Teaching Quantitative Methodology to the Math Averse

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ABSTRACT Many political science students struggle in quantitative methods courses because they have never been taught how to learn math. Learning math is different from learning in other fields, so the techniques students have used successfully in other classes are inappropriate in mathematically oriented classes. However, most students have never been told this, so they blame their difficulty with math on the impenetrability of the subject rather than tactical studying errors. This brief article discusses some of the reasons that common studying techniques do not work in quantitative methodology classes, and discusses some simple techniques to help students develop learning habits that are better suited to quantitative courses.

The primary obstacle to teaching quantitative methodology to math-phobic students is that they have never been taught how to learn math. The tricks and techniques that students have been taught in other fields are detrimental in mathematically oriented classes. However, since nobody tells students that they must adopt a different approach to learning math, they become frustrated when their tried-and-true approaches do not yield the same level of success that they do in other classes. The result is to reinforce the culturally ingrained belief that "math is hard." As a result of this cycle of negative feedback, several reactions occur when math-averse students encounter numbers and equations. First, they panic. Fear can be healthy in some circumstances, but the difference between fear and panic is that panic prevents rational behavior. When students panic, they resign themselves to defeat, scour their memories for any arbitrary technique, and hope for partial credit. Teaching students not to panic when they encounter difficult mathematical concepts is an absolute necessity if they are to truly learn. However, in order to help students move beyond their math phobias, we must show them that the reason they have had difficulty with math in the past is not the impenetrability of the subject, but that they have been using the wrong studying techniques. Learning math is different from learning other subjects, and if we do not give students the tools to learn math, then only those naturally inclined towards it will excel. Furthermore, political science students are disproportionately averse to math because they frequently study social sciences specifically to avoid math. These students have the potential to learn more than they generally do, and unless they are taught how to learn math, they will continue to find quantitative methods impenetrable, and continue to avoid it whenever possible.

What follows is a discussion of some of the misconceptions that political science students have about the process of learning math, and advice on how we can combat these misconceptions because they are at the heart of students' discomfort with quantitative methods. I share these observations with students at the beginning of every methodology class, and simply pointing out how learning math is different from learning other subjects helps them to improve their confidence and to avoid common problems.

"MOVE ON, AND TRY TO FIGURE IT OUT FROM THE CONTEXT"

This may be the most useful piece advice to give students about how to handle challenging readings or foreign languages. However, it may be the most dangerous and damaging advice to follow when trying to learn mathematical concepts. Unfortunately, most students have never been told this, so they wonder why it doesn't work. The reason the context approach does not work in quantitative methods courses is that math is linear, so learning math requires following a progression of steps. One cannot move on and hope to use context to interpret a difficult step because each step follows logically from the previous step. The result of attempting to move on will be to perpetuate confusion. For example, understanding the Central Limit Theorem requires understanding the concept of the sampling distribution. If students don't quite understand what a sampling distribution is, explaining the Central Limit Theorem will not help them to understand

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sampling distributions. The students will simply become more confused, more discouraged, and more likely to give up. The confused students might remember the formula σ^2/n, but they will not understand when it applies, nor why. If B follows from A, then failure to understand A almost guarantees failure to understand B. However, nobody teaches students this simple point, so when they don't understand a concept, many of them "move on, and try to figure it out from the context," as they have been taught to do in English and foreign language classes for their entire academic careers. Furthermore, since this works quite well in most subjects, students have received a great deal of positive reinforcement for this tactic. So, unless we specifically tell them *not* to use it when approaching math, they will continue to do what has worked for them in other fields. When it does not work, they will blame themselves for their confusion when the problem is simply that they are making a tactical error. As teachers, we must not facilitate this pattern of behavior. We cannot just move on. In large lecture halls, of course, professors do not have the luxury of being able to accommodate all students, but those teaching at small institutions (and TAs at research universities) should understand that we are doing more harm than good by moving on, and we must inform the students that they need to understand each step before they can understand the following step. Otherwise, they will remain confused without any understanding of *why* they are confused. This does mean that we must move through the material more slowly. It is far more important that students understand basic concepts in probability than that they memorize formulae for specific statistics. Formulae can be looked up in a book, but students will only be able to do so if they understand the underlying concepts, so if we have to sacrifice a few statistical techniques to give students a better grasp of probability, the students will be better off in the end.

"DO YOU UNDERSTAND SO FAR?" "UHHH . . . YES."

The basic point in the previous section was the simple observation that if B follows from A, students must understand A before they can understand B. However, if we ask them whether or not they understand A, there is an understandable tendency for students to say yes, regardless of whether or not they really do. One reason is that they just want you to move on based on the mistaken belief that doing so will be more helpful than trying to explain the troubling concept in a different way. This tendency can be combated quite simply by explaining to students why this doesn't work (as discussed in the previous section). However, there are two other reasons that are more problematic. Students may think they understand a point when they don't. Unfortunately, there is little that we can do to rectify this until we catch it on problem sets, quizzes, or exams. However, there is a third reason that is possible, although difficult to address. Students hide their confusion because they don't want to admit that they don't understand, either to us or to their peers. Teaching math thus becomes a bit of a poker game. We explain a concept, then ask if everyone understands. Everyone says yes, except for the occasional brave student. Some of them are lying. Frequently, most of them are lying. Quizzes are the ideal way to determine how many of them are telling the truth, but unfortunately, these moments occur too frequently. We cannot give pop quizzes every five minutes, and without that option, and the best way to figure it out is by examining their facial expressions. Luckily, most students either aren't very good poker players, or simply don't bring their poker faces into the classroom. The most helpful thing we can do for these students is not the most comfortable for them—it is to scan the room for people who look troubled, and ask them which step was not clear, being careful to phrase the question in a way that emphasizes the difficulty of the material to allay any embarrassment. This will still be somewhat embarrassing for students, but it is important to remind them that it is exceedingly rare for only one person in the room to have difficulty with a concept, and there is no reason for them to feel embarrassed when many students are in the same situation. In fact, once one student admits to having difficulty, others generally confirm that they were troubled as well. This has the dual benefit of allowing us to clear up anything vague and reducing the embarrassment of asking questions. Students are much more willing to admit that they need help once they understand that they are not alone.

"I PUT ALL OF THE FORMULAE ON FLASHCARDS TO STUDY FOR THE EXAM . . ."

Students think of learning mathematical techniques like learning vocabulary words and conjugations for a class in Mandarin Chinese. Learning vocabulary words in a language like Spanish is made easier by the presence of cognates due to common linguistic roots, but Mandarin must be learned essentially by rote. Mandarin and English have no common linguistic roots, and do not even use the same phonemes. From the perspective of a native English speaker, there is neither rhyme nor reason for Mandarin vocabulary and syntax—they are arbitrary rules, which are the hardest to learn. However, theorems and formulae are not arbitrary rules. They are constructed based on logical principles, and it is significantly easier to remember a formula if you understand the underlying principles than if it is just a sequence of random characters. Remembering formulae should be easier than remembering terms in Mandarin because formulae are built on the ultimate pneumonic device: internal logic. If students understand *why* we do what we do, they will have an easier time remembering *what* to do.

Consider the chi-square statistic:

$$\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}.$$

The formula itself is sufficiently short that most students can remember it. The primary challenge for students is in calculating the expected value for each cell of the cross-tabulation. However, this step is only challenging to students if they do not fully understand the null hypothesis being tested with the statistic. If they focus their efforts on understanding the logic of a hypothesis test, then they do not need to memorize formulae for constructing the table of expectations. They can build it logically.

Consider a simple example: A survey has 50 respondents in Group A, and 100 respondents in Group B. Of the respondents in Group A, 15 responded "yes" to a survey question, and of the respondents in Group B, 45 responded "yes" to the same question. Calculating the chi-square statistic requires calculating the expected number of respondents in each group who would say "yes" if the null were true. If a student sought to apply a formula here, that student would have to remember that the expected number of respondents in Group A saying "yes" given the null would be: (total number in Group A)·(total number saying "yes" in A and B combined/total sample). A student can memorize that formula, but that is just one more formula to put on a flash card.

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Such a student might either misremember some detail of the formula, or incorrectly guess that the expected number of respondents in Group A saying "yes" given the null would be $0.5 \cdot 50 = 25$ since many students have a reflexive tendency to assume that the null hypothesis requires 50/50 divisions. However, a student who understands the logic of the hypothesis test doesn't need to memorize that formula, and will not make the 50/50 error. Such a student will understand that the null hypothesis is that in the population, the proportions of individuals in Groups A and B saying "yes" are identical. Our best estimate of that proportion is the total number of respondents saying "yes" divided by the total sample. In the example above, that would be $(15 + 45)/(100 + 50) = 0.4$. If the null hypothesis were true and we sampled 50 members of Group A, then on average, $0.4 \cdot 50 = 20$ of them would say "yes" to the survey question, and if we sampled 100 members of Group B, then on average, $0.4 \cdot 100 = 40$ of them would say "yes" to the survey question. A student who understands the logic of a hypothesis test does not need to memorize formulae for computing the table of expectations, and that student is less likely to make mistakes than the student who attempts to memorize formulae. Students who attempt to memorize formulae the way that they memorize Mandarin vocabulary words are making their own studying more difficult and increasing the likelihood of making a mistake on an exam.

"JUST LET ME FINISH COPYING DOWN THE FORMULA . . ."

As the previous section discusses, it is much easier to understand the logic behind a formula than it is to memorize it. Unfortunately, though, nobody has ever explained that to most students, so most of them take ineffective notes. When we introduce a theorem, formula, etc., a student's first impulse is to write down what we put on the board character for character. Then, we (hopefully) spend much more time talking about why the formula is constructed a certain way, and why it works from a more intuitive perspective. The problem is that many students write down what we put on the board, and then stop taking notes when we discuss intuitions. They stop taking notes just when it is most important for them to take careful notes! They can always look up the formula in a book, but they will have a much more difficult time reconstructing the logic behind it on their own, so it is much more important that they take notes on that part. We cannot tell them what to write. However, we can instruct them to write down our substantive explanations in ways that make sense to them. What is important is that they not just copy formulae, theorems, and proofs by rote because they won't understand those when they study.

One simple technique to use here is to provide a substantive explanation for a formula and why it is constructed a certain way. Then, ask a student to explain it again in his or her own words (with assistance, of course). Then, provide students with a few moments to write down an explanation that makes sense to them. In fact, explaining why a procedure works makes a much more useful homework assignment than slogging through calculations by hand. Again, this means that we cannot cover as much as we might want to cover in methodology classes. However, there is nothing to be gained by forcing students to memorize formulae for a variety of statistical tests that they do not truly understand, so if we must sacrifice breadth for depth, the students will benefit.

An additional point about note taking is that many students make the mistake of leaving a class and not looking at their notes again until they either have to work on a problem set or prepare for an exam in the immediate future. While that approach can work (although not ideally) for classes in which notes simply contain facts, buzz words, and simple ideas, it does not work at all in mathematically oriented classes. Invariably, students will find that some element of their notes is incomprehensible after the fact, and they will need clarification. It would be ideal if we could trust students to review their notes immediately after each class to crystallize the ideas and to jot down additional clarifications, but many students' schedules make that impossible. However, we can ask students to review their notes before each class and take a few moments at the beginning of every class to clarify any concept that students found unclear in their *own* notes. While this practice is of minimal value in many "substantive" classes, it is critical in methodology classes.

"WHAT FORMULA SHOULD I USE HERE?"

All of the problems discussed above culminate in a fundamentally flawed approach to problem solving. Math-phobic students approach problems on assignments and exams with the mentality of applying formulae by rote. Early education in math, as in any other subject, is done by rote. Students memorize multiplication tables, and practice them the way they practice scales when they first learn an instrument. Eventually, they get to algebra, and those tendencies remain. When given an equation to solve, they follow a set of steps that can always be applied (at least to the questions they are given) based on the intellectual equivalent of muscle memory. Substantively, this method of learning is not much different from the process of memorizing multiplication tables. The college-level problem of this type is the cookbook approach to methodology. By the time they get to a college course in statistics or research methods, they have internalized the belief that getting through a math class means recognizing which technique a problem requires, and applying it by rote. Hence, they find themselves checking their mental cookbooks to see whether they are supposed to use a *t*-test or a chi-square test on question 3. When students take this approach, they are not truly learning research methods. They are learning to mimic research methods. Unfortunately, most methodology classes are structured in a way that reinforces this tendency. First we cover technique A, then we cover technique B. What is missing, and what is most important when we actually do research, is *why* we use technique A or B. Again, we cannot expect students to truly learn methodology unless we cover the logic.

The logical extension of this claim, of course, is that students will have a much stronger grasp of methodology if their knowledge is based on a solid foundation of probability theory, the calculus of expectations, maximization procedures, etc. While it is reasonable to expect students to learn these concepts in graduate methodology sequences, it is certainly not reasonable in one-semester undergraduate courses. However, there is no reason that we cannot make a stronger effort to teach undergraduate students the intuitions behind *why* we do what we do, and when students have an intuitive understanding of the materials, the details will be easier for them. This requires approaching methodology classes from an applied perspective. A statistics course that is divorced from substantive theoretical questions will be virtually useless to students who are not inclined towards math because real world questions do not provide students with the kinds of cues they use on exams to determine which formula to

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apply. Research methods courses must be structured around a unified substantive framework such that each new technique we introduce is aimed at a specific research problem rather than simply an arbitrary procedure. If we teach each technique as a disconnected procedure, students will treat them as disconnected procedures and approach exams by consulting a mental cookbook to find the right black-box formula for each question. That is precisely why they struggle. They do not think through the problems logically. Instead, the look for cues to tell them which technique to apply by rote, and if we teach methodology courses as cookbook courses, they have no reason to do otherwise.

When I teach methodology courses, I build the class around a single, substantive question. I generally build the class around measuring the effects of campaign contributions. The topic is interesting to many students, and it lends itself to a variety of techniques, ranging from simple formal models to comparison of means to regression. Whatever substantive theme we use, though, it is essential that the course teach methodology as a way to solve a substantive problem rather than as a cookbook.

CONCLUDING ADVICE

Is it more important for students to remember the formula for a chi-square statistic, or is it more important for students to understand the logic of a hypothesis test? Virtually nobody would argue that memorizing the chi-square formula is more important, but most methodology courses are designed as though it is. Math is not impenetrable to those who fear it, as political science majors frequently do. However, when we emphasize rote applications of formulae rather than reasoning, we reinforce the misperception that quantitative methods are impenetrable. Many students struggle with quantitative methods because they have never been taught how to learn math, and the best way to help students overcome their fears is to show them that there is an easier way. Learning math is not like learning a foreign language with no common roots, and studying math is not like studying a piece of literature. Only by showing students another way to learn can we help them move past their fears and begin to understand quantitative methods. Hence, I recommend the following steps to help math-fearing students cope with a quantitative methodology course.

- Tell students why learning math is different from learning other subjects. Unlike literature, math is linear, so it can only be learned through a progression of steps. No step can be skipped, and moving on doesn't work. Unlike foreign languages, mathematical rules are not arbitrary. Hence, they should not be memorized like vocabulary words. Students should focus on understanding *why* rather than memorizing *what*. Unfortunately, this has never been pointed out to most students.
- Don't let students pretend to understand. Students will claim to understand concepts when they really don't because they think they can move on, and figure it out from the context. That doesn't work because math is linear, and we must not enable such self-defeating behavior. So, we must poke and prod, even after students claim to understand a concept.
- Depth is more important than breadth. Students cannot truly understand any statistical technique unless they understand why we build the formulae the way that we do. With that understanding, they can reconstruct forgotten formulae. Without that understanding, they are unlikely to remember the formulae correctly, and even if they do, they will forget them immediately after the final exam anyway. So, there is nothing to be gained by sacrificing depth for breadth.
- Ask students to explain *why*. On problem sets, don't just ask students to walk through a set of calculations. Ask them to write an essay explaining why a technique works. When asking the class to predict what step comes next in a demonstration, ask them to explain their reasoning. If they are wrong, they will frequently catch themselves when they have to explain it, and when they are right, this will show whether they actually understand, or are just going by rote.
- Show students how to take notes. The blackboard is not the complete repository of all information they must memorize. It is just a visual aid. Students must take notes on the reasoning behind formulae, not just the formulae themselves. Show them how to take helpful notes.
- Use a unifying substantive theme for an entire course. If each example, problem set, and exam question is a disconnected use of an arbitrary technique, then students will walk away with the impression that quantitative techniques are arbitrary and disconnected tools. Teaching an entire course around a single, substantive question allows them to see how each technique fits into a narrative, and shows the full process of social science.

Quantitative methods are not impenetrable, even to those who are uncomfortable with math. Quantitative methods are just *different* from other subjects, and by showing students a different set of techniques for learning math, we can ease their fears and show them that they are capable of doing more than they might have thought. ■

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