Psychology 405: Psychometric Theory

William Revelle
Swift 315
email: revelle@northwestern.edu

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1 Overview

To understand something is to know how to measure it. This leads to the study of psychological measurement. In particular, psychometrics: the assigning of numbers to observed psychological phenomena and to unobserved concepts. This includes the development and evaluation of the fit of theoretical models to empirical data. Although this can be done in the abstract, psychometrics is easier to understand if done with real (or simulated) data with modern computer techniques.

Psychometrics is that area of psychology that specializes in how to measure what we talk and think about. It is how to assign numbers to observations in a way that best allows us to summarize our observations in order to advance our knowledge. Although in particular it is the study of how to measure psychological constructs, the techniques of psychometrics are applicable to most problems in measurement. The measurement of intelligence, extraversion, severity of crimes, or even batting averages in baseball are all grist for the psychometric mill. Any set of observations that are not perfect exemplars of the construct of interest is open to questions of reliability and validity and to psychometric analysis.

Although it is possible to make the study of psychometrics seem dauntingly difficult, in fact the basic concepts are straightforward. This course (and the accompanying text) is an attempt to introduce the fundamental concepts in psychometric theory so that the student will be able to understand how to apply them to real data sets of interest. It is not meant to make one an expert, but merely to instill confidence and an understanding of the fundamentals of measurement so that the student can better understand and contribute to the research enterprise.

1.1 A word of warning

To learn psychometrics is like learning a new language. It at first appears impossible but with practice one can become fluent. Unlike some material that can be learned in one reading, psychometrics (like a new langauge) requires reading and practicing and questioning and then doing it all again.

2 Objectives

1. To acquaint you with the fundamental vocabulary and logic of psychological measurement and behavioral assessment.
2. To develop your capacity for critical judgment of the adequacy of measures purported to assess behavior in the role of theory development.
3. To acquaint you with some of the relevant literature in personality assessment, psychometric theory and practice, and methods of observing and measuring behavior.
4. To instill in you an appreciation of and an interest in the principles and methods of psychometric theory in general and behavior assessment in particular.

5. This course is not designed to make you into an accomplished psychometist (one who gives tests) nor is it designed to make you a skilled psychometrician (one who constructs tests), nor will it give you "hands on" experience with psychometric computer programs. Rather it is aimed to allow you to understand the fundamental theoretical issues concerning both the psychometrist and the psychometrician.
6. Because modern psychometrics and statistics may be done using open source software such as R, examples will be presented in R. Instructions for installing and using R for psychometrics are available in various parts of this syllabus.

3 Text, readings, and requirements

3.1 Text

The primary text is available on line and is still a work in progress.:

Revelle, W. (in preparation) An introduction to psychometric theory with applications in R. Springer. Draft chapters available at https://personality-project.org/r/book.

Other texts that are useful supplements include (but are not limited to):

Loehlin, J. C. and Alexander Beaujean, Latent Variable Models (5th ed). Routledge, N.J. 2017

Revelle, W. (in preparation) Adventures in Latent Variable Modeling using R. Draft chapters available at https://personality-project.org/r/book.

3.2 Readings

Multiple web based readings including, but not limited to the ones listed in the references. This list will be added to throughout the quarter.

Syllabus and handouts available at https://personality-project.org/courses/405.syllabus.pdf

Please note that although we are organizing the lectures through CANVAS, the lecture notes are all on the personality-project web site.

3.3 Requirements

1. Asking questions! If you are confused, probably at least half of your colleagues are confused as well. You are doing them (and yourself) a favor by asking questions.
2. There are two multiple choice exams. The first one will be on April 17th, the second will be the final exam. Sample questions are just an example of the style.
3. A final paper applying principles of psychometrics to a question of interest to you. This should be roughly 10 pages of text, but can include more computer output. It should be a clear enough statement of the problem that I can understand it.
4. Sporadic homework will be provided. This is mainly for you to see if you understand what we are doing.
5. Familiarity with basic statistics is useful, a willingness to learn about statistics is even more useful.
6. You must be willing to use computer packages that allow for basic and advanced psychometrics. This means R (R Core Team, 2025). Current versions of SPSS and JMP do not do modern statistics.
7. This is a hands on course. You will be expected to try the various programs on simulated and real data sets.

As might be expected, most of my examples and lectures will make use of the powerful statistical system, R (R Core Team, 2025). This is because the open source nature of R allows us to see (if we want) how the calculations are actually done, and to add new features to existing packages. We will use one package a great

deal and another occasionally. The R packages are *psych* (Revelle, 2025) and *lavaan* (Rosseel, 2012). R can be downloaded from https://cran.r-project.org. Once installed packages can be downloaded from the CRAN server. To get the latest, bleeding edge version of the *psych* package, you can install it from my repository using the `install.packages` command.

3.4 Evaluation

1. Homework assignments will be given weekly. These are your benefit and will be graded on a completed, not completed basis.
2. Students will be expected to write a short paper demonstrating the use of psychometrics applied to their particular research interests.

3.5 Accessibility

Any student requesting accommodations related to a disability or other condition is required to register with AccessibleNU (accessiblenu@northwestern.edu; 847-467-5530) and provide me with an accommodation notification from AccessibleNU, preferably within the first two weeks of class. All information will remain confidential.

3.6 Office Hours

Tuesdays (and most Thursdays) from 2-4 in Swift Hall 315. I am also available for other "office hours" by appointment.

4 Outline (to be added to frequently – keep checking)

This is the abbreviated form of the syllabus, The full syllabus is at https://personality-project.org/courses/405/405.syllabus.pd

Current version of April 9, 2025

4.1 News of changes

Will appear here when I make them.

4.2 Assignments as a table

Week	Topic	Lecture Notes	Readings	Homework/ R help
1 a	Correlational and Experimental Psychology	Overview	Chapter 1: the role of measurement	Getting started with R Appendix A: Using R
1b		Theory of Data	Chapter 2: Theory of Data	Homework #1 with answers
2 a	Models of Measurement	Metric properties and the problems of scale	Chapter 3: The problems of scale	Using R for statistics and an even shorter guide to R
2b	Variance and Covariance	Correlation and Regression (Part 1)	Chapter 4: Correlation Francis Galton & Charles Spearman	Simple Regression problems #2 More problems
3a	Variance and Covariance	Correlation and Regression (Part2) Linear algebra	Review of linear/matrix algebra (Appendix E)	
3b		More on correlations and regression	Multiple Correlations (Chapter 5)	Applications of correlations Problem set 3
4a	Latent variable models	Factor Analysis	Constructs, Components, and Factors (Chapter 6)	Factor Analysis (How To)
5 a		Even more fa	latent variables = Easter Bunnies?	Homework set 4
5 a	Midterm			sample questions
5b	Reliability	Reliability Theory	Reliability (Chapter 7) α to ω Supplement to α to ω	Omega Analysis (How To) Homework set 5 Problems
6 a	Item Response Theory	Item Response Theory	Item Response Theory (Chapter 8)	Factor approaches to IRT see section 7 Homework set 6
6 b	Validity	Validity Validity of SAPA methods Validity- another look	Predicting the Persome That takes the BISCUIT fishing nets	
7	Scale Construction	scale construction	Fishing Spears and Fishing Nets	scoring scales
	Confirmatory analysis	efa vs. cfa	more on validity	Homework set 7
8	Structural Equation Modeling	sem vs. cfa continued	sem chapters 3, 4,	Factor analysis and sem
		Goodness of fit	5, 6	
9	Other approaches	Further topics Review of 405		Final Project

This table and the entire syllabus has been converted from HTML to LaTeX.

5 Detailed Notes

5.1 Week 1

Introduction to psychological measurement. Some historical readings are well worth reading. e.g., Cattell (1893) discusses why we are not doing science if we are not concerned with measurement.

Cronbach (1957) was an unanswered plea to unify the two disciplines of scientific psychology.

The Howto's use R and the *psych* package will introduce to some of the ways to analyze psychometric data that we will do.

1. https://personality-project.org/r/psych/intro.pdf Overview I
2. http://personality-project.org/r/psych/overview.pdf Overview II
3. https://personality-project.org/r/psych/HowTo/factor.pdf Factor analysis
4. http://personality-project.org/r/psych/HowTo/omega.pdf omega
5. http://personality-project.org/r/psych/HowTo/scoring.pdf Scoring scales

5.2 Week 2

The problem of the quality of our scales runs through many of the inferences we make from our data.

Review of linear/matrix algebra (Appendix E)

5.3 Week 2

Application of matrix algebra to pattern and structure. Chapter 6: Exploratory factor analysis as a basic latent variable model. Finding the inverse of a matrix. For a review of factor analysis, see `https://personality-project.org/courses/405/405-efa.pdf`.

Structural models and goodness of fit tests. Barrett (2007), Examples with simulated data.

How to simulate structural data. This has been revised with a correction for two factor simulations and with a more extensive analysis of the effects of sample size on estimating parameters in the two factor model.

Using basic sem programs to find structure and apply goodness of fit tests. Using the *sem* (Fox et al., 2013) and *lavaan* (Rosseel, 2012) packages.

5.4 Week 4

Perhaps the fundamental issue of latent variable analysis is why use latent variables. The classic development of latent variable analysis was (Spearman, 1904) with the development of what has come to be called "Exploratory Factor Analysis". While a useful descriptive technique to describe the "common" part of variables, EFA can be made a testable technique using "Confirmatory Factor Analysis" which is the root of most SEM packages. See EFA/CFA for an overview of PCA, EFA, and then the basics of CFA. EFA/CFA – psych, sem and lavaan.

The problem of hierarchical representations of data. Many people claim a "general factor" of personality in analogy to the 'g' factor of ability. This has been disputed (Revelle and Wilt, 2013). See also A general factor of personality? talk given at an "Experts Meeting" on personality structure. Also see Analysis of hierarchical factor models using hierarchical and bifactor solutions. The lecture notes for week 4 are here and prior notes are prior year notes

5.5 Week 5

Exploratory and confirmatory factor analysis, continued. The lecture notes for week 5 are here.

Considering issues of using items rather than continuous measures. items vs continuous measures. Unfortunately, items have serious problems with skew.

One of the most powerful applications of sem is the analysis of change.

5.6 Week 6

Comparing three examples from the literature: a short example (Erdle et al., 2009) of how not to report factor analysis, a sem paper which which actually fails to identify the model correctly (Erdle et al., 2010) and another (Marsh et al., 2010) which systematically compares models. This last one includes a good discussion of how to do measurement invariance.

5.7 Week 7

lavaan uses many examples from the MPlus manual (`https://www.statmodel.com/ugexcerpts.shtml`. See in particular the example data sets at `https://www.statmodel.com/usersguide/chapter5.shtml`. The notes describing *lavaan* output for these examples are available here.

5.8 Week 8

Comparing sem in R and LISREL (Jöreskog and Sörbom, 1999). Consideration of goodness of fit tests (Barratt et al., 2007) (Click on Issue 5 in the left hand column). R and LISREL lecture notes

For a very good discussion of latent change estimation in R see Ghisletta and McArdle,(2014) (Ghisletta and McArdle, 2012). Also see the lecture notes from Yves Rosseel Modeling change with lavaan

For an example of modeling change in cognitive ability and depression to examine the temporal sequencing of the effects, look at Aichele et al. (2018).

An excellent set of lecture notes on testing for invariance comes from Tutorial on measurement invariance Kate Xu.

5.9 Week 10

Course review

5.10 Software

Commercial software for structural equation modeling: EQS Bentler (1995), LISREL (Jöreskog and Sörbom, 1999) MPlus (Muthén and Muthén, 2007).

5.11 R advice

The R tutorial gives a short introduction to the use of R.

- (Macs and PCs) For this, or any other package to work, you must activate it by either using the Package Manager or the "library" command:
  - type library(psych)
  - If loading the psych package works, function such as `describe` and `pairs.panels` should work (or at least give an error message that is NOT "could not find function").
  - entering ?psych will give a list of the functions available in the *psych* package.

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