. The survey also asked for an example of a comment a researcher might include in a command file. Students in the experimental group provided examples of comments while only one person in the control group was able to do so. It appears that lectures can impart a general sense of reproducibility and its importance, but that students do not retain specific details.

It should be noted that it is possible to teach reproducibility without a service–learning project. For example, students could use the Tier protocol to analyze a dataset that they download from the Internet (from Pew for example). The advantages of the service–learning project over this method are at least two–fold. First, our project provides an important community service. A representative from our partner agency comments, "Without the college student analysis, we would not have the manpower or know-how to generate the kinds of

information we need to apply for grants." Second, the service–learning project gives the students real–world data in all its messiness and then conveys to them that their analysis makes a difference. In the survey, we asked the sociology students what the service–learning project added to their knowledge about reproducibility over and above what they learned in the class. While one student said "nothing," the other students mentioned a range of benefits. You can see those responses in the reproducibility files if you are interested. Here we present just two quotes from students:

> Being able to think on my own and with my group about all of the implications that accompany each decision we made as researchers allowed me to see the importance of keeping a detailed account of every action we took in SPSS and wanting to present the most accurate data possible.

> You have to be very precise about how you do things so others can be able to follow what you did and see if it's correct.

Other responses to the question about the benefits of the service–learning project were similar to the students quoted above. They reported that the project helped them to learn how to create reproducible files and to understand why that is important. Additionally, we asked students to rate on a six–point scale how much the service–learning project added to their understanding of reproducibility and to their appreciation of its importance (0 represented "not at all" and 6 represented "a great deal"). The mean response for the first item was 3.68 (SD=1.67) and 4.18 (SD=1.50) for the second. While these responses were not uniformly positive, they indicate that, for most students, the project added to their understanding and appreciation of reproducibility.

HUMAN SUBJECTS AND OTHER NOTES

While this service–learning project has the potential to be a win–win for students and nonprofits, instructors must also remember that there is a third party involved: the clients of the nonprofit. Strong measures need to be put in place to protect the privacy of these clients. This is particularly important in cases like ours because we work with data from a drug and alcohol recovery center. Ideally, partner agencies will be interested in questions that do not involve individual–level data at all. For example, they might want students to correlate their financial contributions with various outreach efforts over time.

When our partner agency asks questions that do involve individual–level information we follow a number of rules. First, as Alter and Gonzalez (2018) recommend in their recent article on responsible data sharing, the agency completely de–identifies the data before we receive it. This includes removing any variables that could possibly be linked to individuals like names, birthdates, dates of admission, specific diagnoses, and—because we live in a predominately white area—race. If we conduct analyses involving age, the agency groups the data so it is not possible to identify who might be a college student (e.g. 18–25, 26–33 etc.). Second, we never present our findings to anyone but the agency itself. In other words, there is no public presentation of data or publications that result from our work. Third, the clients at the nonprofit are requested to sign a release that gives permission for their data to be analyzed in ways that help the agency improve their services. If they do not sign this release, they are not included in the data. Finally, although the data are completely de–identified, students are instructed to erase it after the

completion of the project and—if they must work on a campus computer—they are told to only save the dataset to their personal college workspace, not to the local computer.

We have worked with the Human Subjects Review Board at our university to ensure that what we are doing is ethical, but program evaluation does not technically fall under the federal government's definition of research and thus, does not require formal IRB approval (see https://ovpr.uconn.edu/services/rics/irb/researcher-guide/does-evaluation-require-irb-review/ for a good discussion of this topic). At the same time, we urge instructors to contact their local IRB to talk through their project before implementation.

In addition to human subject issues, there are other limitations and challenges associated with this project. First, it is important for an instructor to manage the nonprofit's expectations. They should know that the students are undergraduates and have only basic statistical knowledge. The reproducibility files help greatly with this situation, however, because they contain a record of all student decisions. Both instructors and nonprofits can easily check for errors that might significantly impact their findings. Second, prior to the semester, the instructor should read the Tier Protocol and its associated material. The protocol may appear to be daunting at first, but it quickly becomes second nature. For those who are interested, there is an exercise available that walks through the steps using a free Pew dataset (see https://tierexercise.voices.wooster.edu/)

CONCLUSION

In 2018, the EPA considered implementing a policy under which only reproducible research findings could be used to make policy decisions (Friedman 2018). While this policy was highly

controversial, the fact that it was proposed at all points to the growing importance of the issue. It is clear that students who go on to graduate school or to careers in data analysis will need to have an understanding of how to create reproducible data. This note describes how a service–learning project added to a statistics class can effectively teach these skills to undergraduates. Students come out of the class with an understanding of the mechanics involved in creating reproducible data. They also come to see its value as a method of communication. In addition to its usefulness in teaching reproducibility, previous research on similar projects suggest that this one is likely to reinforce students' statistical comprehension (Garfield and Ben-Zvi 2007; Hakeem 2001; Potter et al. 2003; Smith 1998) and help nonprofits who tend to lack the time or expertise to run statistical analyses. Adding reproducibility to the undergraduate curriculum is an exciting opportunity to prepare our students for the future and provide a crucial public service.

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Table 1 Comparison of Mean Assessment Scores for Control and Experimental Groups

	Experimental, N=22		Control, N=18	
Variable	Mean	SD	Mean	SD
Imagine you are in graduate school and your advisor tells you to make sure that your data are reproducible. On a scale of one to six, how confident are you that you could do that without further instruction? (0 is not at all confident, 6 is extremely confident)	3.55	1.63	3.94	1.31
On the following five-point scale, how do you feel about this statement: We should trust social scientists to be honest about how they analyze their data. (0 is strongly disagree, 5 is strongly agree)	3.73	.99	3.56	1.04
On the following five-point scale, how do you feel about this statement: Social scientists who collect their own data should have complete ownership over it. (0 is strongly disagree, 5 is strongly agree)	2.86	.83	3.17	1.04
On the following five-point scale, how do you feel about this statement: Data should be shared widely so that multiple people can re-analyze it. (0 is strongly disagree, 5 is strongly agree)	4.64	.50	4.56	.51

*In t-tests, no differences reach statistical significance