Using Psychometrics to Improve Cognitive Models–and Theory

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Introduction

The history of science is the history of measurement.
–James M. Cattell, 1893

The field of psychometrics has undergone substantial evolution over the past several decades, both in terms of advances in methodology and improved software and hardware for deploying new methods. Despite these strides, many of these developments have not been integrated into the broader field of psychology, as highlighted by Embretson (2005) and Borsboom (2006). Understanding and incorporating these psychometric advances is crucial to enable cognitive scientists to address growing concerns about validity and reliability, as well as to develop robust theoretical frameworks for understanding cognition.

At its core, psychometrics offers a nuanced approach to measuring (and thereby understanding) mental capacities and processes. Psychometric methods allow for accurate assessment of individual differences in cognitive skills, along with tools for theorizing about and testing psychological constructs. Why do cognitive scientists not use psychometric models? We suggest that the underutilization of modern psychometric methods in cognitive science practice today is largely a result of unfamiliarity with psychometrics and how to apply it in a given domain. This workshop will help bridge this gap, explaining how psychometric methods can enhance cognitive science research, and showcasing example applications of these methods in a variety of domains. By bringing together psychometric experts and practitioners, this workshop will serve as a catalyst for cognitive scientists who seek to produce highly reliable and valid results, and who are also interested in creating testable theoretical frameworks (Smaldino, 2020; Guest & Martin, 2021).

In particular, we seek to explore what psychometric methods can bring to cognitive science. There are at least three key fronts which can be advanced with psychometrics: (1) understanding individual differences, (2) understanding variability across items, and (3) constructing formal models. The first front is clearly an important goal in cognitive science, because it allows for exploration of the mechanisms and development of various cognitive functions and abilities. For example, capturing individual-level variability across a range of cognitive abilities allows us to study how these abilities change over time, and whether they may lie along developmental cascades (Oakes & Rakison, 2019), whereby the development of one ability causes further downstream changes in another. Reciprocal interactions during the development of these abilities reflects the theory of mutualism (van der Maas et al., 2006), which provides a model for why many cognitive abilities are positively correlated. Understanding individual differences allows for the more careful examination of such dynamically interactive development, since the particular temporal characteristics are likely to vary substantially among individuals.

Psychometric methods also allow for the study of variability across items. Unlike classical test theory, which assumes that all items contribute equally to the measurement of any particular latent factor, more sophisticated psychometric models such as item response-theoretic (IRT) models incorporate the observation that items themselves may differ. These approaches have enabled innovations in measurement tools—for example, careful, parametrized selection of items using adaptive testing allows for an accurate measurement of an individual's ability while using markedly shorter assessments (e.g., Kachergis, Marchman, Dale, et al., 2022). Furthermore, psychometric approaches can shed light on whether particular items exhibit measurement equivalence across different subgroups (e.g., across cultures or genders), and can also elucidate the relationship between different items (e.g., using factor analysis).

Finally, psychometric models can serve as the basis for defining formal, extensible theories – which psychology largely lacks (Muthukrishna & Henrich, 2019). Formalizing theories in a model requires making assumptions explicit, which clarifies thinking, allows the theory to generate testable predictions, and enables direct comparisons to other theories (Smaldino, 2020; Guest & Martin, 2021). Psychometric models can formally unite studies of different aspects of a phenomenon, for example connecting per-child language input measures to per-child and per-word uptake (Kachergis, Marchman, & Frank, 2022).

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Goal and Scope

This workshop will bring together cognitive scientists who have used psychometric models as a vehicle for understanding individual differences in diverse cognitive domains, from language to math and reasoning. We have invited researchers who are leveraging psychometric models to understand individual differences and developmental change in a variety of tasks. Our central aim is to give workshop participants concrete examples of how their research can benefit from the adoption of psychometric methods, and to help them find ways to reduce barriers to adoption. Towards this end, interested participants will be invited to participate in a remote 90-minute pre-conference tutorial to learn some basic psychometric methods, and will be offered additional resources via the workshop's website (`https://psychometrics-workshop.github.io`).
Finally, participants will be invited to discuss how their research can (or does) benefit from psychometrics.

Main topics of discussion will be:

- Why is psychometrics important to cognitive science?
- How can psychological theories be built and tested as psychometric models?
- What are some good examples of psychometrics being used in cognitive science?

Target Audience

We expect that the topic of this workshop will be of broad appeal to the cognitive science community, as psychometric methods have wide applicability in cognitive science and in a variety of public-facing, societally-relevant applications, from admissions exams to ranking game players (e.g., the ELO rating system used in chess, or Microsoft's TrueSkill system). In particular, we expect this workshop will appeal to graduate students and postdocs who are interested in learning new methods, and in formalizing theories.

Organizers and Presenters

Alvin Wei Ming Tan (organizer) is a Ph.D. student in Psychology at Stanford University. He has worked with item response theoretic models of word learning across different language contexts.

George Kachergis (organizer) is a research scientist at Stanford University. He has studied language acquisition with psychometric models as well as process-based cognitive models of memory and self-directed learning.

Michael C. Frank (organizer) is Benjamin Scott Crocker Professor of Human Biology at Stanford University. His work combines the creation of computational models of language development with efforts to create and curate larger datasets to constrain these models.

Abe Hofman is an Assistant Professor at the Psychological Methods group at the University of Amsterdam. He works on algorithms for adaptive learning systems and modelling the large log data to understand learning.

Stefan Vermeent is a Ph.D. candidate at Utrecht University and the Max Planck Institute for the Study of Crime, Security, and Law. His work focuses on better understanding cognitive adaptations to adversity using cognitive modeling.

Jill de Ron is a Ph.D. student at the University of Amsterdam. As part of the Theory Methods Lab, she works to advance the methodology of formal theory construction in psychology. Her recent work has focused on translating resource competition models from ecology to cognitive development.

Nicholas Judd is a postdoctoral researcher at the Donders Institute for Mind, Brain, and Behaviour. His work applies psychometric models to study the development of cognition, with a particular focus on environmental impacts.

Jessica Schaaf is a postdoctoral researcher in Cognitive Neuroscience at the Radboud University Medical Center. She works on extending time-series models to capture individual variability in the development of cognitive abilities.

Workshop Structure

We propose a half-day workshop consisting of three parts. The first part will be an optional 90-minute tutorial on psychometric methods, held remotely a week before the conference. The second part will be a series of 20-minute talks, outlined in Table 1. After the talks, we will lead a 40-minute session in which small groups will brainstorm how to apply psychometrics in their own research, and then present their ideas to the whole group.

Table 1: Presenters and talk topics.

Presenter	Topic
Tan, Frank & Kachergis	Using item-response theory to understand language development Differential item function and adaptive tests of early language
Hofman	Modeling the developmental dynamics of learning in an adaptive learning app
de Ron	Modeling resource competition in cognitive development
Vermeent	Modeling cognitive deficits and enhancements in adversity-exposed youth using Drift Diffusion Modeling
Judd	Modeling cognitive variability in 11 tasks
Schaaf	Modeling the development of cognitive abilities over time

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