

## 9<sup>th</sup> GESIS Summer School in Survey Methodology Cologne, August 2020

### Syllabus for course 3: "Mathematical Tools for Social Scientists: A Refresher Course with R"

Lecturers: Prof. Dr. Oleg Nenadić  
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Date: 03-07 August 2020  
Time: 09:30-12:00 + 13:00-15:30  
Time zone: CEST, course starts on Monday at 09:30  
Venue: Online via Zoom

#### About the Lecturer:

Oleg Nenadić is associate professor in Finance and Applied Econometrics at the Nord University in Bodø, Norway. Before he was a Postdoc in Statistics at the University of Göttingen and a visiting professor for Econometrics at the universities of Göttingen and Erfurt. His interest lies in Applied Statistics across various disciplines such as Economics, Social Sciences and Biology, and his focus is on Computational Statistics with the statistical software environment R (<http://www.r-project.org>). He is author of several R-packages and has given workshops on R on four continents.

#### Selected Publications:

- Blasius, J., Nenadić, O., Thiessen, V. (2018): The Dirty Data Index - Assessing the Quality of Survey Data in International Comparison, *Italian Journal of Statistics*, 29 (2-3), 137–152.
- Zucchini, W., Schlegel, A., Nenadić, O., Sperlich, S. (2009): *Statistik für Bachelor- und Masterstudenten - Eine Einführung für Wirtschafts- und Sozialwissenschaftler*. Springer, Berlin, Heidelberg.
- Greenacre, M. and Nenadić, O. (forthcoming): *Mathematical Tools for Social Scientists—An Introduction with R*. BBVA Foundation, Bilbao.

#### Short Course Description:

This course aims to refresh mathematical concepts which are required for the understanding and the application of recent developments in empirical research methodology. The course covers the fundamentals of Mathematics (functions, linear algebra, calculus, and optimization), focusing on the understanding of the concepts. Instead of pursuing a formal approach, this course will help participants to familiarize themselves with what we consider as essential and useful mathematical knowledge. Thus, one aim of the course is to remove the commonly experienced uncertainty when researchers are dealing with mathematical concepts and expositions in their research.

An important part of this workshop is the active use of the open-source statistical programming language R. Since its introduction in the 1990s, R has become a de facto standard for statistical computing. As such, this workshop combines communicating mathematical concepts with an introduction and the active application of R, both of which are taught in parallel.

The course sessions basically comprise of two continuously alternating parts: the "theoretical part" covers the mathematical explanations while the "applied part" re-elaborates and reinforces the theoretical part by actively using R. In this way, the course lays the foundations for advanced empirical research methodology by covering the theoretical background as well as providing the participants with an insight and competence in R.

#### Keywords:

Mathematics, empirical social research, R.

## Course Prerequisites:

- The only prerequisite for the workshop is the motivation to learn (or to repeat) the fundamentals of Mathematics and R.
- Note: Familiarity with R is not a prerequisite (but highly welcome). Downloading and installing R (<http://cran.r-project.org>) and Rstudio (<http://rstudio.org>) prior to the course is strongly suggested. Participants are encouraged to play around with the software before the course in order to get a feeling for it.

## Target Group:

The course is conceptualized to support scientists who want to improve their mathematical background knowledge as a prerequisite for advanced empirical research. It is commonly found that mathematical prerequisites are an obstacle for understanding advanced statistical methods. In many cases, this may be due to the fact that the last Mathematics course has been taken at least some time ago. Thus, the course is aimed at students and researchers, especially in the social sciences, who wish to renew their mathematical competence as well as learn or fine-tune their programming skills using R.

## Course and Learning Objectives:

By the end of the course, participants will:

- have an understanding of the fundamentals of Mathematics, as well as several advanced topics
- have learnt how several basic as well as advanced statistical methods are conceptualized mathematically and how they are implemented analytically and computationally
- give R beginners an introduction to the most powerful and universal computing tool available
- give existing R users new insights into the R environment

## Organizational Structure of the Course:

This course is innovative in that the "theoretical" and the "practical" parts will alternate continuously and not be totally separated within each day. Typically, after a theoretical chunk (approximately 20-30 Minutes), the discussed topics will be elaborated in R in the practical chunk (approximately 20-30 Minutes). This makes the learning process dynamic, as opposed to delivering all the theory in the morning, for example, and doing the practical part separately in the afternoon. In addition, exercises for each topic will be provided, a few of which participants will have to solve during the class. Most exercises will be done after class, and participants will be strongly encouraged to solve as many of these as they can on their own after each daily session. Problems arising from the exercises will be discussed at the start of the following day, which also provides a revision of the previous day's material before starting with new topics.

## Software and Hardware Requirements:

*Required hardware:*

- Students have to provide their own laptop/computer.

*Required software:*

- R (<https://cran.r-project.org>) and RStudio (<https://www.rstudio.org>). No additional R packages are required.

## Long Course Description:

Detailed course contents:

### 1 Introduction to Mathematics & R

- 1.1 Numbers
- 1.2 Powers and common transformations
- 1.3 Equations and inequalities
- 1.4 Some mathematical notation
- 1.5 Sets, categories and logical variables

### 2 Functions

- 2.1 Examples of functions
- 2.2 Inverse functions
- 2.3 Functions of two or more variables

### 3 Linear algebra

- 3.1 Many into one
- 3.2 Linear transformations
- 3.3 Operations on vectors and matrices
- 3.4 Linear equations and matrix inverses
- 3.5 More matrix-vector operations
- 3.6 Some special matrix transformations

### 4 Calculus

- 4.1 A simple example
- 4.2 Limits
- 4.3 Basic forms and rules of derivatives
- 4.4 Second derivatives
- 4.5 Partial derivatives and derivatives of vectors
- 4.6 Integration
- 4.7 Difference and differential equations

### 5 Optimization

- 5.1 Finding the best
- 5.2 Optimizing functions with "closed form" solutions
- 5.3 Optimizing single-variable functions by iterative methods
- 5.4 Optimizing multivariable functions: direct search method
- 5.5 Optimizing multivariable functions: gradient methods

### 6 Statistical applications

- 6.1 Simple linear regression: least-squares fitting
- 6.2 Multiple linear regression
- 6.3 Maximum likelihood estimation of simple regression model
- 6.4 Maximum likelihood estimation of Poisson regression model
- 6.5 Principal component analysis and factor analysis
- 6.6 Mathematics of networks

## Day-to-day Schedule and Literature:

| Day | Topic(s)   |
|-----|--|
| 1   | 1.) Introduction to Mathematics & R<br>2.) Functions   |
|     | <u>Suggested reading:</u><br>Chapters 1 and 2, "Mathematical Tools for Social Scientists—An Introduction with R" |
| 2   | 3.) Linear Algebra   |
|     | <u>Suggested reading:</u><br>Chapter 3, "Mathematical Tools for Social Scientists—An Introduction with R"        |
| 3   | 4.) Calculus   |
|     | <u>Suggested reading:</u><br>Chapter 4, "Mathematical Tools for Social Scientists—An Introduction with R"        |
| 4   | 5.) Optimization and 6.) Statistical Applications  |
|     | <u>Suggested reading:</u><br>Chapter 5 & 6, "Mathematical Tools for Social Scientists—An Introduction with R"    |

## Preparatory Reading:

Note that the workshop follows the book "Mathematical Tools for Social Scientists—An Introduction with R" by M. Greenacre and O. Nenadić (forthcoming). The participants will be provided with a copy of the book.