The Mathematics Enthusiast

Manuscript 1575

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Naomi J. Spence

Rachel Anderson

Sherryse Corrow

Susan A. Dumais

Lisa Dierker

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Naomi J. Spence
Lehman College, City University of New York, USA

Rachel Anderson
Bethel University, USA

Sherryse Corrow
Bethel University, USA

Susan A. Dumais
Lehman College, City University of New York, USA

Lisa Dierker
Wesleyan University, USA

ABSTRACT: This paper describes the use of scientific practices in the Passion-Driven Statistics CURE and presents the results of surveys from the implementation of this CURE at three different colleges. Overall, students experienced positive changes in thinking and working like a scientist, personal gains related to research, and gains in research skills, attitudes and behaviors. The Passion-Driven Statistics CURE aims to equip the future STEM workforce with the data analysis skills and reasoning needed across industries.

Keywords: Undergraduate research experience, Passion-Driven Statistics, data-driven course

The Mathematics Enthusiast, **ISSN 1551-3440, vol. 19, no. 3**, pp. 759–770

Introduction

Passion-Driven Statistics is a course-based undergraduate research experience (CURE) that has been used in statistics, research methods, and data science courses across a wide variety of disciplines. Funded by the National Science Foundation, Passion-Driven Statistics empowers students to take the lead in the decision-making, execution of scientific inquiry, and the production of new scientific knowledge [DK]. Utilizing a flipped classroom approach, students learn statistical programming in the pursuit of managing, analyzing and interpreting data. Liberal arts colleges, large state universities, regional colleges/universities, medical schools, community colleges, and high schools have all successfully implemented the data-driven CURE curriculum [DR, RD].

Published research has shown that students enrolled in Passion-Driven Statistics are more likely to report increased confidence in working with data and increased interest in pursuing advanced coursework [DW]. This data-driven CURE was also shown to promote further training in data and applied statistics. Using causal inference techniques to achieve matched comparisons across three different statistics courses, students originally enrolled in Passion-Driven Statistics were significantly more likely to take at least one additional undergraduate course focused on statistical concepts, applied data analysis, and/or use of statistical software compared to students taking either an activity-based psychology statistics course or a traditional lecture-based math statistics course [NR]. Further, Passion-Driven Statistics students took a larger number of these additional courses compared to students originally enrolled in either of the comparison courses.

Because of the focus on programming in the context of data analysis, we have also compared enrollment of the data-driven CURE to traditional introductory programming experiences, revealing higher rates of female and under-represented minority enrollment compared to both a general introductory programming course and an introductory course representing a gateway to the computer science major [CD]. Overall, when compared to both traditional introductory statistics and introductory programming courses, the data-driven CURE has been shown to attract students from a much wider range of academic backgrounds as measured by Math SAT scores [CD, DCS].

This paper describes the use of scientific practices in the Passion-Driven Statistics CURE—discovery, iteration, collaboration, and broad and relevant work write [AU]—and presents data from pre- and post-course surveys from the implementation of this CURE at three different colleges. The results highlight the promise of this model for getting students hooked on the power and excitement of research. Overall, students experienced positive changes in thinking and working like a scientist, personal gains related to research, and gains in research skills, attitudes and behaviors. The Passion-Driven Statistics CURE aims to equip the future STEM workforce with the data analysis skills and reasoning needed across industries.

1 Use of scientific practices

The Passion-Driven Statistics CURE provides an opportunity to become fluent in the work of quantitative research. Allowing flexibility for the discretion of each instructor, this CURE provides the structure for students to engage in the following steps:

1. Reading through data dictionaries focusing on topics or constructs that they find relevant and interesting.

2. Developing a hypothesis based on the available data.

3. Conducting a review of the literature evaluating previous work related to the hypothesis and evaluating how they will contribute to the existing literature.

4. Using statistical software (e.g., SAS, R, Stata, Python and SPSS) to examine frequency tables, variability and central tendency for the selected variables.

5. Performing data management on the chosen variables (e.g. setting aside missing data, creating a new variable by collapsing response categories, creating a new variable by aggregating across more than one variable, and/or labelling variables).

6. Graphing individual variables and the associations between pairs of variables.

7. Evaluating associations with inferential statistical tools.

8. Testing for moderation (i.e. differences in observed associations based on a third variable).

9. Building and evaluating multivariate models.

10. Interpreting and presenting results.

The curriculum covers basic themes such as measurement and interpreting statistical results, emphasizes choosing analytic techniques that are appropriate for the data, and using software and coding to generate statistics, without neglecting the underlying theory and mathematics. For example, in hypothesis testing, students learn fundamental concepts related to making inferences about populations from samples, including the role of probability; sampling variability and distributions; central limit theorem; significance levels (p-value); Type 1 and Type 2 errors.

To test bivariate hypotheses, students learn to choose analysis of variance (ANOVA), chi square test of independence, and/or Pearson correlation as suitable for their research questions and variable measurement. As an example, the ANOVA lesson introduces students to the calculation of F as the ratio of the variation among sample means to the variation within groups; the use of boxplots and scatterplots to visualize variation; and interpreting F with the associated p-value. When making multiple group comparisons, students are taught post-hoc tests to avoid excessive type 1 error with an explanation of family-wise type 1 error rates calculated as:

$\alpha_{FW} = 1 - (1 - \alpha_{PC})^c$, where c is the number of comparisons and α is the normal Type 1 Error (.05).

Then, they are shown how to use code to run Tukey's HSD test and how to interpret the results of differences in means between groups with confidence intervals and associated p-values.

In addition, great care is taken to present translations of terminology and vocabulary that are used across different disciplines for similar statistical concepts (e.g., independent and dependent variables vs. predictors and outcomes vs. explanatory and response variables). Students are immersed in the practices of real scientists, including discovery, collaboration, iteration, and broadly important work.

1.1 Discovery

Passion-Driven Statistics is designed to take advantage of students' natural curiosity and provide a common language for approaching questions across numerous disciplines. This CURE is based on original questions and hypotheses that are driven by students' passions. Students begin by examining variables available for the class (from public datasets and codebooks), which precludes them from choosing research questions for which data are not available to address. Students work individually or in pairs to pose a research question that interests them. Some examples include: *Is exposure to a drug use prevention curriculum associated with lower rates of experimentation with substances? Is there a relationship between migraine headaches and educational attainment? What factors predict 'safe sex' practices?* This helps students recognize the usefulness of data for answering questions of interest to them and to society.

After choosing questions, students do a literature review to discover what is already known about their topic of interest. Through this process, many of these students find that a lot is already known about their choice. For example, a student might pose the research question *Does childhood abuse increase the incidence of mental health issues?* and discover that much has been published on this topic. This can be discouraging at first, but students are guided in approaches to refine the research question, hone in on a subset of the sample, and/or explore different measurement approaches to allow for novel discoveries. Many projects combine some replication of prior studies with an extension of what is already known. When lesser studied questions are posed, students may struggle to find relevant research in their literature searches, but in such cases, students are thrilled to have the outcome of their research question be unknown and discover things that have yet to be known by the larger scientific community.

It is not uncommon for students to find results that are unexpected or the opposite of what they hypothesized. As an example, a student investigated the role of religiosity in feelings of support during difficult times. The analysis revealed that people who reported strong reliance on their faith and regular attendance of faith-based services also reported the lowest amount of support during difficult times. This was not what the student expected to find. This led the student to seek additional literature review to help explain these results.

Students think critically about their research questions throughout the steps of the research process. One thing that makes the Passion-Driven Statistics approach unique is students become proficient in statistics as their own research questions dictate. It is through the processes of discovery and collaboration that students learn how scientific knowledge is produced.

1.2 Collaboration

This data-driven CURE is designed to support large numbers of students through a collaborative mentorship model involving the students, peer mentors and instructors to learn the statistical software and the process of executing a research project. While each project reflects the individual student's interests and efforts, it is the result of a collaborative process of thinking through each step of the research process. As students engage in productive struggle in the context of doing original research, the instructor and peer mentors support each student individually through ample one-on-one mentoring.

When possible, and commonly in classes with an enrollment greater than 15–20 students, peers who previously completed the CURE are involved in the mentoring process. Peer mentors may serve as volunteers because of a desire to learn the specific software being taught, be paid through student work programs or training grants, or receive course credit as teaching assistants or through other course designations (e.g., a statistics education practicum). Peer mentors may also be part of the collaborative research environment when simultaneously investigating a new research question of interest to them. For example, one peer mentor, who sought to conduct research in conjunction with another course, independently found an open dataset with variables about cognitive and emotional effects of implicit and explicit racism. As part of this cross-course collaboration, she completed a literature review, generated a novel research question, analyzed the data using her skills acquired in the Passion-Driven Statistics course.

In the classroom, there are multiple levels of collaboration occurring simultaneously. On the student-to-student level, students may learn which of their classmates are working on similar research questions so that those students have the chance to bounce ideas off each other (e.g., decisions about recoding variables). Because the peer mentors have been through the CURE themselves as students, they are a critical component of the learning environment. Students feel comfortable asking the peer mentors for advice because the peer mentor genuinely understands the student perspective. With regard to using statistical software, students work together as a class or in smaller groups to master it, as they work to manage and analyze the data. The instructor and peer mentor provide practical and moral support. They model the thought processes and demonstrate that research can be a trial-and-error process (e.g., through being "stumped" by an issue or making coding mistakes and fixing them). Collaboration also serves to help students avoid pitfalls and not flounder on a challenging task.

By supporting students as they make decisions about the most appropriate ways to visualize, explore, and analyze data, the CURE emphasizes conceptual understanding and application in the context of authentic research. Rather than focusing on rules associated with traditional lists of tools, the CURE proceeds with the decisions and skills involved in quantitative research. The Passion-Driven Statistics CURE takes students completely out of their comfort zone, but the collaborative process "loves them through it" by creating an inviting classroom culture and an experience that gives them a safe and supportive space to "get it wrong before they get it right." In that way, the CURE develops students' conceptual understandings through the iterative processes in the context of their own authentic research.

1.3 Iteration

The Passion-Driven Statistics CURE provides a foundation for understanding the iterative nature of science research beginning with an introduction to data sets and conducting a literature review of primary source research articles. These first components of the CURE teach students to understand the cumulative processes through which data are collected and research studies are conducted, while prompting them to use this insight to develop their own research questions using data codebooks and literature review. Subsequently, data management, exploratory data analysis, and inferential analysis enable preliminary hypothesis testing and implicate additional variables and measurement approaches.

During data management and exploratory data analysis, variable measurement is frequently revised to distinguish the research from existing studies identified in literature review. Students may also identify empirical reasons (e.g., small cell sizes) to revise construct measurement as a result of their data analysis. Further, the Passion-Driven Statistics CURE teaches moderation and confounding to have students incorporate additional variables, rule out alternative explanations, and increase confidence in the findings. As students hone variable measurement and build models, each iteration may require: revisiting literature review to ensure that their approach is novel; additional data management to recode variables; revised exploratory data analysis and graphing to generate descriptive statistics and visualizations representing any measurement changes; alternate inferential statistical analysis as appropriate for variable measurement.

The concluding portion of the Passion-Driven Statistics CURE engages students in the processes of evaluating their hypotheses to make claims that are supported by evidence. In developing papers or presentations of their research project, students reflect upon the numerous iterations and summarize the insights gained through the use of statistics to address research questions on their chosen topics. As with all dissemination of scientific research, students are faced with the final challenge of culling out the relevant details and concluding with implications for future research.

1.4 Broadly relevant or important work

Because the Passion-Driven Statistics curriculum provides the opportunity for students to build on current scientific knowledge (i.e., discovery), this CURE encourages students to share their novel discoveries with their local and academic communities. Students have presented their research posters at local, state, national, and international conferences. Commonly, many Passion-Driven Statistics sites hold poster presentation sessions that allow not only for a meaningful summative assessment of student learning but also the opportunity for students to situate their results within the context of previous research. At this concluding event, students describe their process of inquiry, including their premises, decisions made along the way, conclusions, and any barriers that they faced to audiences of peers, instructors, and external experts. In many cases, poster sessions are open to the campus community, or even to the local community. In this way, students disseminate their novel research findings and come away from the experience with a sense of pride about their contribution to knowledge. This is amplified by the community reaction to their findings, emphasizing the importance of their research questions, findings, and hard work invested. This poster presentation provides an empowering capstone experience.

Students have also utilized their skills gained in Passion-Driven Statistics to support their involvement in larger research projects (e.g., senior project or as a research assistant). This gives the opportunity for them to expand upon the knowledge gained through this CURE. At the end of the course, students have developed the passion for doing statistics and enough of a foundation in statistics for them to branch out into learning more advanced statistical techniques. For example, one biology major used their Passion-Driven Statistics skills to evaluate a biological dataset for their senior project and presented it in a senior symposium. Another student (and peer mentor) began working with a faculty member on a neuroscience research project analyzing a large dataset. This project was part of an international collaboration between several labs. She used the opportunity to execute her Passion-Driven Statistics skills, conduct a secondary analysis of the dataset, and examine the potential for additional discoveries and pathways to publication. The aforementioned peer mentor studying cognitive and emotional effects of implicit and explicit racism subsequently wrote a manuscript that was submitted for publication in an undergraduate research journal. In each of these examples, students have transferred the skills from Passion-Driven Statistics into their own disciplines, in some cases even opening doors for research publications.

2 Current Analyses

To date, assessment has largely focused on outcomes related to statistics skill building and intentions to pursue upper division courses focused on data and applied statistics. In the present analyses, we examine self-reported gains made in three areas: thinking and working like a scientist, personal gains related to research and skill building.

2.1 Participants

Pre- and post-course survey data from 166 students enrolled in the Passion-Driven Statistics CURE during the 2018-2019 academic year and during fall semester 2019 at three different post-secondary institutions were examined. These participants included 29 students from a private liberal arts college in the Midwest, 51 students from a public college system, and 86 students from a liberal arts college in Northeast. Class sections were each taught by one of the authors. The average enrollment per class section was 23 (median= 25, range: 16–35 students).

2.2 Courses

One or more of the following data sets was made available to students enrolled in the CURE as the basis for their chosen research project: Wave 1 of the U.S. National Epidemiologic Survey of Alcohol and Related Conditions; Wave 1 or Wave 4 from the U.S. National Longitudinal Study of Adolescent to Adult Health; the General Social Survey; and the Outlook on Life Survey.

Each implementation of the CURE was considered introductory; however, within the public college it is taught as an introductory statistics course that has a required prerequisite of an introductory research methods course. CURE course titles included Introduction to Statistical Methods and Experimental Design, Applied Data Analysis, Psychological Statistics, and Quantitative Analysis of Sociological Data. Each instructor chose the statistical software platform to be used in their course. These included R or SAS. At each school, the CURE course counted toward or was required by one or more majors, primarily including psychology, sociology, nursing and neuroscience. Final products were either a research paper or a scientific poster for presentation.

2.3 Measures

The pre-course survey was completed prior to the end of the second week of classes and the post-course survey was completed during the last weeks of the semester. Each survey took approximately 10-15 minutes to complete.

Background characteristics measured in the pre-course survey included age, gender race/ethnicity, first-generation college student status, class standing, previous statistics courses, any programming experiences, whether required for their major and likelihood of taking the course if it were not required.

The Undergraduate Research Student Self-Assessment (URSSA) was used to measure self-reported gains in thinking and working like a scientist, personal gains related to research, gains in research skills, and attitudes and behaviors. Previous research has shown that the URSSA represents separate but related constructs for cognitive skills and affective learning gains from the undergraduate research experience. Average scores formed reliable, moderate to highly correlated composite measures. Student learning gains have been shown to correlate with ratings of satisfaction with external aspects of the research experience [WES].

2.4 Results

A comparison of demographic and other background characteristics among students enrolled in the CURE at each of the three schools is presented in Table 1. Students from the public college were significantly more likely to be female, underrepresented, and the first in their family to attend college compared to students from both private liberal arts colleges. They were also more likely to be juniors or seniors and to have previously taken a statistics course. Students from the liberal arts college in the Northeast were more likely to have had previous experience with programming compared to students from the public college and the Midwestern liberal arts college. The majority of students enrolled in the CURE to fulfill a requirement for their major though this was true of somewhat fewer students in the Northeastern liberal arts college compared to Midwestern liberal arts college.

Despite these differences in demographic and background characteristics, Analysis of variance (ANOVA) models comparing mean ratings on each of the URSSA survey items assessing self-reported post-course gains were not statistically different among the three schools, before and/or after adjustment for multiple comparisons.

When considering gains *related to thinking and working like a scientist*, Figure 1 shows that more than half of students completing the Passion-Driven Statistics CURE reported "great gain." More than

	Private Liberal Arts College (Midwest) $n = 29$	Public College $n = 51$	Private Liberal Arts College (Northeast) $n = 86$	Statistics		
Age: n (s.d.)	Mean=19.3[a] (s.d. 0.59)	Mean=29.2[b] (s.d. 9.39)	Mean 20.2[a] (s.d. 3.71)	$F(2, 162) = 44.0$		$p < .0001$
Gender: (% female)	21 (72.4%)[b]	44 (93.6%)[a]	48 (56.5%)[b]	$X^2 = 20.0$	df 2	$p < .0001$
Under-represented minority (URM)	2 (6.9%)[b]	43 (84.3%)[a]	20 (23.3%)[b]	$X^2 = 65.4$	df 2	$p < .0001$
First generation student	5 (17.2%)[b]	26 (51.0%)[a]	30 (25.3%)[b]	$X^2 = 9.2$	df 2	$p < .0098$
Class standing (% freshman or sophomore)	23 (79.3%)[a]	3 (5.9%)[b]	62 (72.1%)[a]	$X^2 = 66.1$	df 2	$p < .0001$
Previously taken a statistics course	7 (24.1%)[b]	41 (80.4%)[a]	38 (44.2%)[b]	$X^2 = 27.6$	df 2	$p < .0001$
Previous experience with programming	3 (10.3%)[b]	9 (17.7%)[b]	36 (42.4%)[a]	$X^2 = 15.4$	df 2	$p < .0004$
Required course for major	28 (96.6%)[a]	40 (78.4%)[a,b]	61 (70.9%)[b]	$X^2 = 8.24$	df 2	$p < .0162$
Likelihood of taking the course if not required	Mean 2.0[c] (s.d. 0.78)	Mean 2.5[b] (s.d. 1.03)	Mean=3.2[a] (s.d. 1.07)	$F(2, 162) = 18.1$		$p < .0001$

Table 1: Background Characteristics by School. Mean (M) and standard deviation (s.d.) presented for quantitative variables; n and % presented for binary variables. Percentages are based on valid responses Results of post hoc paired comparisons are denoted with superscripts (a,b,c). Statistics sharing the same superscript within row are statistically similar. The Duncan test was used following ANOVA and a $p < .0166$, Bonferroni adjustment was used for Chi Square Tests of Independence.

85 percent reported either "good gain" or "great gain" for *analyzing data for patterns*, *figuring out next steps in a research project*, *formulating a research question that could be answered with data*, and *understanding the relevance of research to my coursework.* Between 75 percent and 85 percent of the sample reported good or great gain for the remaining items (i.e., *problem solving, identifying limitations of research methods and design, understanding theory and concepts guiding my research*, and *understanding the connections among scientific disciplines*). As displayed in Figure 2, more than 75 percent of the sample reported good or great personal gains related to research which included *confidence in contributing to science, comfort in discussing scientific concepts with others, ability to work independently, developing patience with the slow pace of research, understanding what everyday research work is like* and *taking greater care in conducting procedures.* Fewer than three quarters of the sample (60-71 percent) reported good or great gains in comfort in working collaboratively with others and confidence to do well in future science courses.

The largest gains in research skills (see Figure 3) were reported for *preparing a scientific poster, using statistics to analyze data, choosing the correct statistical test for your question*, and *coding or writing computer programs* with more than 80 percent of the sample reporting good or great gains. The most highly rated items in the attitudes and behavior scale (shown in Figure 4) included *trying out new ideas or procedures on your own* and *feeling responsible for the project.* A total of 39.9 percent and 67.5 percent of the sample, respectively, reported these "a great deal".

3 Online Format

Having moved to online formats in March 2020, students, mentors, and instructors originally faced some challenges, but ultimately, the flow of the CURE and the collaborative process succeeded. In general, we found that students were more engaged with their peer groups than in previous semesters, perhaps due to the "closed" nature of the breakout rooms in Zoom and their ability to easily share their screen with their peers in the troubleshooting process. While we find the course is more enriching when taught in person, the course transitioned well to an online format particularly when taught synchronously.

4 Discussion

Taken together, our CURE was successfully delivered within multiple post-secondary educational settings and provides a promising model for getting students hooked on the power and excitement of research.

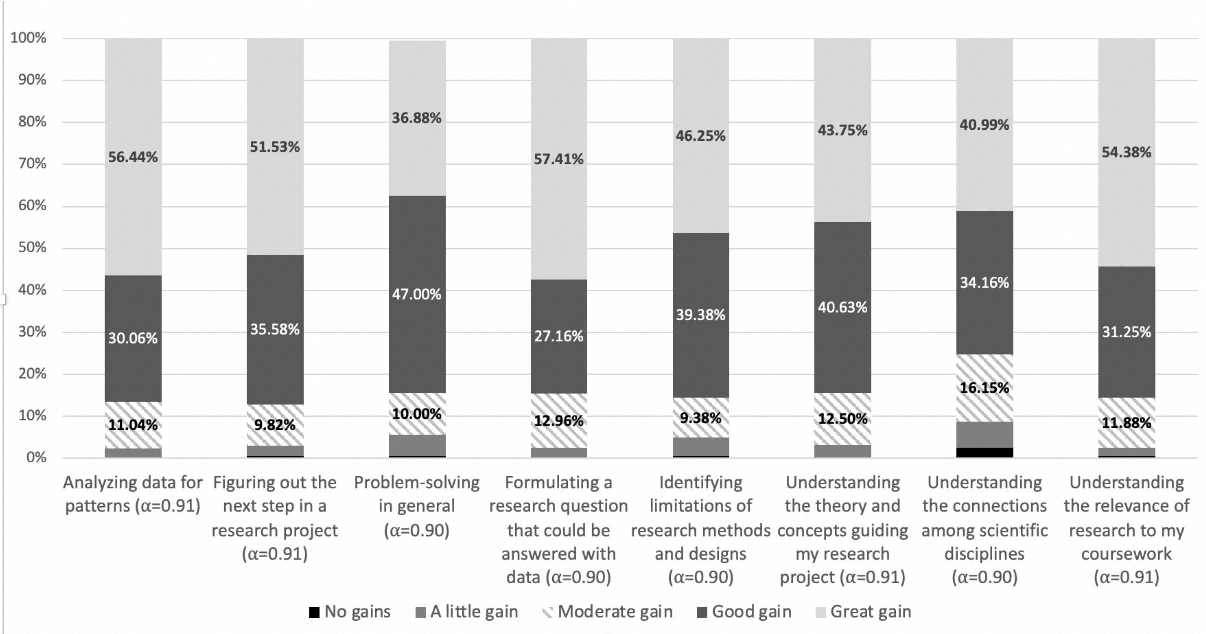

Figure 1: URSSA Evaluation of Gains in Thinking and Working Like a Scientist

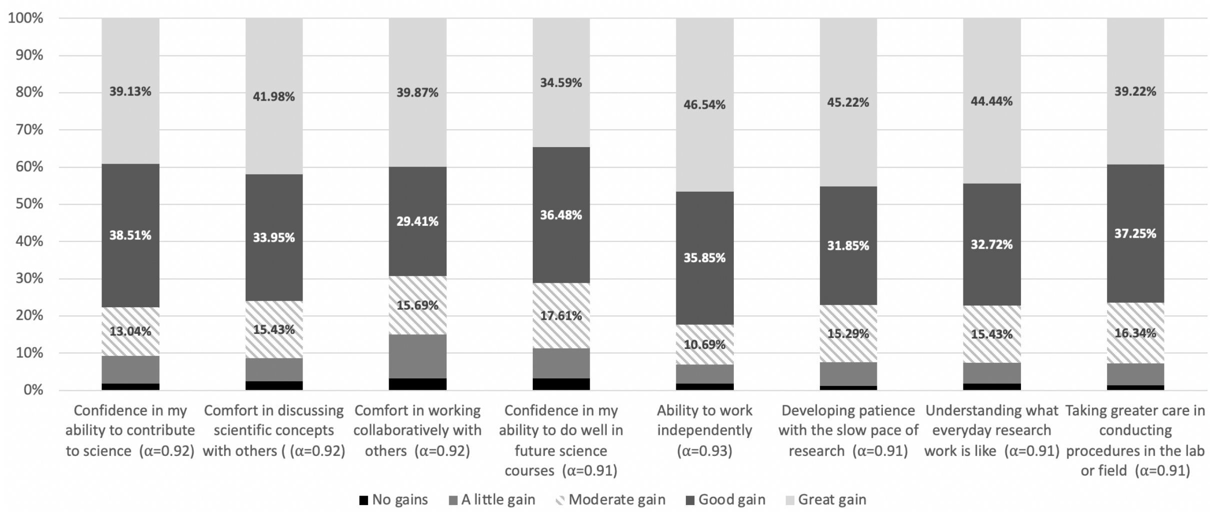

Figure 2: URSSA Evaluation of Personal Gains Related to Research

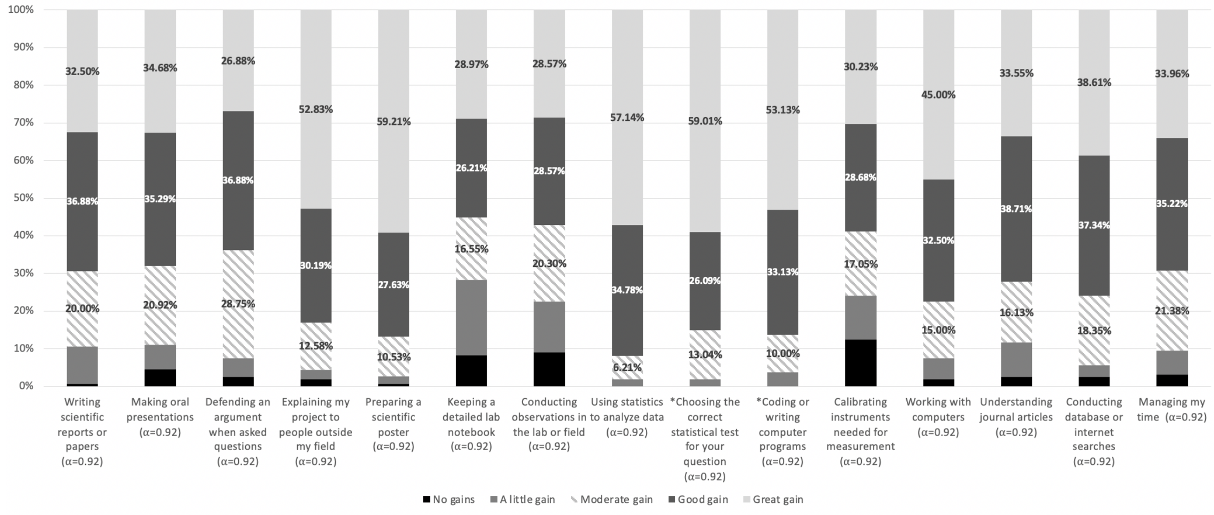

Figure 3: URSSA Evaluation of Gains in Skills

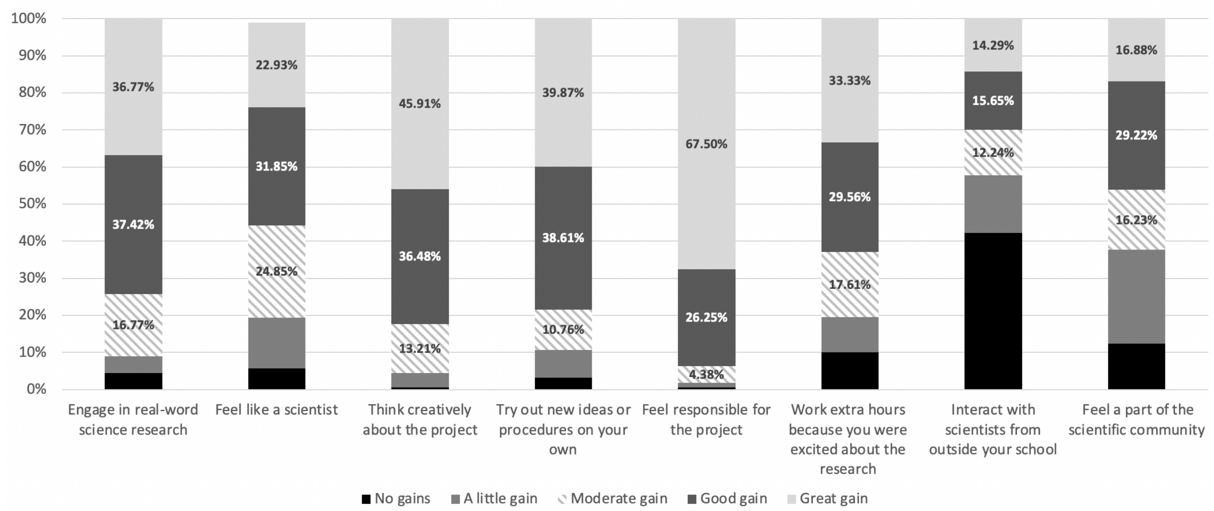

Figure 4: URSSA Evaluation of Gains in Attitudes and Behaviors

High proportions of enrolled students reported good and great gains in thinking and working like a scientist, personal gains related to research, gains in research skills, and in attitudes and behaviors, despite differences in demographic characteristics of students across the three sites.

There is ample evidence that the highest-paying, in-demand jobs now require specialized or general skills in data analysis, data processing and applied statistics [GLA]. While these and other technical occupations have been predicted to rise by 17.7 percent between 2012 and 2022 [USB, USB2], the relevance of data-oriented skills in many other growing careers and industries, previously less directly focused on analytics (e.g., health care and manufacturing) is also expanding [USB3]. It is critical that data-oriented CUREs become common, mainstream opportunities at the college level. As has been described by many previous authors, it is important that these experiences are provided early and often.

Dissemination of the Passion-Driven Statistics CURE has proceeded through the sharing of open educational resources (OER), and supporting materials can assist the analysis phase of other CUREs in which data is collected on a variety of topics. Resources are available at `https://passiondrivenstatistics.com/`. See also our free e-book at (`http://bit.ly/Passion-DrivenStatistics`), with links to videos that allow you to “flip” the classroom and translation code (`http://bit.ly/PDS_TranslationCode` aimed at supporting the use of statistical software across all of the major platforms (i.e., SAS, R, Python, Stata and SPSS). We have developed a community of instructors who share additional ideas and resources though a devoted Slack channel and space on `Schoology.com`. For access to this community, you may contact the fifth author. Despite ample available resources, any CURE that starts with real data, encourages students to develop their own questions, and teaches all that is needed to answer those questions has already embraced this model! Whether you use our resources or your own, we have found this to be an engaging and empowering experience for students.

Acknowledgment. *The development of this course and supporting instructional materials was supported by grants no. 0942246, 1323084, and 1820766 from the National Science Foundation, Improving Undergraduate STEM Education (IUSE).*

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Dr. Naomi Spence is an Associate Professor of Sociology at CUNY Lehman College. She received her Ph.D. in Sociology from Florida State University and completed postdoctoral training in Social Demography and Life Course Studies at the Carolina Population Center, University of North Carolina at Chapel Hill. Her research on the demography of families and health focuses on lesser studied groups and the consequences of non-normative experiences in U.S. society.
Department of Sociology, Lehman College, City University of New York, Bronx 10468, USA
Email address: `naomi.spence@lehman.cuny.edu`

Dr. Rachel Anderson is an Assistant Professor of Psychology at Bethel University. She received her Ph.D. in Behavioral Neuroscience from the University of Iowa and completed postdoctoral training at the University of Minnesota. Her research focuses on how psychological stress alters prefrontal cortex functionality and structure.
Email address: `rm-anderson@bethel.edu`

Dr. Sherryse Corrow is an Associate Professor of Psychology at Bethel University. She received her Ph.D. in Developmental Psychology from the University of Minnesota and completed postdoctoral training in Neuroscience at the University of British Columbia. Her research interests focus on face processing, with a particular emphasis on the characteristics and treatment of prosopagnosia, a deficit in the recognition of faces. *Email address*: `s-corrow@bethel.edu`

Dr. Susan A. Dumais is an Associate Professor of Sociology at CUNY Lehman College and the Graduate Center. She received her Ph.D. in Sociology from Harvard University. Her current research focuses on the educational experiences and outcomes of college students from underrepresented backgrounds. *Email address*: SUSAN.DUMAIS@lehman.cuny.edu

Dr. Lisa Dierker is the Walter Crowell University Professor of Social Sciences and Professor of Psychology at Wesleyan University. She received her Ph.D. in Developmental Psychology from the University of Connecticut and completed postdoctoral training in Epidemiology at the Yale School of Medicine. A researcher of addictive behaviors, her more recent work based on the NSF-funded Passion-Driven Statistics Project centers on the dissemination of innovative pedagogical practices. Email address: ldierker@wesleyan.edu