The "Math Prefresher" and the Collective Future of Political Science Graduate Training

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ABSTRACT The political science math prefresher arose a quarter-century ago and has now spread to many of our discipline's PhD programs. Incoming students arrive for graduate school a few weeks early for ungraded instruction in math, statistics, and computer science as they relate to political science. The prefresher's benefits, however, go beyond its technical content: it opens pathways to mastering methods necessary for political science research, facilitates connections among peers, and—perhaps most important—eases the transition to the increasingly collaborative nature of graduate work. The prefresher also shows how faculty across a highly diverse discipline have worked together to train the next generation. We review this program and advance its collaborative aspects by building infrastructure to share teaching content across universities so that separate programs can build on one another's work and improve all of our programs.

Math prefresher (or "math camp") programs in political science invite newly admitted PhD students to graduate school a week or two before their official start date to attend classes in math, statistics, computer science, and related technical material designed especially for them. Although differences exist among universities, the usual pattern has students attending lectures in the morning, working on problem sets together in the afternoon, and having informal lunches with faculty who have differing perspectives across the department. Typically, no grades are assigned and individual attendance records are not kept. Most programs are entirely voluntary; however, almost all students choose to attend the entire program, regardless of their background or interests. A faculty adviser organizes and guides the program, and senior graduate students or faculty serve as instructors.

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The program turns out to have substantial benefits well beyond the specific technical material learned. It has value for pedagogy, showcasing different pathways to learning various methodologies, building camaraderie in the entering class, and forging connections with senior graduate students. Perhaps most important, the program eases the transition from undergraduates studying mostly on their own to graduate students who learn to work collaboratively. Experience with the math prefresher also highlights a valuable example of how faculty from all parts of a highly diverse discipline have worked together to design an introduction to graduate training. As a result, versions of the math prefresher program have been adopted by political science departments across many universities and other social science disciplines.

Despite its prevalence as the de facto introduction to a graduate program, the prefresher has not been widely discussed in the discipline, perhaps because faculty advisers design prefreshers primarily for their own department. Based on our 25-year experience and interviews with instructors from nearly 20 different graduate programs, we clarify the advantages of the prefresher in helping students transition to collective learning styles. We then discuss the role of and reason for math as the substantive content in the math prefresher. Finally, we propose to take the idea behind the prefresher to the next level by building open-source infrastructure to share teaching materials across political science prefreshers at different universities so that new and existing

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programs can build on one another's work and improve all of our programs.

GRADUATE SCHOOL AS A TRANSITION TO COLLECTIVE LEARNING

Graduate school in political science is not merely advanced study and it is not merely more focused study. It is a time of transition to a collective model of teaching and learning, one in which collaboration, cooperation, contributions to the broad literature, and connections among students, the department, the university, and the profession are increasingly central. For instance, rates of article coauthorship in leading political science journals have grown spectacularly since the 1950s—with increases from 638% to 1,739%, depending on the journal (Teele and Thelen 2017). As the first collective event of graduate school designed for learning, the math prefresher begins this transition.

Although undergraduates have many collective experiences—from residential and extracurricular activities to study groups—their intellectual experience is relatively solitary compared to graduate students. Each undergraduate is evaluated alone and graded individually and frequently. Although graduate students begin with classwork as they did as undergraduates, every step along the way eases them into the broader community of scholars—beginning with taking orders from the professor to taking the initiative and collaborating with others as colleagues. What matters is that graduate students learn how to do research, become comfortable teaching others, practice collaboration, begin to understand how to manage a research team, and contribute to a broader literature.

Another important part of this transition is a change in the nature of relations between students and faculty as graduate school begins. Faculty want more connections with graduate students because they help faculty achieve their career objectives as teaching and research assistants, coauthors, and members of the scholarly research community. Moreover, in sheer numbers, the graduate student–faculty ratio is on the order of 20 times smaller than for undergraduates. The collective-learning structure of the math prefresher, therefore, prepares incoming graduate students for deeper engagement and collaboration with colleagues—faculty and fellow students alike.[1]

THE IMPORTANCE OF COLLABORATION AND HOW TO FOSTER IT

A typical review of the math prefresher might merely summarize which technical material is taught in different departments. However, the math prefresher also plays a more fundamental role in introducing students to the transition to collaborative learning. Therefore, we begin with these benefits and how we facilitate the transition.

To facilitate the transition away from the undergraduate model of evaluation, most math prefreshers issue no grades, and the ones that do make it clear to students that grades will not be tracked in their transcript. At Harvard, we convey that if you want to learn this material, we will help; if you do not, that is up to you. Motivation comes from the student or not at all. Of course, we are social scientists and know how to use behavioral incentives to turn the anxiety we all remember prior to starting graduate school into motivation and action (!); however, student motivation is rarely in short supply for incoming students.

Instead, the main challenge in fostering collaboration is to "level the playing field" for the incoming class. Instructors must teach to the wide range of technical backgrounds of the usual incoming students (see appendix figure 1). To overcome these initial barriers, we have found it helpful to provide resources for students to review during the summer before arriving on campus, assign them to small groups during the prefresher to encourage peer-to-peer learning, and emphasize community and cooperation by identifying each other's comparative advantages.

The practice of collaboration and drawing on one another's comparative advantages prepares students well for the remainder of their graduate school career and beyond. This is an industry in which helping competitors helps ourselves, and this initial experience before graduate school helps orient students in this productive direction.

WHY TEACH MATH IN THE PREFRESHER?

As the first intellectual experience students encounter, the material taught in the prefresher should be designed for the motivations and interests of beginning political science graduate students. This is the main difference between a political science math prefresher and a generic mathematics review.

Perhaps most important, the program eases the transition from undergraduates studying mostly on their own to graduate students who learn to work collaboratively.

The path to graduate school in political science often involves intentionally forking off to the social sciences or humanities and leaving behind possible careers in mathematics, science, and engineering. Thus, landing in graduate school and learning that many parts of political science require heavy doses of math, statistics, programming, and other technical material can feel like a breath of fresh water. This is not a flaw in our student pool; we want students focused on the substance of government and politics and do not want to turn graduate training in political science into a technical training program. So, we design the prefresher to motivate students to get the background to do their research, given their highly diverse technical backgrounds and substantive interests (see appendix figure 1).

The math prefresher program eases students into technical material—including material they may have thought they would never need to know—by orienting them to the importance of those technical topics in learning to do research in their preferred subject area. The prefresher, along with the first-year graduate methods and formal theory courses, then takes students up the ramp of knowledge so they can eventually produce—or at least engage with—research that makes use of various quantitative methods.

In principle, the prefresher might be able to accomplish its collective goals by delving deep into specialized knowledge from any of the political science subfields. However, for at least five reasons

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(in addition to the fact that the political methodology subfield is among the largest of the 49 APSA organized sections), most political science prefresher programs focus on quantitative material from math, statistics, and computer programming.

First, math is important for the *style* of learning, not only the content. Graduate school and the profession beyond are about delving deep and learning enough about a specific subject to make a real contribution. Thus, beginning graduate school with, say, a brief introduction to each subfield may be useful in the same way as reading the department website might be. But all-introduction-all-the-time is not what graduate school is supposed to be. Focusing on any single subfield may have subsidiary benefits, but math is especially useful to illustrate the go-deep style of learning because instructors can teach relatively easily how learning key mathematical concepts immediately helps students understand research in their substantive fields of interest. For example, in our own prefresher, we have taught the Meltzer–Richard model after covering calculus and Google PageRank after covering linear algebra.

Second, math, statistics, and related material are essential to understanding *theories of inference*—using facts you know to learn about facts you do not know—which are fundamental to all subfields of political science. Even for students who do not ultimately use primarily quantitative methods for their research, learning the building blocks of statistical inference allows them to understand, engage with, and build on empirical research in the vast reaches of the discipline that use those approaches.

Third, technical material requires learning the building blocks of knowledge in a sequence, like foreign languages but unlike most substantive areas of political science. Therefore, helping students see the trajectory of technical courses they will take over the next several years can be helpful when beginning early.

Fourth, math is scary! Everyone knows more than you do (the reverse is true too). This fear is useful for building camaraderie and fostering the likely lifelong connections begun during the prefresher and in graduate school, which students can use to decide among the many possible paths before them. It is especially good to get all that started from the outset.

Finally, the idea that mathematics, statistics, and programming could provide a unifying experience to the diverse array of incoming political science graduate students may seem paradoxical, given that the most fervent intellectual debates in our field have often taken place over a quantitative–qualitative divide. What this perspective misses is that the debate also has been highly productive for both sides. Qualitative researchers—who typically are overwhelmed with field notes, audio tapes, video recordings, speeches, treaties, and archival texts—are now regularly receiving help from quantitative scholars who have been developing methods to derive substantively important meaning from this unstructured information in ways no human beings could do on their own. Quantitative scholars now appreciate and learn from qualitative scholars who know far more about any region or event than could be hoped for with quantified variables. And everyone recognizes that every book and article written in political science is qualitative and only some fraction of these are also quantitative. The debate will continue for the foreseeable future, but the divide has long since transitioned from siloed subfields, to an open war, and finally to a deep partnership for the good of the broader discipline—all of which is a tremendously important development (King 2014, 167).

In fact, the math prefresher has developed because of, not despite, these hard-fought debates, in which each side has provided tremendous encouragement and assistance to the other. The same scholars who levy the harshest criticisms of quantitative techniques have chosen to institute requirements for political methodology courses in the majority of political science graduate and undergraduate programs, to hire mathematically and statistically trained colleagues, and to encourage math prefreshers. The formation and spread of math prefresher programs could not have happened without help from entire departments, including the most qualitative among us.

WHICH MATHEMATICAL CONTENT SHOULD BE IN THE MATH PREFRESHER?

Because much of the value of the prefresher comes from its collective aspects, it has advantages independent of the specific type of mathematical content taught (cf. Anand 2016). Indeed, we conducted a survey of political science prefreshers[2] and found that departments design them to suit diverse incoming classes, the particular knowledge and teaching skills of faculty sponsors and senior graduate students available to teach, and the needs of the department and direction of the discipline.

Much of the variation in prefreshers over time is the result of the development of the political methodology subfield. For example, our prefresher began in the mid-1990s with reading materials produced in and for statistics, mathematics, and econometrics (Simon and Blume 1994). That early curriculum emphasized optimization, linear algebra, and computational software for solving math problems. Today, a quarter-century later, our focus on mathematics remains but the changes are illuminating. Probability theory and linear algebra appear more prominently as a tool to characterize social phenomena. Statistical programming is taught as a central tool for empirical analysis. Students more regularly take advantage of datasets and examples generated by political scientists and specifically tailored for an audience of political scientists (Imai 2018). These applications now often cover all major subfields in our discipline and give incoming students exposure to political science studies in addition to instruction in math and programming (Hochschild and Powell 2008; Nunn and Wantchekon 2011; Ober, Pyzyk, and Krishnan 2014; Oneal and Russett 1999; Persson and Tabellini 2000).

Departments also adjust the content of their prefreshers to meet their particular strengths, program requirements, and culture. In our interviews, we found that some programs emphasize mathematical preparation in analyzing game theoretic models (e.g., New York University, Princeton University, and Texas A&M); others cover concepts from machine learning (e.g., University of California, San Diego); whereas still others cover

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computing and technical word processing (e.g., Cornell University). The modal prefresher had about a week of instruction but ranged from one day (e.g., University of North Carolina) to assignments and online discussion interspersed during the summer before an in-person prefresher (e.g., Duke University and Princeton University). Some institutions offer two separate prefreshers—one before the first year and another before the second (e.g., Massachusetts Institute of Technology and Princeton University). Reading materials range from a set of published exercises (Kropko 2015; Moore and Siegel 2013) to no textbook at all. About half of the programs we surveyed teach programming (all using R) to some extent. The University of Chicago prefresher (taught for many years by John Mark Hansen) includes students in all social science disciplines except economics; the one taught for the Princeton sociology department (by political scientist Brandon Stewart) is supplemented with small-group discussions with department faculty using ethnographic methods.

Finally, in ongoing discussions, some programs emphasize fundamental concepts in proofs and probability theory instead of simply previewing the material students encounter in the first-semester methods class (e.g., MIT, UCLA, and Emory University). The informality of the math prefresher makes experimentation and adaptation to local circumstances particularly seamless.

WHO TEACHES THE MATH PREFRESHER?

Senior graduate students are the sole (paid) instructors in most of the programs we surveyed (e.g., Harvard, University of Michigan, the Ohio State University, and University of Wisconsin–Madison), with the remaining programs taught by faculty accompanied by graduate students serving as teaching assistants (e.g., Duke University, Stanford University, Washington University–St. Louis, and University of Pennsylvania). Senior graduate students also are involved in reexamining and renewing the content of the prefresher each year, which provides additional flexibility, customization, and innovation. Moreover, by conveying to incoming students at the outset that they should begin to rely on and help one another, the leadership of senior graduate students reinforces the collaborative, peer-learning environment that the math prefresher introduces and promotes.

The instructor's responsibilities are not to be taken lightly: in addition to teaching technical material, they provide students the first introduction to their new graduate programs, level the playing field among incoming graduate students, and set the tone for collegiality. Faculty sponsors also may share teaching material and pedagogical insights with graduate student instructors, which in turn improves their teaching skills. For many student instructors, the math prefresher is the first class they teach in their teaching career and, by all accounts, they take this important assignment seriously.

CONCLUDING REMARKS: A PROPOSED COLLECTIVE FUTURE FOR CROSS-DEPARTMENT TRAINING

The math prefresher has benefited from competition and cooperation across political science departments copying, competing with one another, and innovating to improve their own program. We propose to build on this productive interaction by introducing infrastructure for all departments to tap into, contribute to, or build on. For this purpose, we created a website (https://bit.ly/prefresher) with all of the teaching materials from Harvard's prefresher, which we have fine-tuned and morphed over the years. The website includes the syllabus for our most recent program; an entire book manuscript that our faculty and graduate student instructors created with teaching materials designed specifically for the prefresher; and a version-controlled repository that makes it possible for other programs to use, modify, or contribute back to our materials. This material is available for free with an open-source license.

The website also has consolidated syllabi, assignments, and material that are publicly available online from prefreshers in other departments, to which we invite others to add. This platform makes public a process that has been occurring organically, as new instructors have launched math prefreshers in their department based on teaching material handed down to them by their advisers and colleagues. We hope these materials make it easier for departments to improve their prefreshers. We also welcome contributions or suggestions for links to materials from other programs. Perhaps this also will help smaller departments without a prefresher to create one.

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NOTES

1. Consider also the difference between undergraduate and graduate students from the perspective of faculty. The number of undergraduates per faculty member is so large at most universities that faculty have no choice but to find ways to reduce demands on their time. When demand is greater than supply, the possibilities include (1) raising prices, which obviously is not an option; (2) reducing the quality of the service, which is not a wise career move; and (3) rationing, which is used everywhere with undergraduates, such as by restricting access to a few faculty office hours per week.
2. We identified 27 political science PhD programs and contacted instructors by email in the spring of 2019. We managed to conduct in-person or telephone interviews with the faculty sponsor or instructor for 16 of them. Whether or not we were able to schedule an interview, our website includes links to online material from all programs we found.

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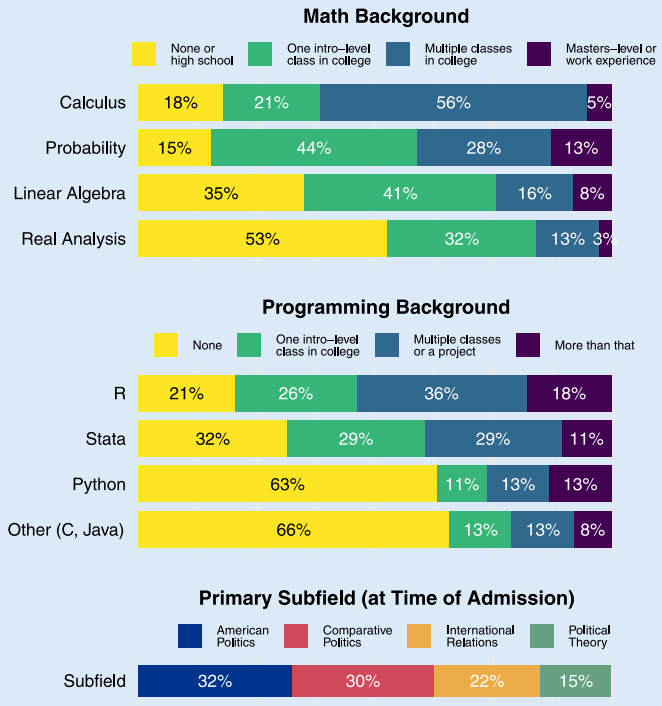
APPENDIX: DIVERSITY OF INCOMING STUDENTS' MATH BACKGROUNDS

This appendix presents the results of a survey of two cohorts of students participating in the Harvard Government PhD program math prefresher (2018 and 2019, $n \approx 40$). Figure 1 provides a breakdown of the students' self-reported mathematical and programming background. Students from all four subfields participated, and they break down roughly evenly between having little experience and having substantial experience in the fundamental tools of probability, linear algebra, R, and Stata before starting graduate school. From our conversations with prefresher instructors and faculty supervisors from other departments, this high level of diversity in technical preparation seems to be a common characteristic of most incoming PhD cohorts. This diversity in student backgrounds poses a challenge for teaching, but it also serves as a motivation for holding the prefresher in the first place—all the more reason why it is helpful if different programs work together to develop tailored training materials.

Figure 1

Diversity of Student Backgrounds at the Harvard Prefresher



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