1 Background

Much of the current literature in psychology and related disciplines includes variables which are not directly observable but rather are inferred from the observed variables. That is, our observable measures are thought to reflect some underlying latent process or processes. Our theories tend to be formulated in terms of these
latent processes. The problem then is how to measure or model these unobservable processes. This is the challenge of this course.

2 Objectives

To understand the fundamental concepts in latent variable modeling in order to make you a better consumer and producer of latent variable models in your research. This includes a number of latent variable techniques, including, but not limited to Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA), Structural Equation Modeling (SEM) and Item Response Theory (IRT). By necessity, it also includes fundamental issues in reliability.

Thus, the goal of this course is to help you understand how to evaluate the quality of models when applied to data by understanding various sources of variability as measured by goodness of fit tests. The emphasis will be upon model comparison rather than model confirmation.

A further goal is to learn how to apply these concepts to real data sets using a variety of standard statistical packages (in particular in R (R Core Team, 2020) using the lavaan package (Rosseel, 2012)). Some examples will be given from other software (e.g., EQS, Lisrel, Prelis, Amos, and MPlus).

3 Text, readings, and requirements

3.1 Text


This book is well worth purchasing and a quick web search will show a variety of options ranging from unauthorized pdf copies to used copies to the latest version.


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 http://personality-project.org/courses/454.syllabus.pdf as well as the NU CANVAS website. In the spirit of open science and its basic principle that materials should be shared, all readings and assignments will be available through the http://personality-project.org/courses/454/ website and are linked from here.

3.3 Requirements

The most important requirement is the willingness to ask questions and to try the examples.

Additional requirements include:

1. Some basic knowledge of psychometric theory (to be reviewed in week 1). This course is a natural sequel to Psychology 405: Psychometric Theory. Some of the web readings will be taken from the 405 syllabus.

2. Familiarity with linear (matrix) algebra (to be reviewed in week 1). Or at least a willingness learn a little bit about linear algebra.
3. Willingness to use computer packages that allow for structural equation modeling. These can either be downloaded to your computer (e.g., the open source packages R, and lavaan), or ones that you have a license for (e.g., MPLUS, EQS?)

4. Willingness to ask questions and add to the class discussion.

As might be expected, most of my examples and lectures will make use of the powerful statistical system, R (R Core Team, 2020). 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. Most importantly, from the point of open science, by documenting your manuscripts with the code you used, other people can replicate your work. R makes the providing of scripts in a manuscript very easy.

We will use two packages a great deal. The R packages psych (Revelle, 2020) and lavaan (Rosseel, 2012). Most of our data sets are included in the psychTools package. These packages are all available for download from CRAN.

3.4 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.

3.5 Office Hours

Tuesdays (and most Thursdays) from 2-5. If we ever are meeting physically, my office is Swift Hall 315. Otherwise I am available for “office hours” by Zoom. I strongly encourage you to take advantage of this time to ask additional questions.

3.6 Evaluation

Homework assignments will be given weekly. These are your benefit and will be graded on a completed, not completed basis.

Students will be expected to write a short paper demonstrating the use of structural equation techniques applied to their particular research interests. They will also be asked to present their use of latent variable models in short (15-30 minute) presentations in the last few weeks of the course.

This is a hands on course. You will be expected to try the various programs on simulated and real data sets.

4 Privacy considerations

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 Fall Quarter, 2020 course. The recordings will be available in CANVAS so that you can review the materials after class as well. In addition, I hope to make publicly available a set of short tutorials on various aspects of R and the use of the psych package.

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 Fall Quarter, 2020 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.

Having said that, materials on CANVAS follow that policy. Materials I release on the https://personality-project.org/courses/454 will be in the public domain.

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

Updates:
September 21: Added a link to the regression and mediation vignettes
September 23: Revised and improved Week 2 slides
September 28: Corrected a few slides from wk.2
September 30: Modified the slides for simulating factor structures
Added a homework assignment
<table>
<thead>
<tr>
<th>Week</th>
<th>Topic</th>
<th>Reading</th>
<th>Lecture Notes</th>
<th>Homework</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Background</td>
<td>Computers and Psychology</td>
<td>Overview</td>
<td>Loehlin Chapter 1</td>
</tr>
<tr>
<td></td>
<td>Correlation/Regression</td>
<td>Correlation/Regression</td>
<td>Correlation and Regression</td>
<td>Problem set 1</td>
</tr>
<tr>
<td></td>
<td>Reliability</td>
<td>Reliability</td>
<td>Introduction to R</td>
<td>Exercises from Loehlin</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Revelle and Condon, 2018 2019</td>
<td>Linear Algebra</td>
<td>1-12 (page 32-34)</td>
</tr>
<tr>
<td>2</td>
<td>Basic Model fitting</td>
<td>Loehlin Chapter 2</td>
<td>Path models (deprecated)</td>
<td>Problem set 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>regression vignettes</td>
<td>Week 2 slides</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Model fitting -</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>regression vs. latent variables</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>regression/mediation/latent</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Using R</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Simple models</td>
<td>Loehlin Chapter 3</td>
<td>OLS/WLS/MLR regression and sem</td>
<td>6.3.1 Problem set 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Even more on regression</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Simulating structural data, A general</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>factor of personality</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Exploratory FA</td>
<td>Loehlin Chapter 5</td>
<td>EFA/CFA - psych, sem and lavaan</td>
<td>Problem set 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hierarchical factor models</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>EFA (continued)</td>
<td>Loehlin Chapter 6</td>
<td>items vs continuous measures</td>
<td>Problem set 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Goodness of fit</td>
<td>Item Response Models</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Guttman models</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>more on skew</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>change and more on change</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>CFA</td>
<td>Loehlin Chapter 4</td>
<td>SEM = regression + reliability</td>
<td>Problem set 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>one good and one bad example of</td>
<td>How to define a model</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>modeling complex structures</td>
<td>analysis and critique</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R and LISREL models</td>
<td>R and lavaan models</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>More on change</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>types of variables, types of models</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Goodness of Fit</td>
<td>Loehlin Chapter 7</td>
<td>Advanced modeling with Lavaan</td>
<td>Problem set 7</td>
</tr>
<tr>
<td></td>
<td>Evaluating Alternatives</td>
<td></td>
<td>measurement invariance</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Latent Classes</td>
<td>Loehlin Chapter</td>
<td>Causality?</td>
<td>Problem set 8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>More on IRT</td>
<td></td>
</tr>
</tbody>
</table>

6 Detailed Notes

6.1 Week 1 Introduction to latent variables (405 in a week).

The past century has seen a revolution in the way scientists can analyze data using computers. Over the past 50 years psychologists have gone from using main frame computers that took hours to days to analyze simple problems to the use of lap tops to analyze much more complex problems. With the introduction of the open source statistical sytem R ([R Core Team, 2020](https://www.R-project.org)) we can now do in classes as exercises what used to be months of research. We will do so.

This will require installing R on your computer (go the CRAN project), download the appropriate version of R and becoming familiar with the basic syntax of R commands. You will probably also want to install R studio at the same time.

Although there are many introductions to the R language, I have written one for personality researchers. It needs to be updated, but the current version is useful.

The concept of latent variables has been with us since at least [Plato (1892)](https://www.loc.gov/item/98017034/) and the cave. The need to see beyond appearances and to think in higher dimensions was brilliantly (and humorously) discussed by [Abbott (1884)](https://www.loc.gov/item/93466127/) (see also a pdf version).
Review of Correlation and Regression and classical reliability theory (Revelle and Condon, 2018, 2019). 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) See the Linear Algebra slides.

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 http://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.

6.3.1 Homework: Problem set 3

Try to simulate a one factor model and then factor it using EFA and the CFA (using lavaan). First simulate with no error and then add error by specifying a sample size.

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. It has been known since Spearman (1904) that ability measures may be represented hierarchically. This is true at the data level as well as the genetic level (de la Fuente et al., 2020). However, this does not imply that there is one causal ’g’ (Bartholomew et al., 2009; Thomson, 1916; Revelle et al., 2020).

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 (http://www.statmodel.com/ugexcerpts.shtml. See in particular the example data sets at http://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


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


Psychology has had its critics of latent variables, with Skinner (1976) being a well-known modern one. However, latent variables have been so useful in science that they pervade virtually all fields (see Glymour et al. 1987, pp. 22–26). Although latent variables are part of numerous statistical and data analyses models, we do not have a single general denition of a latent variable that would include these diverse applications. Rather we have denitions of latent variables that are closely tied to specific statistical models and few systematic comparisons of these different denitions and the implications of the differences. Furthermore, the common problems that accompany the use of latent variables are obscured by the diverse denitions, each of which is tied to a limited number of applications.

Objectives

To understand the fundamental concepts in latent variable modeling in order to make you a better consumer and producer of latent variable models in your research. To understand how to evaluate the quality of models when applied to data by understanding various sources of variability of goodness of fit tests. To learn how to apply these concepts to real data sets using a variety of standard statistical packages (e.g., R, M, Overview Latent variables r and R Path models Measurement models Structural Models References Psychology 454: Latent Variable Modeling Notes for a course in Latent Variable Modeling to accompany Psychometric Theory with Applications in R William Revelle Department of Psychology Northwestern University Evanston, Illinois USA September, 2016 1/ 59. Lawrence Erlbaum Associates, Mahwah, N.J. 2004 (recommended) â€¢ Revelle, W. (in prep) An introduction to Psychometric Theory with Applications in R. Springer. Psychology 454: Psychological Measurement An introduction to latent variable modeling. William Revelle Swift 315. email: revelle@northwestern.edu. November 2, 2016. 1 Objectives. To understand the fundamental concepts in latent variable modeling in order to make you a better consumer and producer of latent variable models in your research. To understand how to evaluate the quality of models when applied to data by understanding various sources of variability of goodness of fit tests. To learn how to apply these concepts to real data sets using a variety of standard statistical packages (e.g., R,