Research Statement – V.N. Vimal Rao

Research Interests No inference is 100% certain. An important part of decision-making is to reason about degrees of the inherent uncertainty – this is the core purpose and function of statistics. This is particularly important for scholars generating and consuming scientific research, given recent methodological crises (e.g., replication crisis, NHST controversy). My research investigates the psychology of statistics, i.e., what does it mean to do statistics or think statistically, and how does one learn to do this?

I utilize a wide variety of research methods especially from the cognitive and learning sciences to investigate statistical thinking, and use these diverse tools to collect new types of evidence as we test and generate psychological theories of statistics. This interdisciplinary diversity is not possible without collaborations, and as both a statistician and a psychologist, I am uniquely positioned to bridge both fields. I often serve as a quantitative methodological consultant for psychologists, and a qualitative methodological consultant for statisticians. By bringing my connections in each of these two fields together, and building new connections, I am able to develop a generative environment for research and scholarship in the psychology of statistics.

Statistically Situated Numerical Information Processing My main project is the investigation of the categorical interpretation of p-values on individuals' cognition. After a century of '$p < .05$' as a categorical boundary for "statistical significance", in 2019 the American Statistical Association gave a warning not to categorize any statistical measure. Yet, to cognitive psychologists, categorization is fundamental to cognition, and cognitive effects of categorization are easily and passively acquired by repeated training and practice. Has categorically thinking in a '$p < .05$' world led to a distortion in the way graduate students perceive decimals in a statistical context?

This program of research began with an initial study (hereafter, PV1) testing the standard model of numerical cognition (the logarithmically compressed mental number line) against our proposed theory of a categorically distorted mental number line. We found a boundary effect at .05 consistent with a categorical distortion, and antithetical to statisticians' recommendations to no longer dichotomize p-values. In our follow-up study (PV2), the effect was replicated with a larger sample and larger number of stimuli. PV2 also extended the study to a different task and included a control group, lending further credence to our theory.

To test our theory on a different statistical measure, one for which boundaries are not explicitly specified, we studied the way graduate students categorize Cohen's *d* effect sizes (hereafter, ES1). In both implicit and explicit tasks, graduate students consistently drew boundaries between common benchmark values, as predicted by psychological theories of categorization. An extension (ES2) focused on how Cohen's *d* effect size estimates are labeled in published manuscripts. These findings will help us understand the scope of the problem of categorical statistical thinking, and how categories develop and form in cases with explicitly recommended boundaries (as in *p*-values) or explicitly recommended benchmarks (as in Cohen's *d* effect sizes).

Statistically Situated Numerical Cognition Beyond the initial information processing, we extended the project with a study of the role of working memory in the processing of *p*-values (hereafter, PV3). Interestingly, in a post-task survey in PV2, participants indicated that they were trying to follow consistent arithmetic heuristics when selecting responses, even though their response profiles indicate otherwise. Thus, PV3 examines statistical cognition on a longer time scale to distinguish whether graduate students are able to self-regulate out of prepotent categorical interpretations of *p*-values that were seen in PV1 and PV2, or whether categorical information permeates throughout encoding and retrieval. These findings will help us understand how graduate students process information about *p*-values (i.e., their numerical value and/or their category membership as 'statistically significant') in a more ecologically-valid time-span.

Implications for Teaching and Research I will pursue two further extensions of this project as I build a theory of statistically situated numerical cognition. The first extension (PV4) will investigate the effect of categorical learning and training activities on students' thinking about *p*-values. Current recommendations for breaking out of the '$p < .05$' world focus on conceptual instruction (e.g., reasoning about *p*-values as a 'continuum of evidence'). However, reasoning and thinking, as advanced cognitive processes, depend on information processing, encoding, and retrieval. Therefore, if initial processing and encoding of *p*-values favors categorical information, so too will subsequent reasoning. In order to ameliorate the categorical effects on these initial cognitive processes that underlie statistical thinking and reasoning, we then must target information processing, encoding, and retrieval with specific training. I propose to develop and compare three training methods in terms of their effects on students' *p*-value cognition: (1) categorical training, (2) self-regulation/inhibition training, (3) conceptual training.

The second extension (PV5) develops research methods to study contextually situated numerical cognition. PV1 and PV2 used 'discrimination tasks' often used in the study of categorical perception of physical stimuli such as speech sounds and color. However, adapting these tasks to numeric stimuli required unique considerations, and leaves open questions as to the exact mechanism underlying the documented effects. Therefore, I plan to investigate, develop, and test a variety of tasks, based on methods in categorical perception as well as methods in numerical cognition, to obtain a reliable measure of categorical effects in the reasoning about numerical stimuli, and to better understand the cognitive mechanisms underlying statistical cognition.

Broader Scholarship While statistical cognition is my focus, I also plan to conduct more research in justice, diversity, equity, and inclusivity oriented aspects of statistics education. For example, I worked on a project to develop a framework for a social justice oriented data science curriculum and subsequently adapted the framework to create activities focused on demonstrating the potential of statistical analysis for social action, activities that focus on marginalized groups and social issues, and workshops for instructors to use these resources. This work is the basis of a grant proposal I am writing, to continue to develop resources and provide professional development to teachers interested in integrating social justice initiatives in their classroom. I have also applied for mini-grants to help fund the development of these resources.

Research Goals My career research goal is to develop a social cognitive theory of statistics that can help explain how individuals and groups quantify and communicate information about uncertainty, especially in formal research settings. I will do this by continuing to collaborate with a diverse group of scholars across psychology, education, and statistics. I also hope to found two lab groups, one research group focused on the study of the psychology of statistics, and one teaching group focused on the generation of resources for the teaching and learning of statistics. My desire is that these efforts will produce well-trained scholars to continue studying the psychology of statistics as well as graduate students who are thoughtful methodologists.