Psychology 405: Psychometric Theory

William Revelle
Swift 315
email: revelle@northwestern.edu

April 24, 2023

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 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 and holding them with ZOOM, 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. Normally, we have two multiple choice exams. But this quarter is different and I am not yet sure what we will do.

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, 2023). 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, 2023). 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, 2023) 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. If we were to be meeting physically, Swift Hall 315. Otherwise I am available for "office hours" by Zoom. With any luck, we might actually see each other eventually.

4   Privacy considerations

This class or portions of this class will be recorded by me for educational purposes. These recordings will be shared only with students enrolled in the course and will be deleted at the end of the end of the Spring Quarter, 2021 course. I hope to have these recordings available in CANVAS so that you can review the materials.

4.1   Recording of Class Sessions by Students

Unauthorized student recording is prohibited. Faculty should not grant individual requests for students to record class sessions. Students requesting the use of assistive technology as an accommodation should direct such requests to AccessibleNU.

As part of our communication to students, all instructors have been asked to include the following statement on all Syllabi for Spring Quarter, 2023 classes:

> Unauthorized student recording of classroom or other academic activities (including advising sessions or office hours) is prohibited. Unauthorized recording is unethical and may also be a violation of University policy and state law. Students requesting the use of assistive technology as an accommodation should contact AccessibleNU. Unauthorized use of classroom recordings – including distributing or posting them – is also prohibited. Under the University's Copyright Policy, faculty own the copyright to instructional materials – including those resources created specifically for the purposes of instruction, such as syllabi, lectures and lecture notes, and presentations. Students cannot copy, reproduce, display, or distribute these materials. Students who engage in unauthorized recording, unauthorized use of a recording, or unauthorized distribution of instructional materials will be referred to the appropriate University office for follow-up.

5   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 24, 2023

5.1 News of changes

5.2 Assignments as a table

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

This table and the entire syllabus is being converted from HTML to LATEX. The original version is here

6 Detailed Notes

6.1 Week 1

Introduction to latent variables (405 in a week).

Review of Correlation and Regression and classical reliability theory (Revelle and Condon, 2018a,b). See also Chapter 4 on Correlation and regression as well as Chapter 5 on multiple correlation and regression.

Review of linear/matrix algebra (Appendix E)

What is a latent variable? Some opposing viewpoints (Bartholomew et al., 2009; Loevinger, 1957; Markon and Jonas, 2016; Jonas and Markon, 2016)

6.2 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.

6.3 Week 3

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.

6.4 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

6.5 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.

6.6 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.

6.7 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.

6.8 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.

6.9 Week 10

Course review

6.10 Software

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

6.11 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.

References

Aichele, S., Ghisletta, P., Corley, J., Pattie, A., Taylor, A. M., Starr, J. M., and Deary, I. J. (2018). Fluid intelligence predicts change in depressive symptoms in later life: The Lothian birth cohort 1936. *Psychological Science*, 29(12):1984–1995.

Barrett, P. (2007). Structural equation modelling: Adjudging model fit. *Personality and Individual Differences*, 42(5):815–824.

Bartholomew, D., Deary, I., and Lawn, M. (2009). A new lease of life for Thomson's bonds model of intelligence. *Psychological review*, 116(3):567–579.

Bentler, P. M. (1995). *EQS structural equations program manual*. Multivariate Software, Inc., Encino, CA.

Erdle, S., Gosling, S. D., and Potter, J. (2009). Does self-esteem account for the higher-order factors of the big five? *Journal of Research in Personality*, 43(5):921 – 922.

Erdle, S., Irwing, P., Rushton, J. P., and Park, J. (2010). The general factor of personality and its relation to self-esteem in 628,640 internet respondents. *Personality and Individual Differences*, 48(3):343–346.

Fox, J., Nie, Z., and Byrnes, J. (2013). *sem: Structural Equation Models*. R package version 3.1-3.

Ghisletta, P. and McArdle, J. J. (2012). Latent curve models and latent change score models estimated in R. *Structural Equation Modeling: A Multidisciplinary Journal*, 19(4):651–682. PMID: 25505366.

Jonas, K. G. and Markon, K. E. (2016). A descriptivist approach to trait conceptualization and inference. *Psychological Review.*, 123(1):90–96.

Jöreskog, K. G. and Sörbom, D. (1999). *LISREL 8: Structural equation modeling with the SIMPLIS command language*. Scientific Software International, Lincolnwood.

Loehlin, J. C. and Beaujean, A. (2017). *Latent variable models: an introduction to factor, path, and structural equation analysis*. Routledge, Mahwah, N.J., 5th edition.

Loevinger, J. (1957). Objective tests as instruments of psychological theory. *Psychological Reports Monograph Supplement 9*, 3:635–694.

Markon, K. E. and Jonas, K. G. (2016). Structure as cause and representation: Implications of descriptivist inference for structural modeling across multiple levels of analysis. *Journal of Abnormal Psychology*, 125(8):1146 – 1157.

Marsh, H. W., Scalas, L. F., and Nagengast, B. (2010). Longitudinal tests of competing factor structures for the rosenberg self-esteem scale: Traits, ephemeral artifacts, and stable response styles. *Psychological Assessment*, 22(2):366 – 381.

Muthén, L. and Muthén, B. (2007). *Mplus User's Guide.* Muthén & Muthén, Los Angeles, CA, fifth edition edition.

R Core Team (2023). *R: A Language and Environment for Statistical Computing.* R Foundation for Statistical Computing, Vienna, Austria.

Raykov, T. and Marcoulides, G. A. (2006). *A first course in structural equation modeling.* Lawrence Erlbaum Associates, Mawwah,N.J, 2nd edition.

Revelle, W. (2023). *psych: Procedures for Psychological, Psychometric, and Personality Research.* Northwestern University, Evanston, https://CRAN.r-project.org/package=psych, 2.3.3 edition. R package version 2.3.3.

Revelle, W. (in prep). *An introduction to psychometric theory with applications in R.* Springer.

Revelle, W. and Condon, D. M. (2018a). Reliability. In Irwing, P., Booth, T., and Hughes, D. J., editors, *The Wiley Handbook of Psychometric Testing: A Multidisciplinary Reference on Survey, Scale and Test Development.* John Wily & Sons, London.

Revelle, W. and Condon, D. M. (2018b). Reliability from α to ω: A tutorial. *(under review: https://osf.io/e685p/).*

Revelle, W. and Wilt, J. (2013). The general factor of personality: A general critique. *Journal of Research in Personality*, 47(5):493–504.

Rosseel, Y. (2012). lavaan: An R package for structural equation modeling. *Journal of Statistical Software*, 48(2):1–36.

Spearman, C. (1904). "General Intelligence," objectively determined and measured. *American Journal of Psychology*, 15(2):201–292.