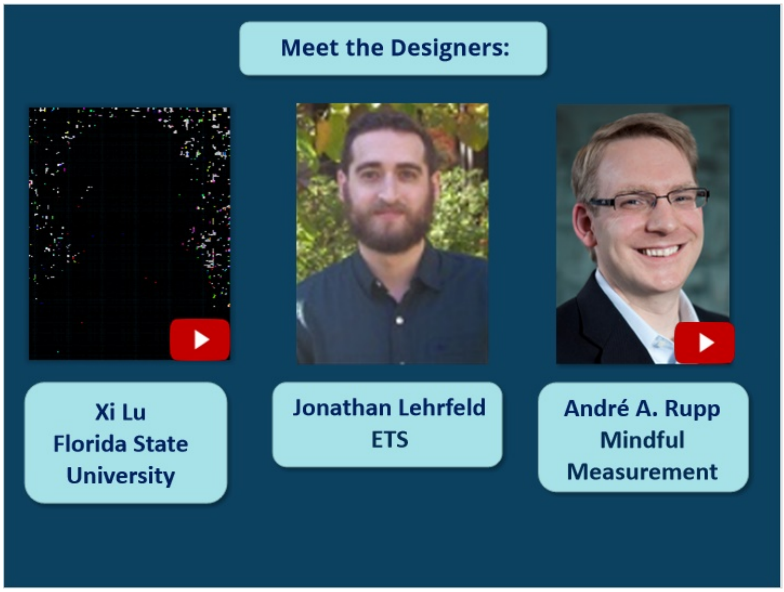
DM16 SLIDES (Version 1.0)

1. Module Overview

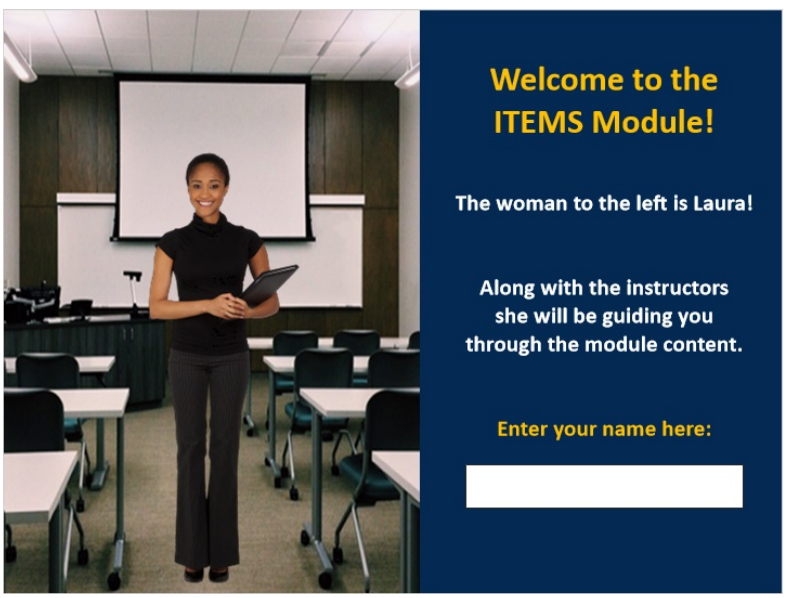
1.1 Module Cover (START)

1.2 Instructors

1.3 Designers



1.4 Welcome



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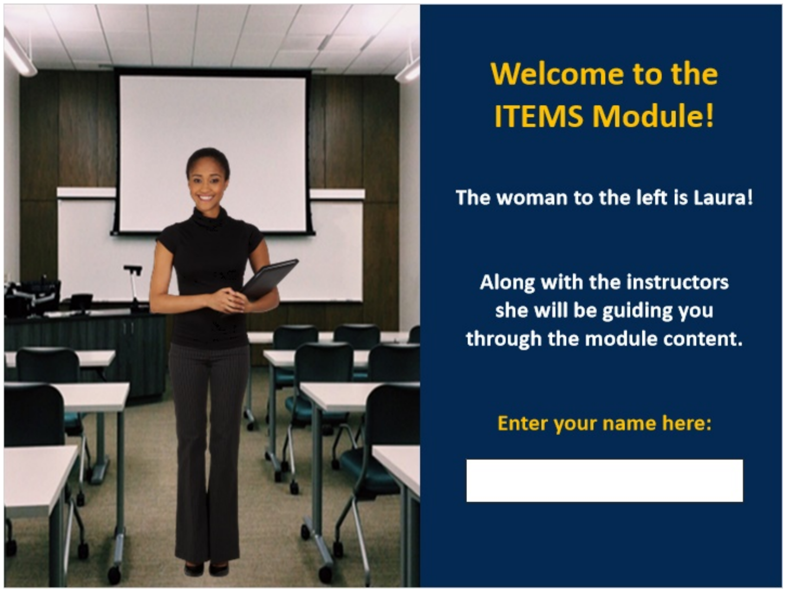
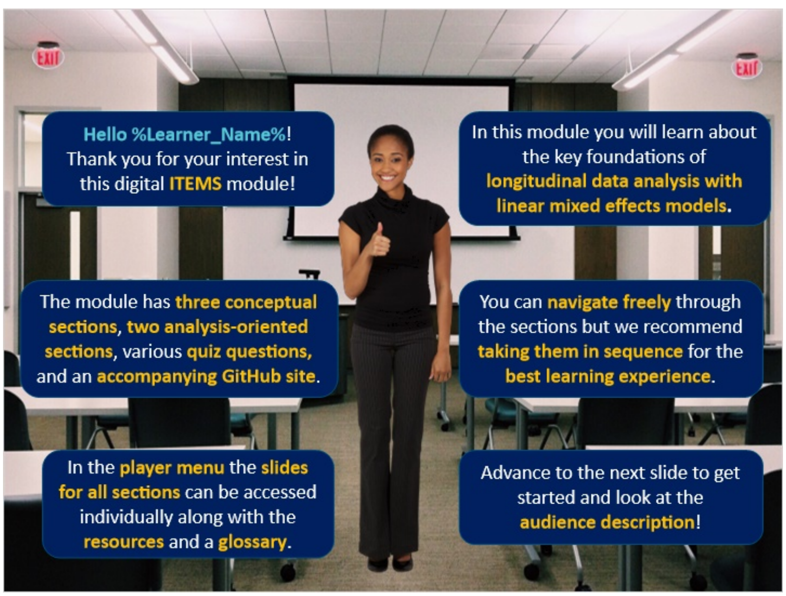
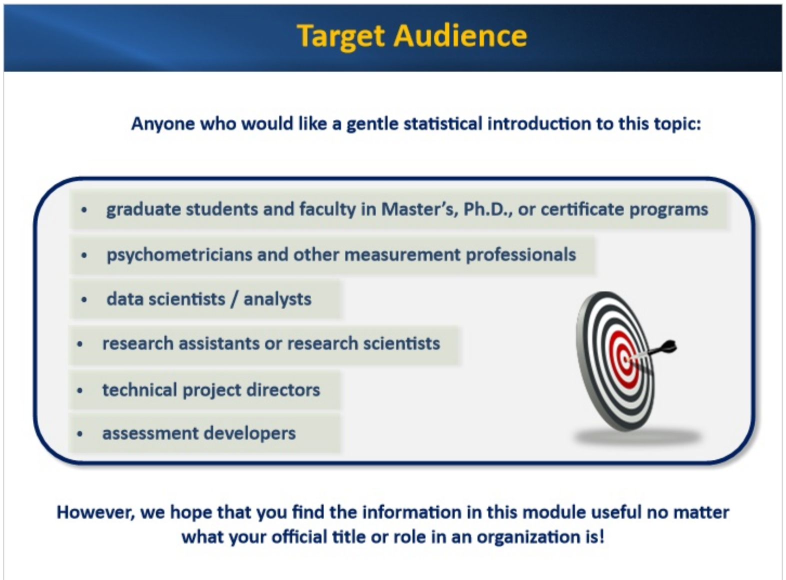


1.5 Overview



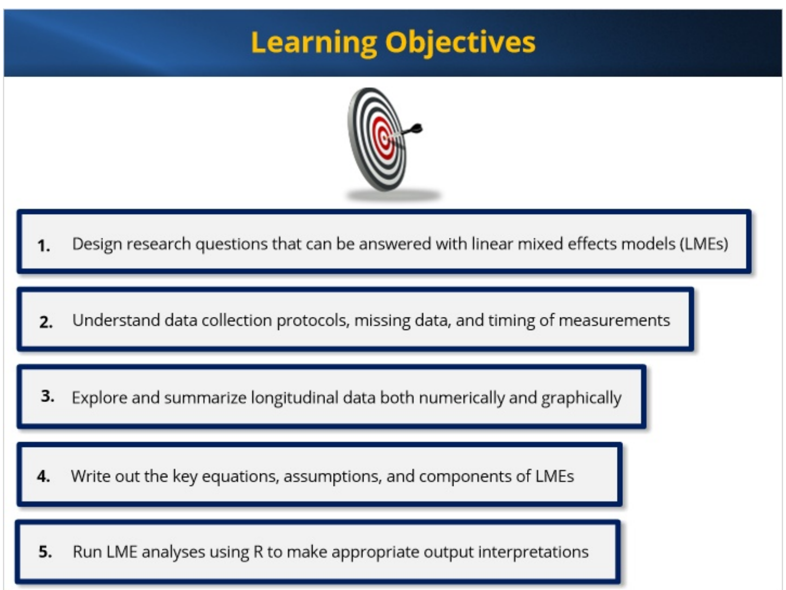
1.6 Target Audience



1.7 Expecations (I)

1.8 Expectations (II)

1.9 Learning Objectives



1.10 Prerequisites

Prerequisites

- **Working knowledge of the following topics:**
  - ✓ Hypothesis testing and *p*-value interpretation
  - ✓ Principles of exploratory data analysis
  - ✓ Multiple linear regression models
  - ✓ General linear models / ANOVA models
- **Basic practical experience with:**
  - ✓ Summarizing data numerically and graphically
  - ✓ Working with *R* and associated *R* packages
  - ✓ Interpreting model output for decision-making

1.11 Resources

Resources

Module Citation

Harring, J. R., & Johnson, T. L. (2020). Longitudinal data analysis (Digital ITEMS Module 16). *Educational Measurement: Issues and Practice, 39*(4), XX-XX.

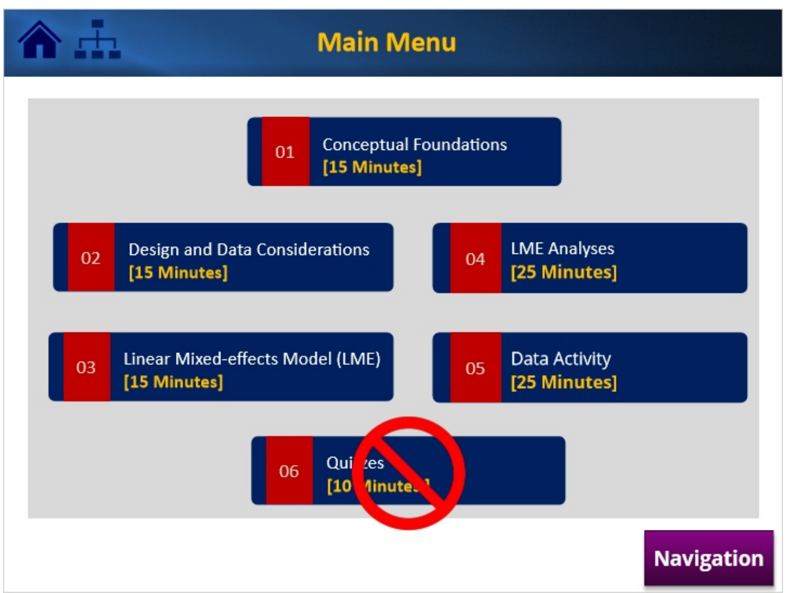
GitHub Tutorial

https://tessaleejohnson.github.io/ITEMS-Longitudinal/

Additional Resources

References (Slide Layer)

1.12 Main Menu

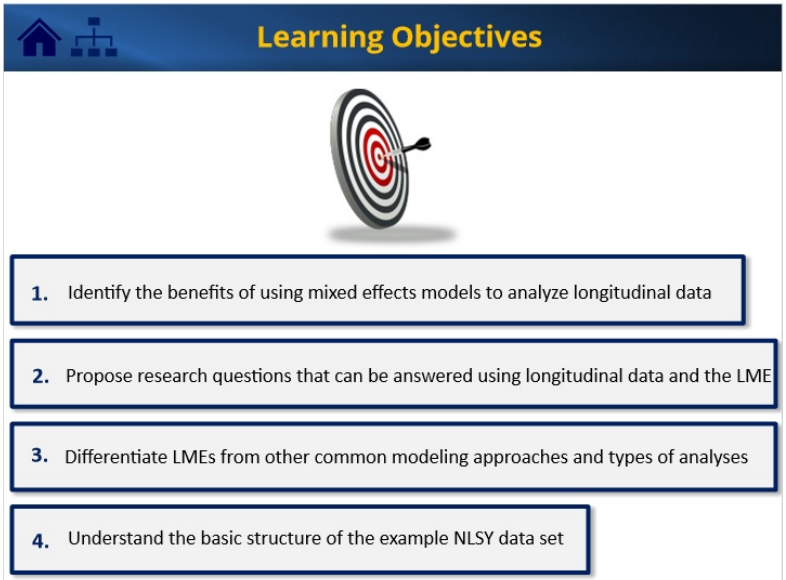


Navigation (Slide Layer)

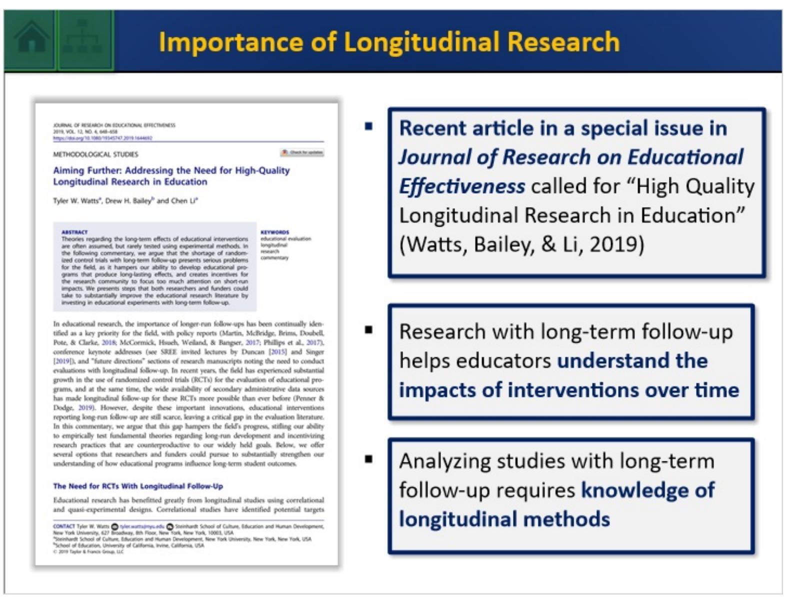
2. Section 1: Conceptual Foundations

2.1 Cover: Section 1

2.2 Learning Objectives: Section 1



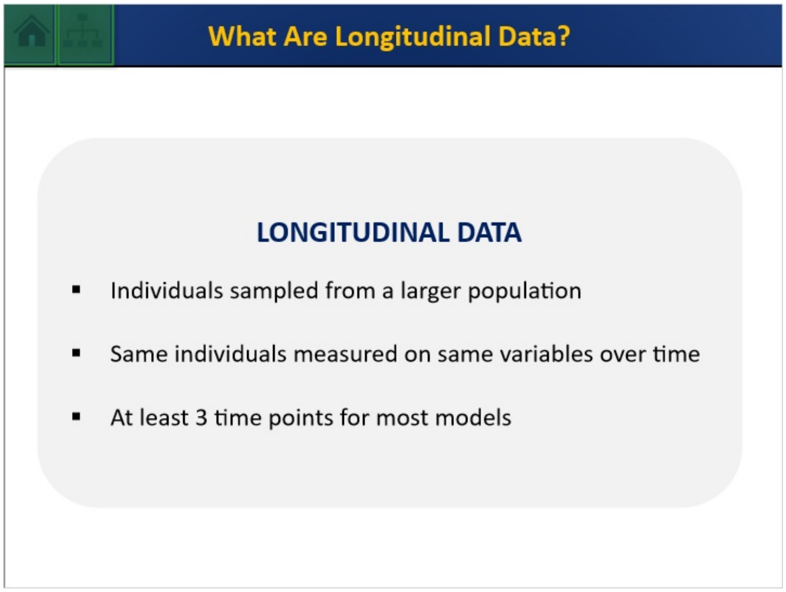
2.3 Importance of Longitudinal Research



2.4 Topic Selection

2.5 Bookmark: Longitudinal Data

2.6 What Are Longitudinal Data



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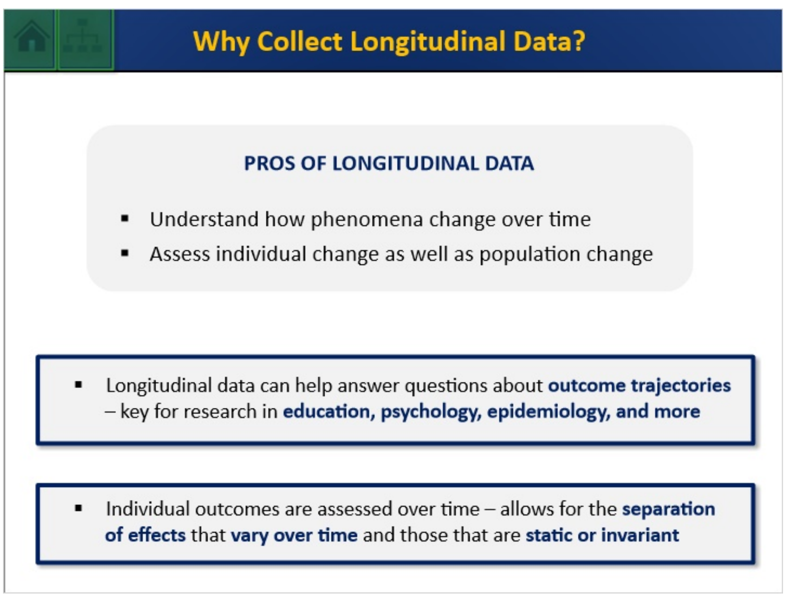
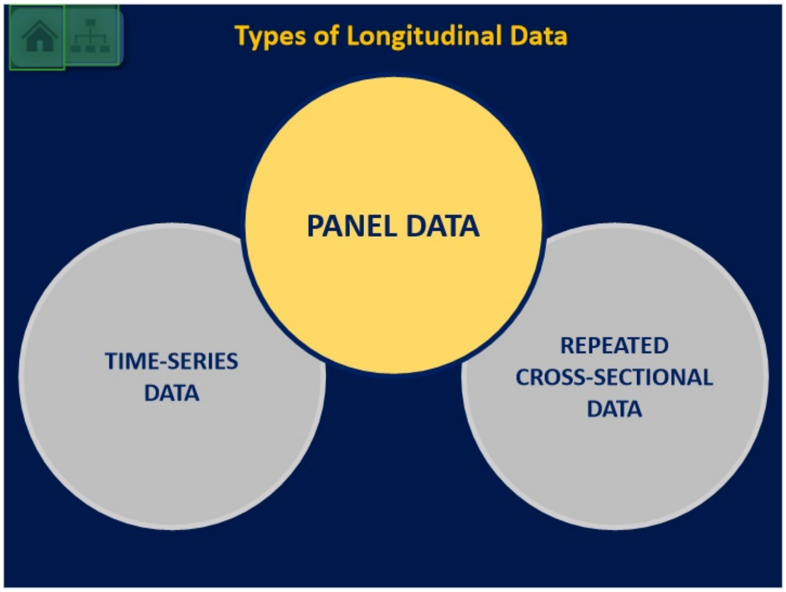
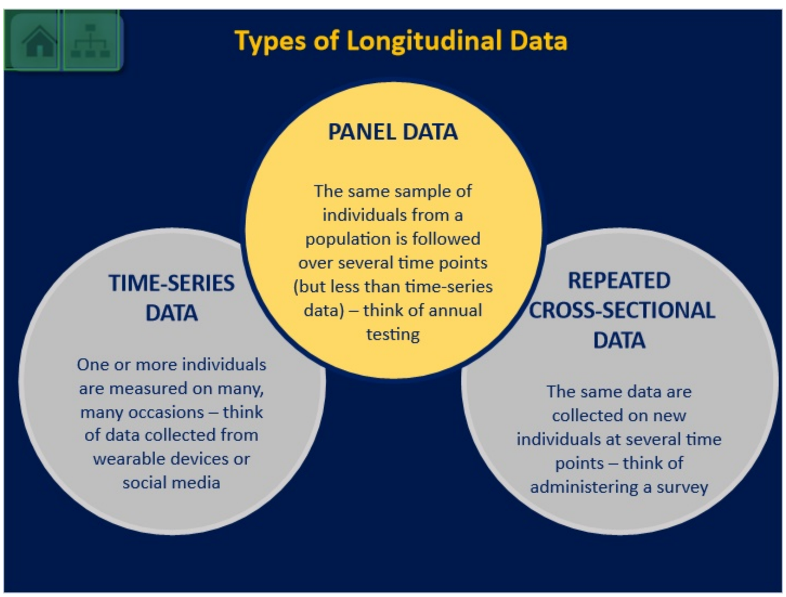


2.8 Types of Longitudinal Data I



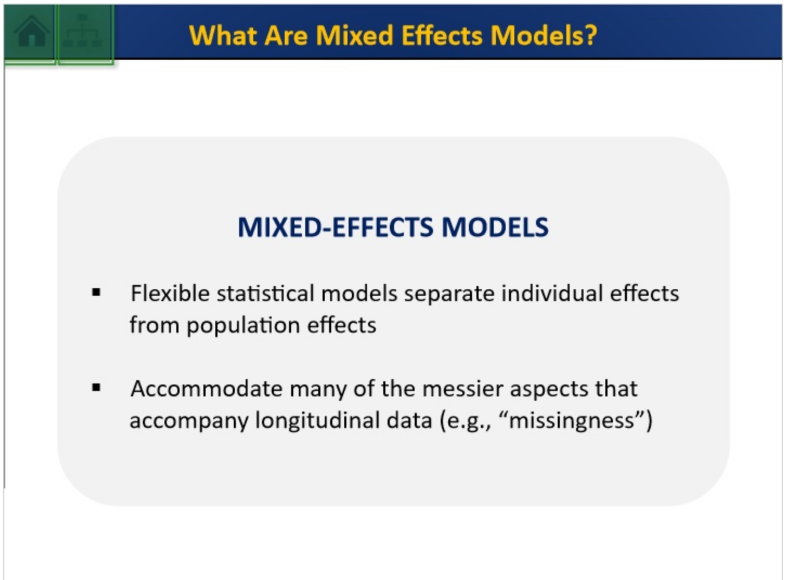
2.9 Types of Longitudinal Data II



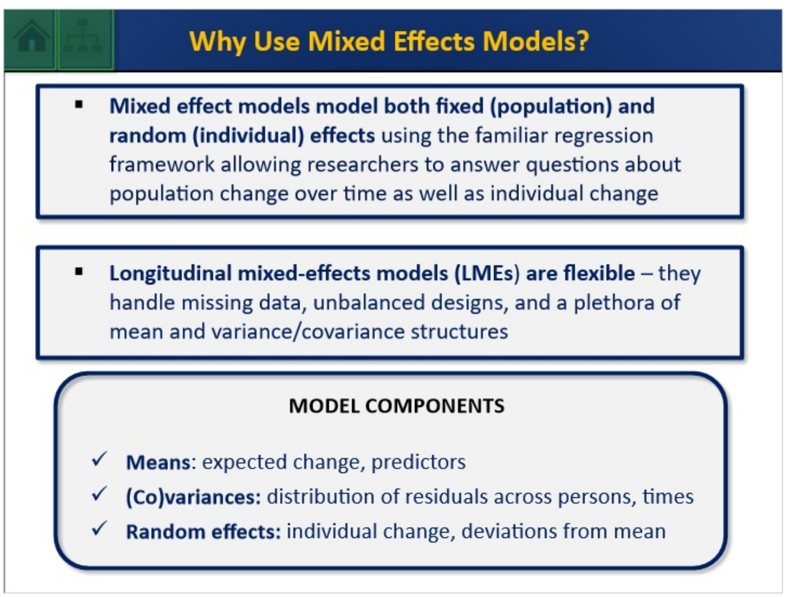
2.10 Bookend: Longitudinal Data

2.11 Bookmark: Mixed Effects Models

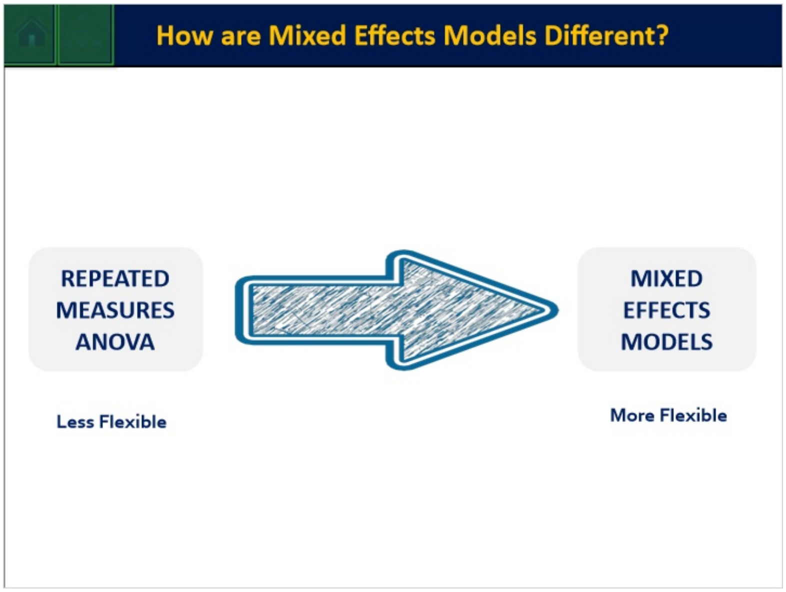
2.12 What Are Mixed Effects Models



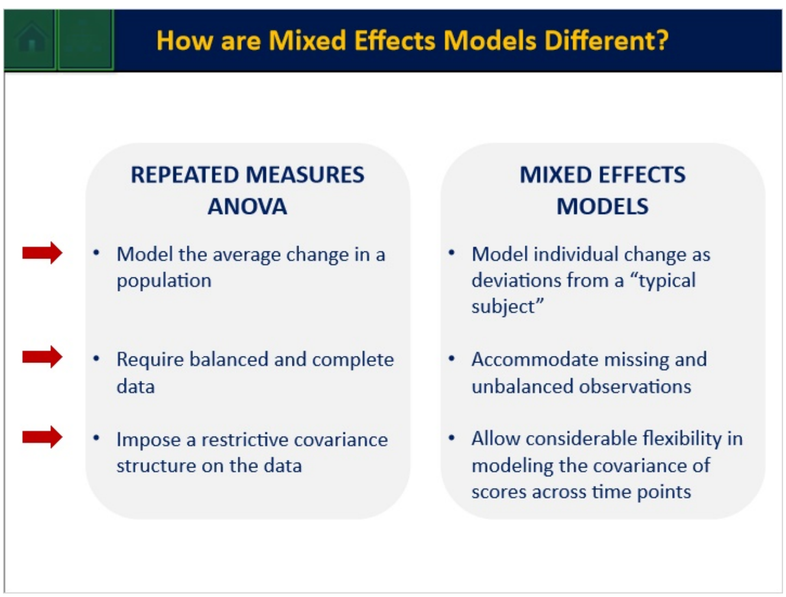
2.13 Why Use Mixed Effects Models



2.14 How Are Mixed Effects Models Different I



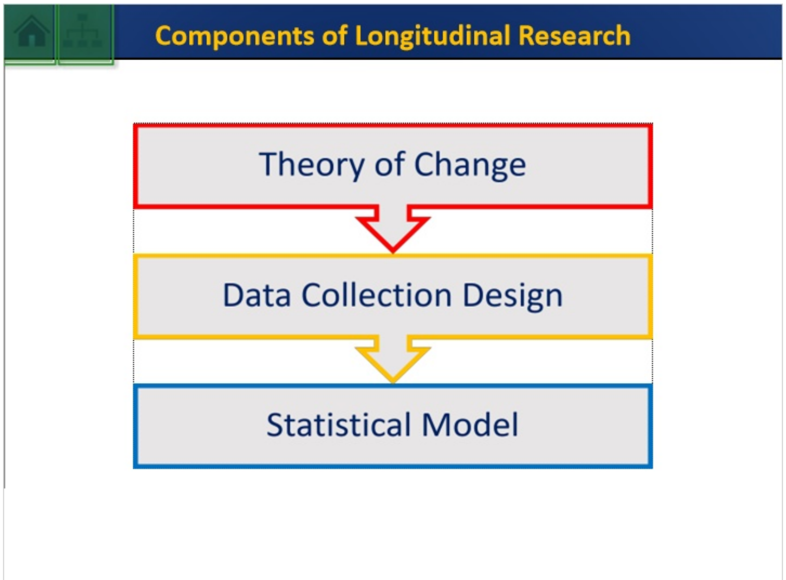
2.15 How Are Mixed Effects Models Different II



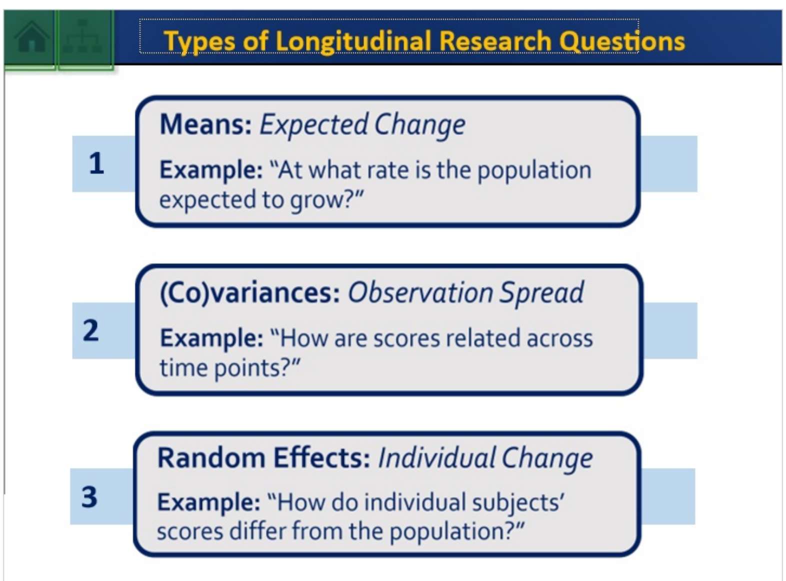
2.16 Bookend: Mixed Effects Models

2.17 Bookmark: Research Components

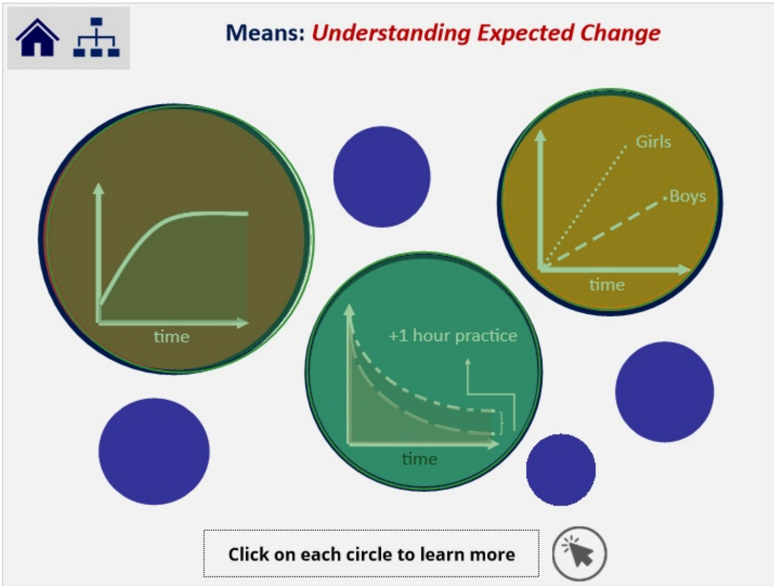
2.18 Components of Longitudinal Research



2.19 Types of Longitudinal Research Questions



2.20 Understanding Expected Change



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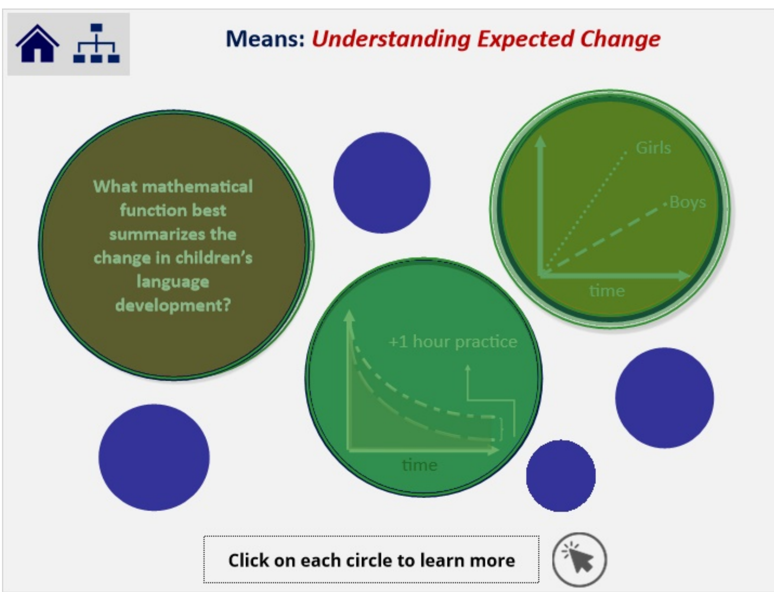

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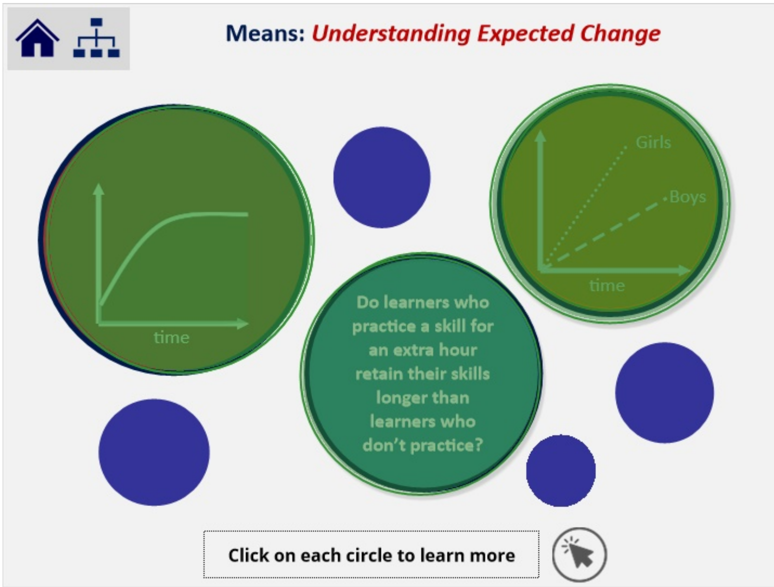

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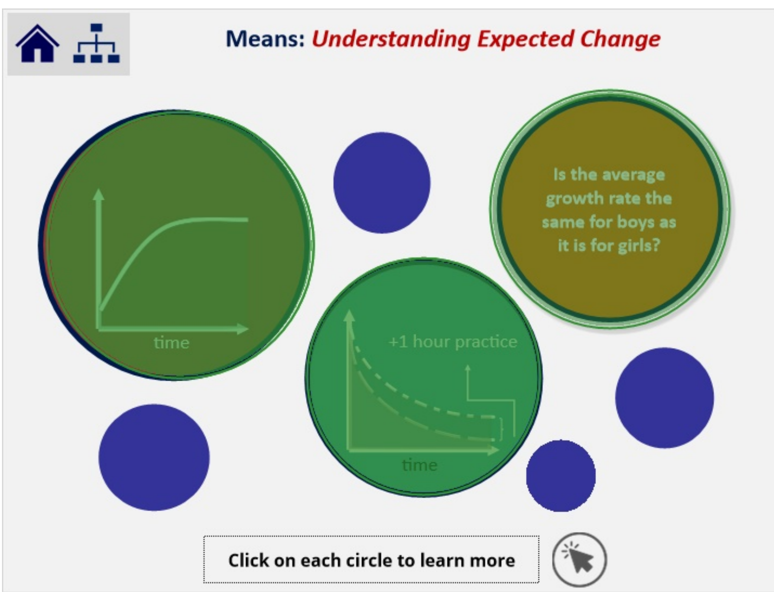
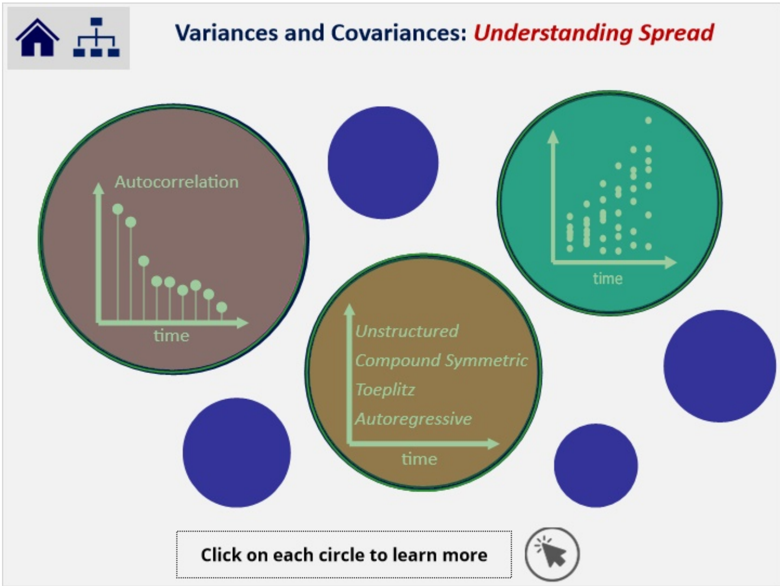


2.21 Understanding Spread



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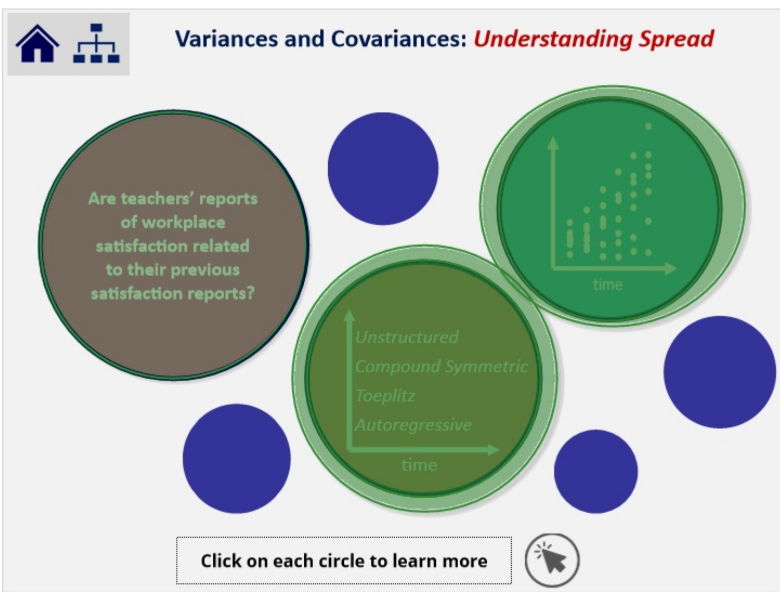

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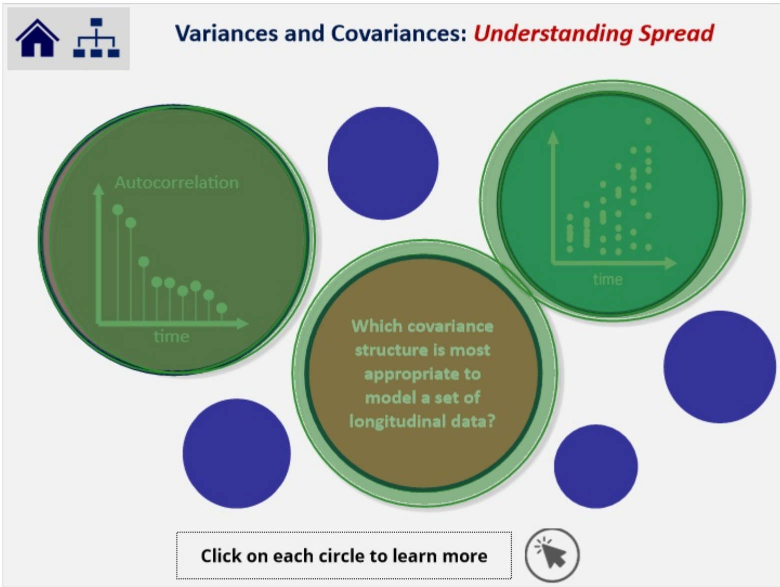

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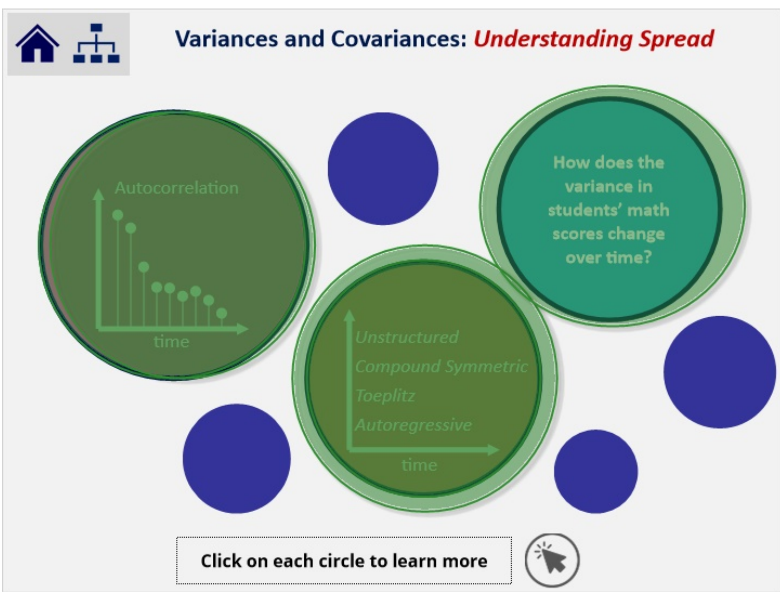
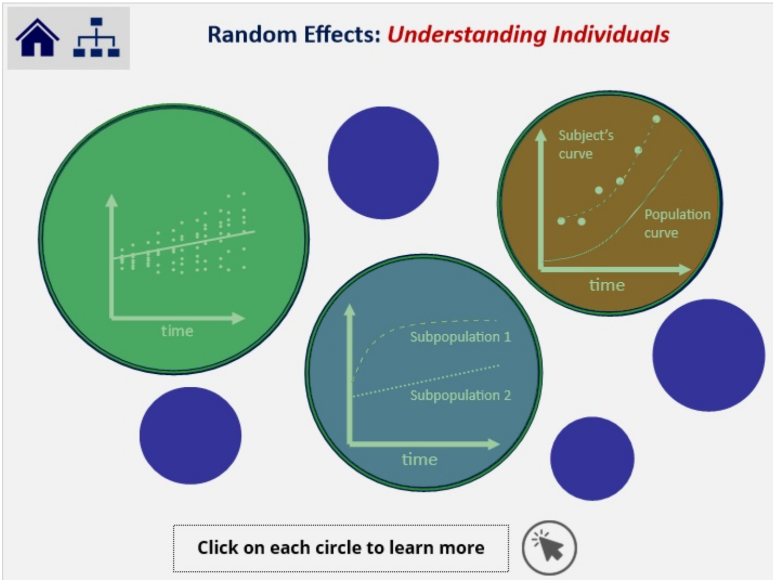


2.22 Understanding Individuals



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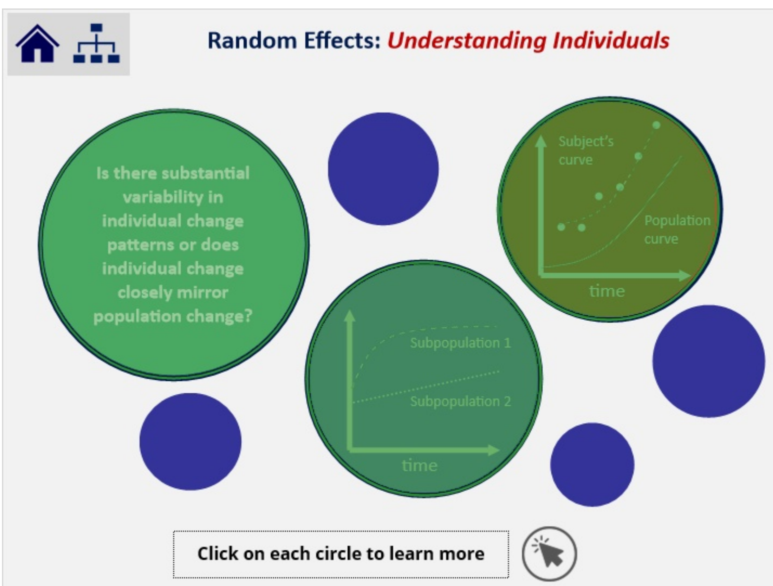

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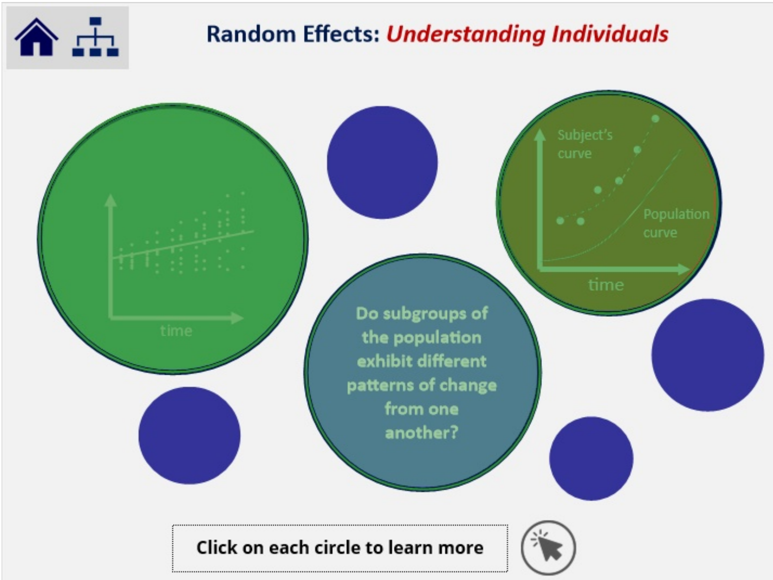
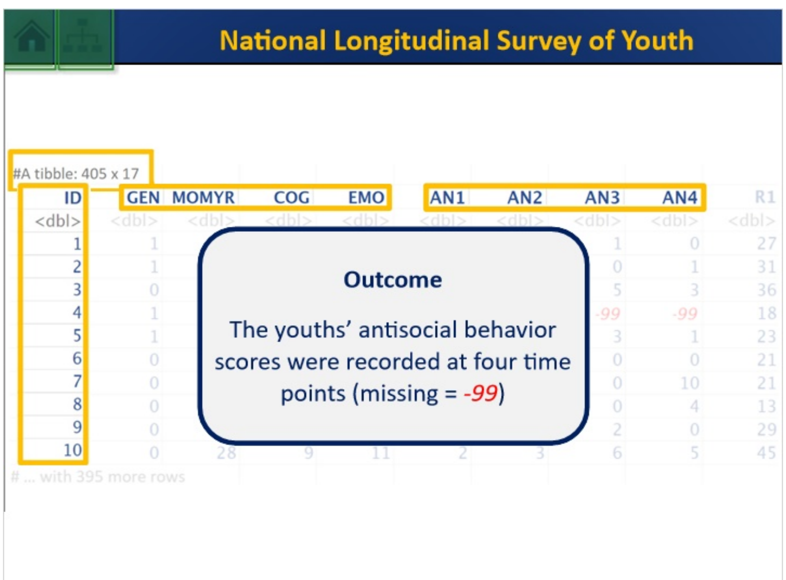


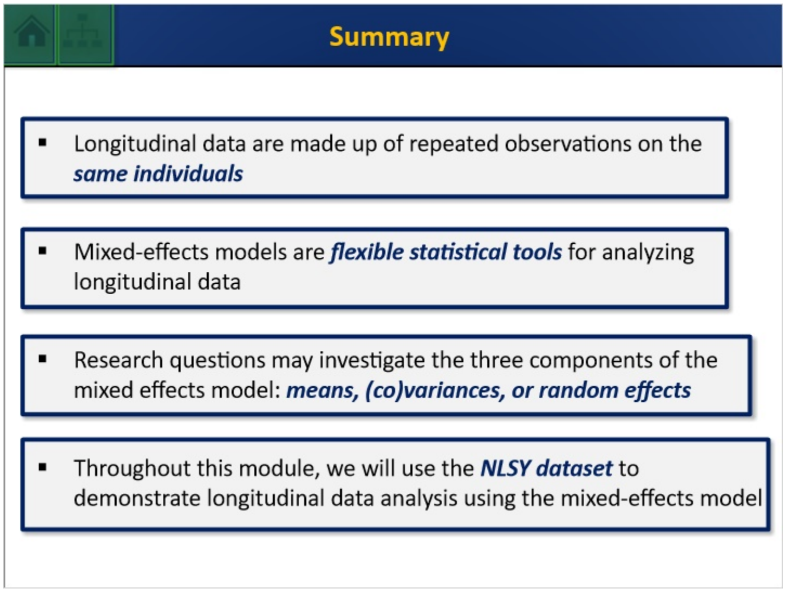
Q3 (Slide Layer)

2.23 Bookend: Research Components

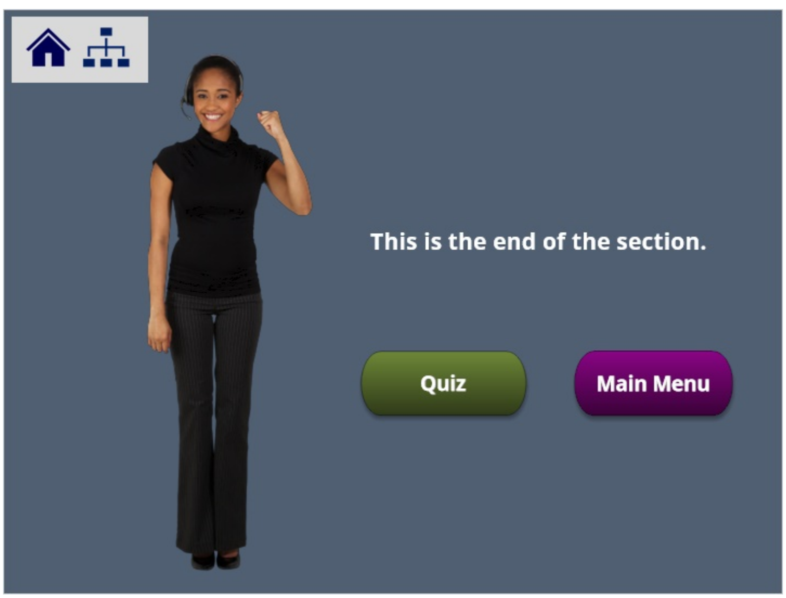
2.24 Example NLSY



2.25 Summary



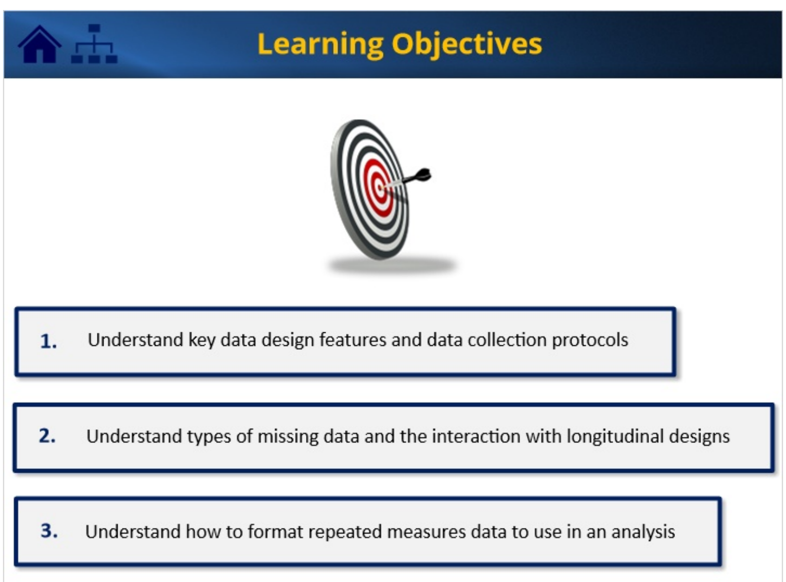
2.26 Bookend: Section 2



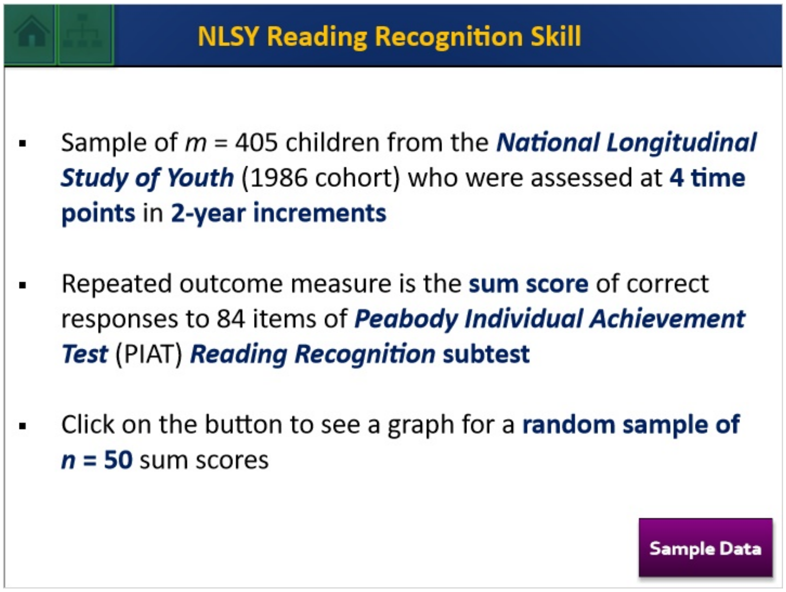
3. Section 2: Design and Data Considerations

3.1 Cover: Section 2

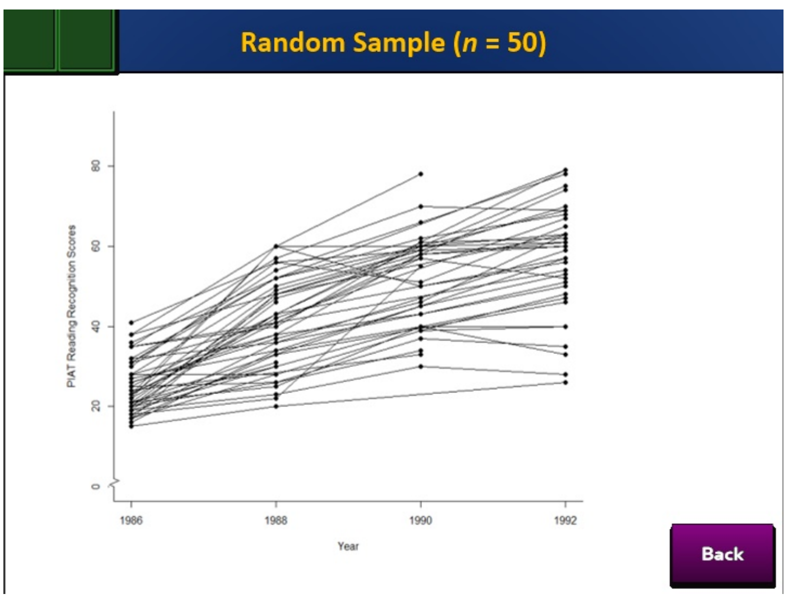
3.2 Learning Objectives: Section 2



3.3 NLSY Reading Recognition Skill

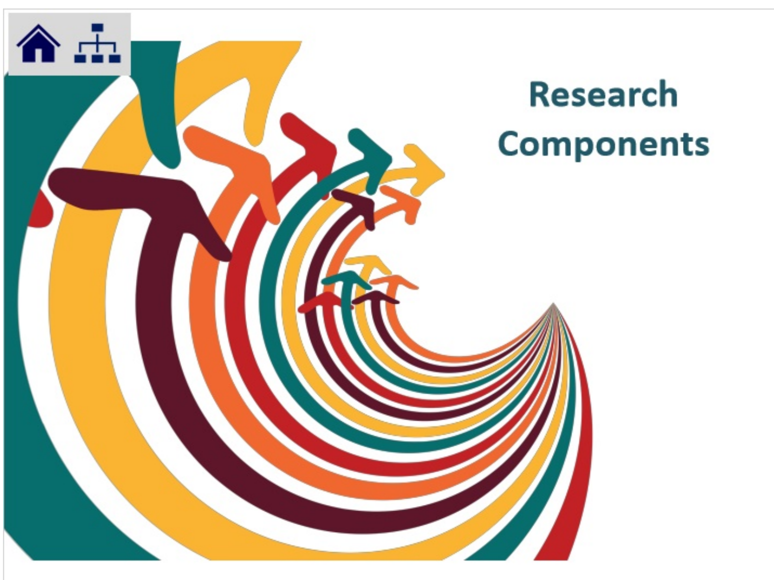


Sample Data (Slide Layer)

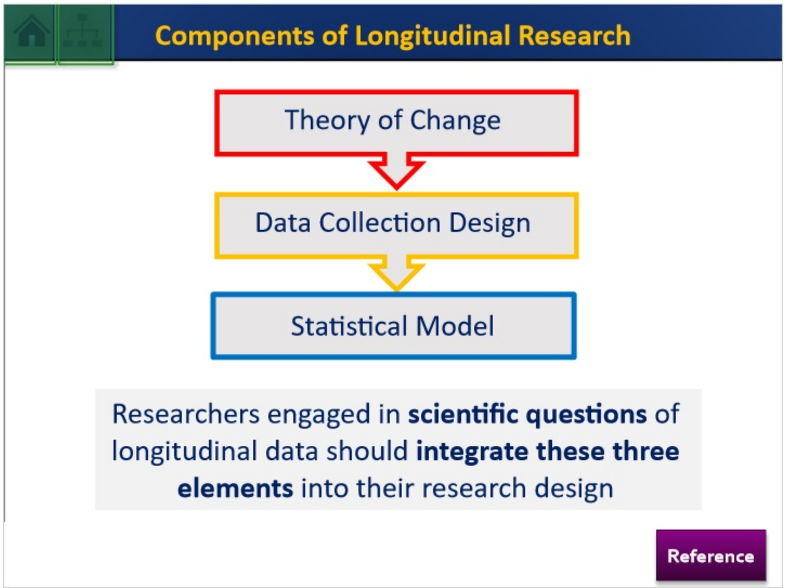


3.4 Topic Selection

3.5 Bookmark: Research Components

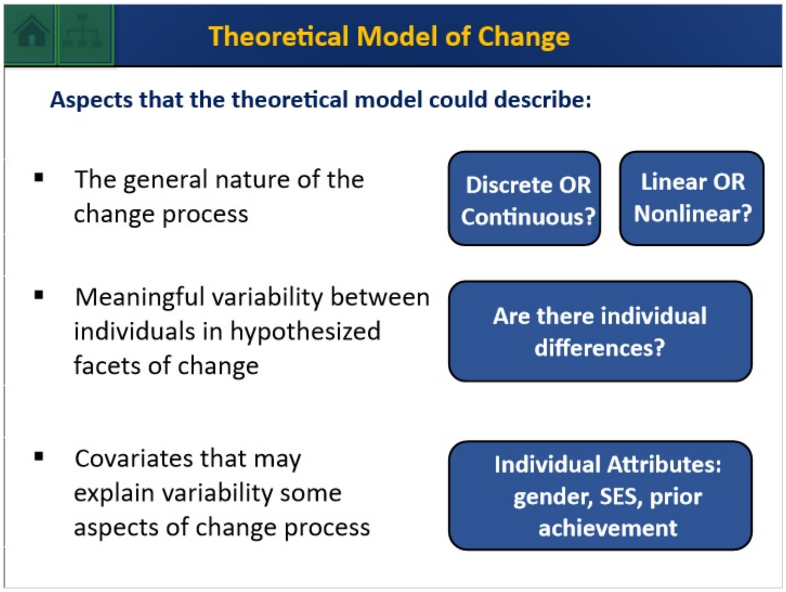


3.6 Components of Longitudinal Research

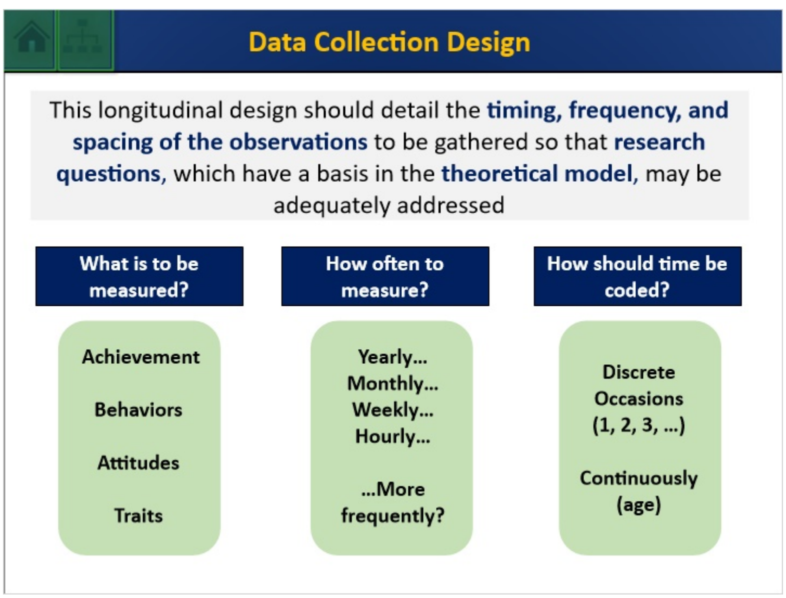


Reference (Slide Layer)

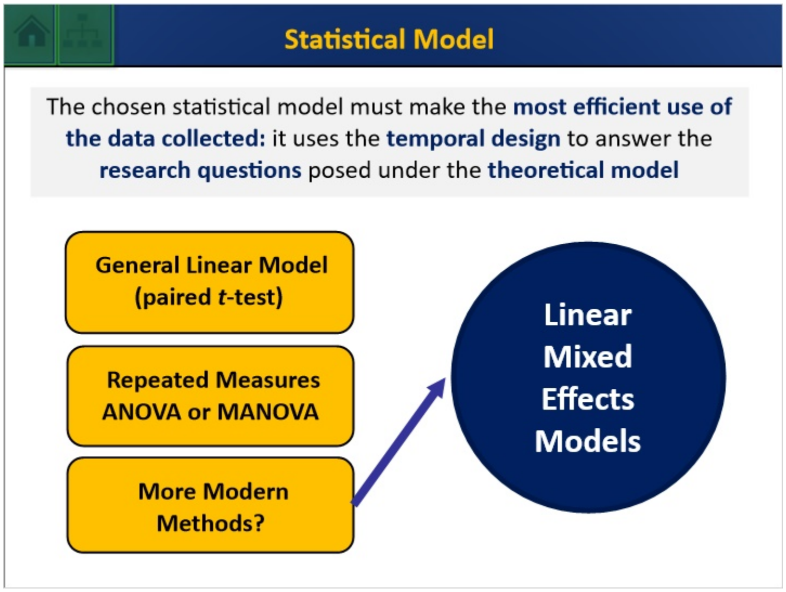
3.7 Theoretical Model of Change



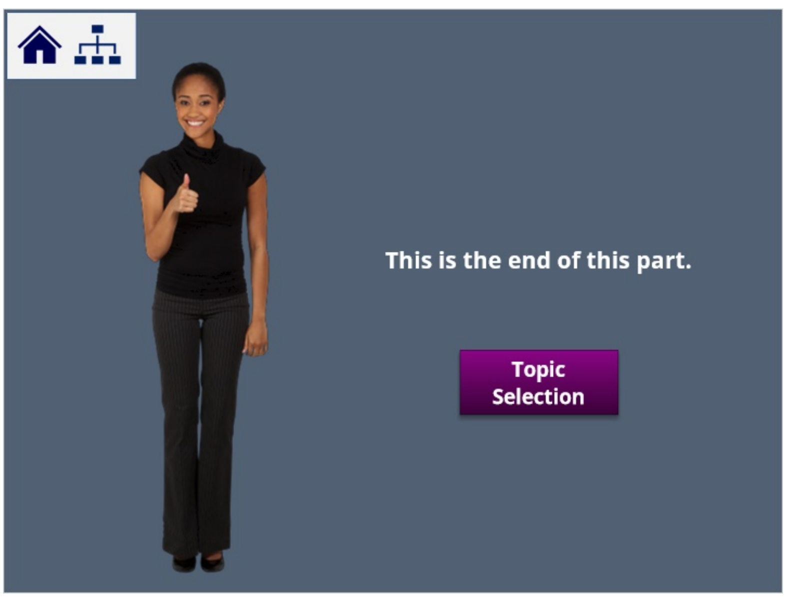
3.8 Data Collection Design



3.9 Statistical Model

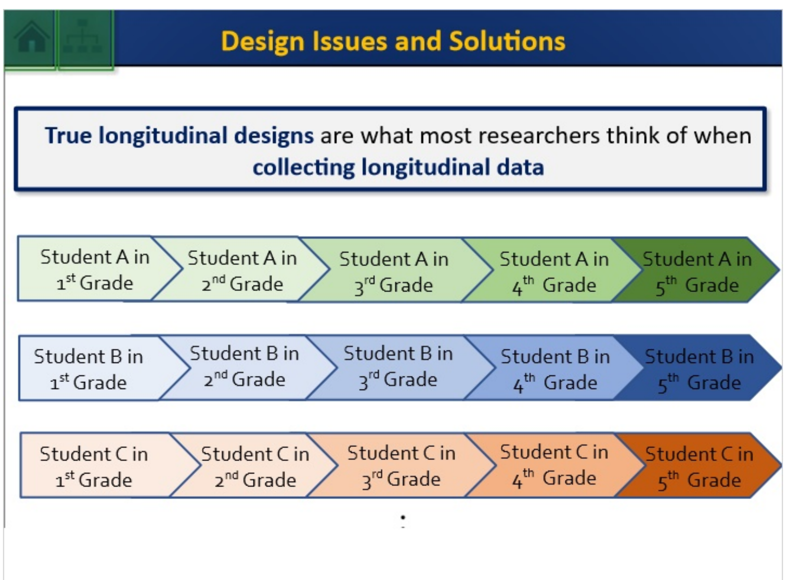


3.10 Bookend: Research Components

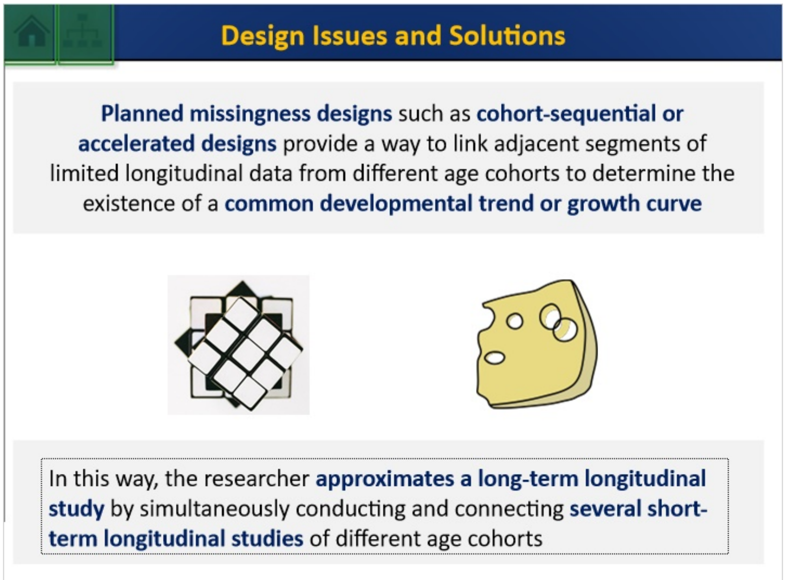


3.11 Bookmark: Data Designs

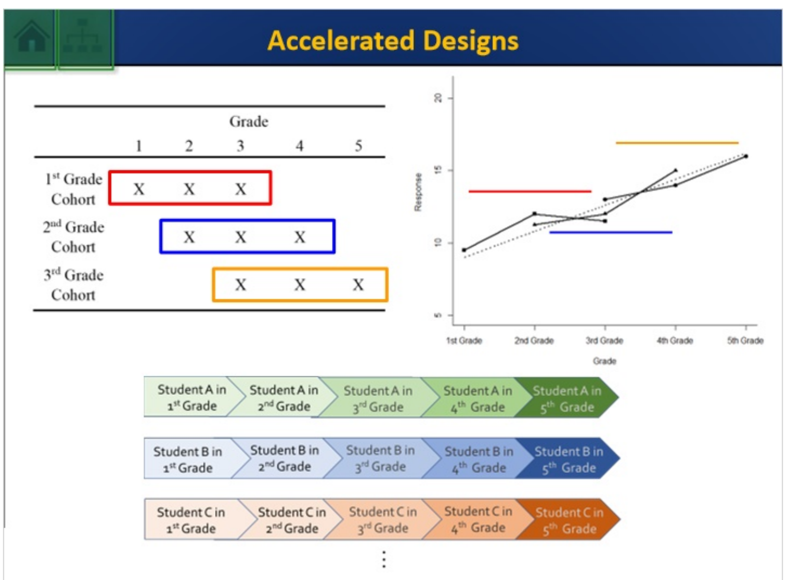
3.12 Design Issues and Solutions I



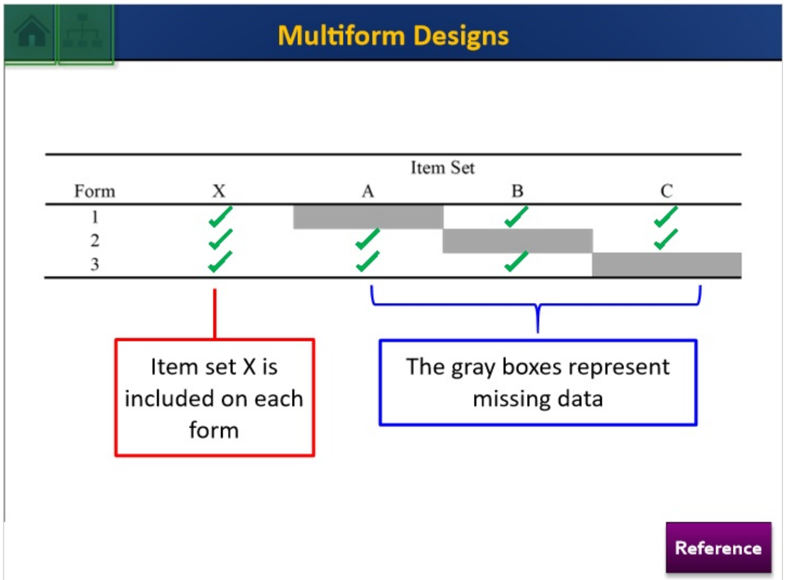
3.13 Design Issues and Solutions II



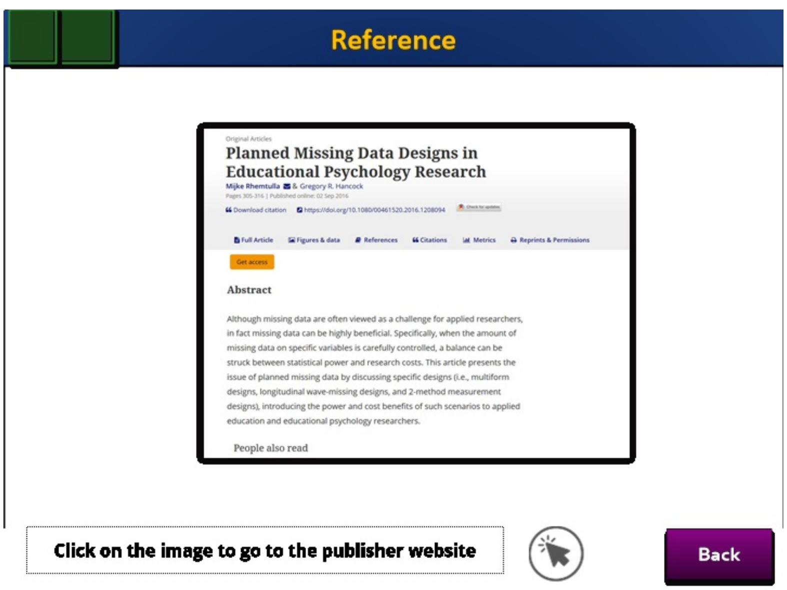
3.14 Accelerated Designs



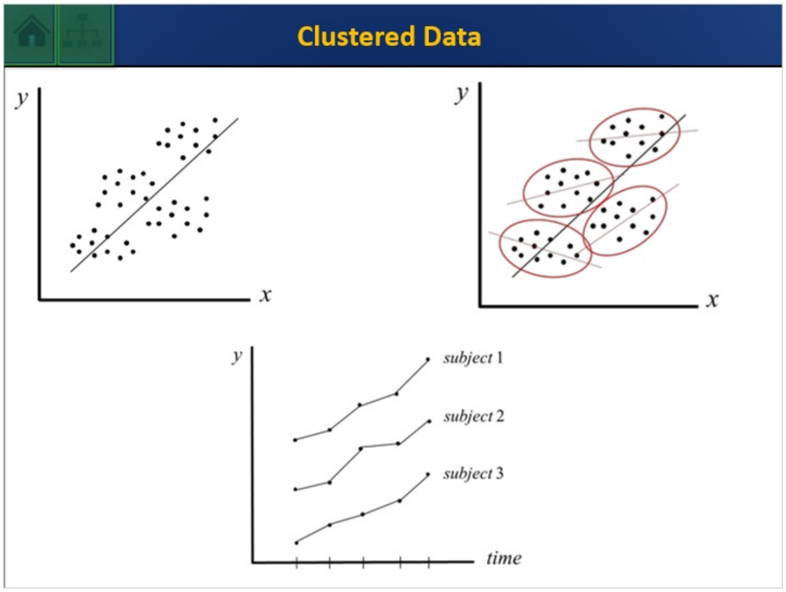
3.15 Multiform Designs



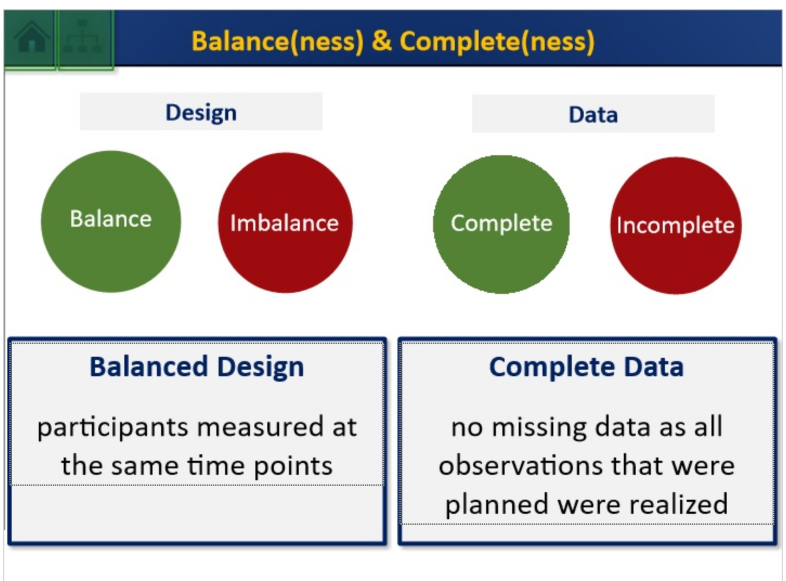
Reference (Slide Layer)



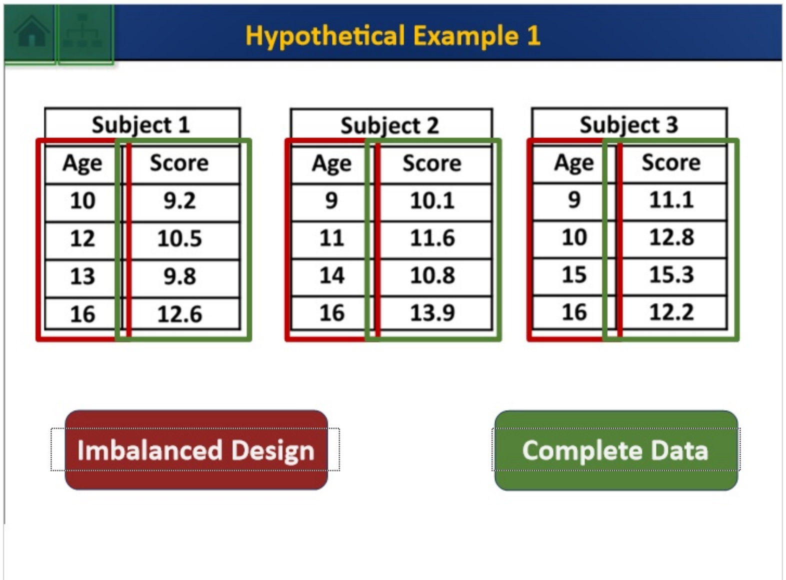
3.16 Clustered Data



3.17 Balanceness & Completeness

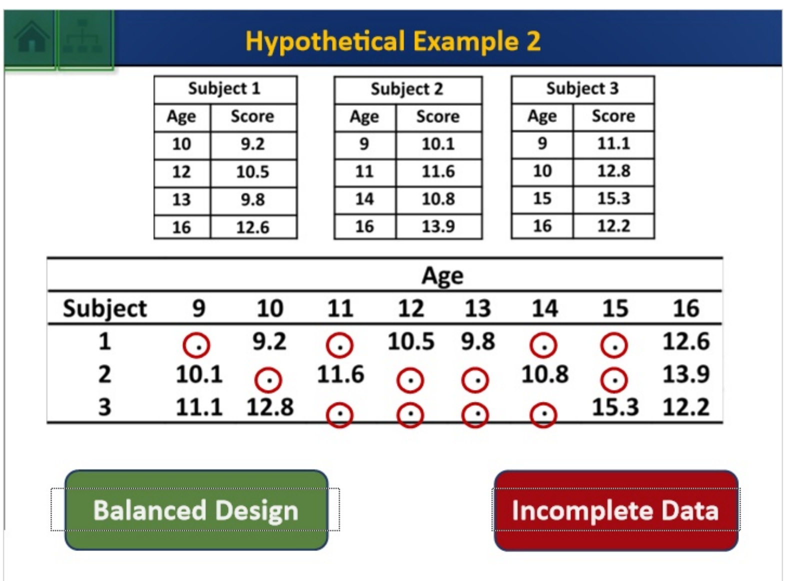


3.18 Hypothetical Example I



Subject 1		Subject 2		Subject 3	
Age	Score	Age	Score	Age	Score
10	9.2	9	10.1	9	11.1
12	10.5	11	11.6	10	12.8
13	9.8	14	10.8	15	15.3
16	12.6	16	13.9	16	12.2

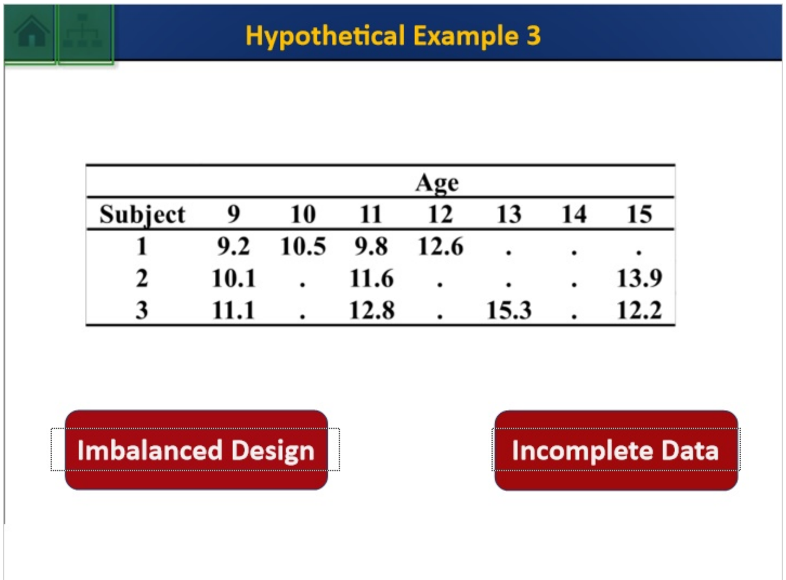
3.19 Hypothetical Example II



Subject 1		Subject 2		Subject 3	
Age	Score	Age	Score	Age	Score
10	9.2	9	10.1	9	11.1
12	10.5	11	11.6	10	12.8
13	9.8	14	10.8	15	15.3
16	12.6	16	13.9	16	12.2

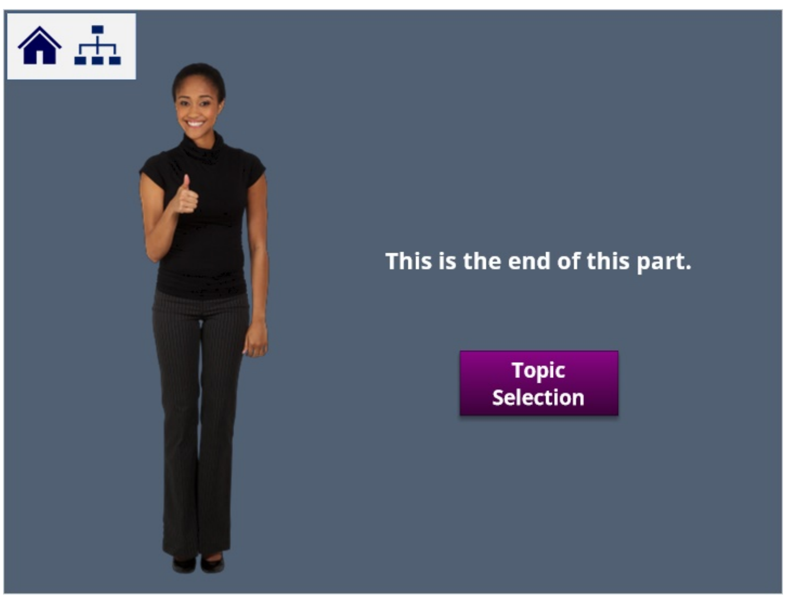
	Age							
Subject	9	10	11	12	13	14	15	16
1	⊙	9.2	⊙	10.5	9.8	⊙	⊙	12.6
2	10.1	⊙	11.6	⊙	⊙	10.8	⊙	13.9
3	11.1	12.8	⊙	⊙	⊙	⊙	15.3	12.2

3.20 Hypothetical Example III



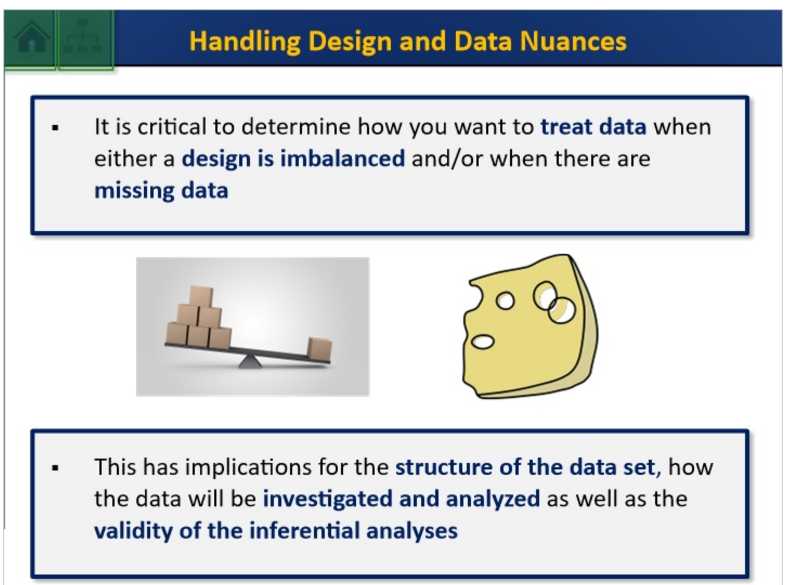
	Age						
Subject	9	10	11	12	13	14	15
1	9.2	10.5	9.8	12.6	.	.	.
2	10.1	.	11.6	.	.	.	13.9
3	11.1	.	12.8	.	15.3	.	12.2

3.21 Bookend: Data Designs

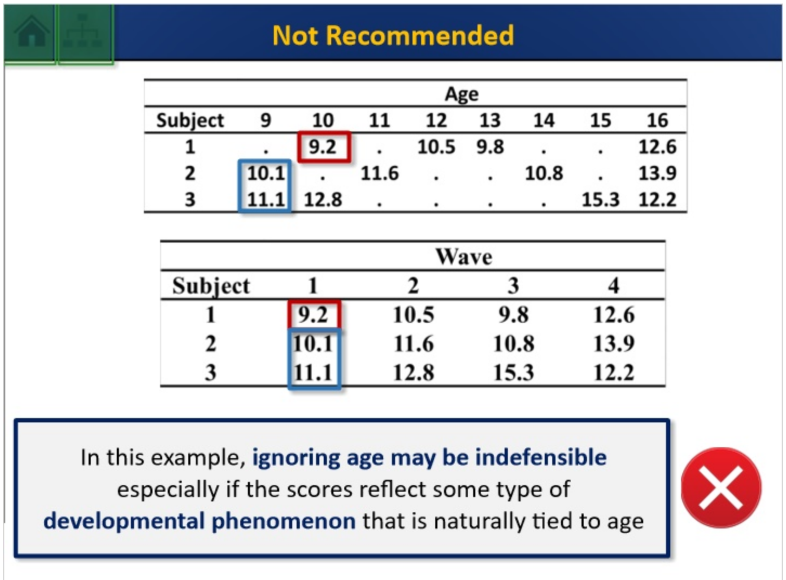


3.22 Bookmark: Handling Data Issues

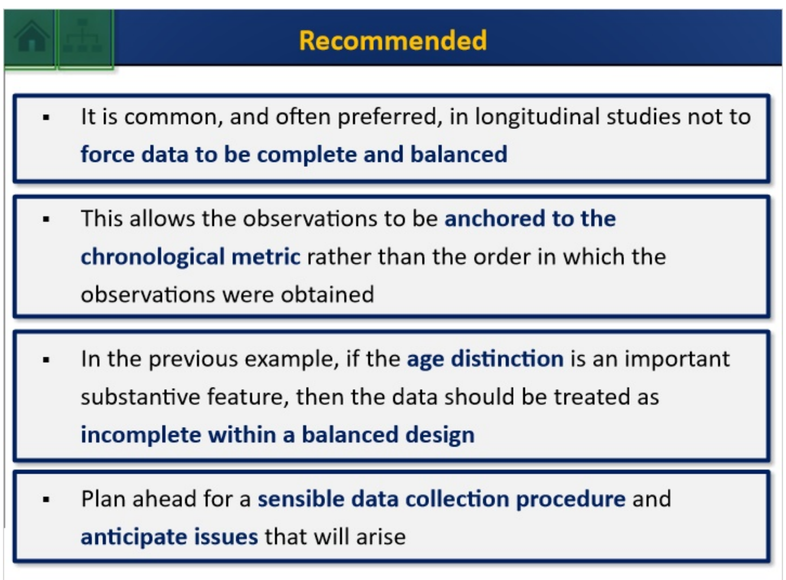
3.23 Handling Design and Data Nuances



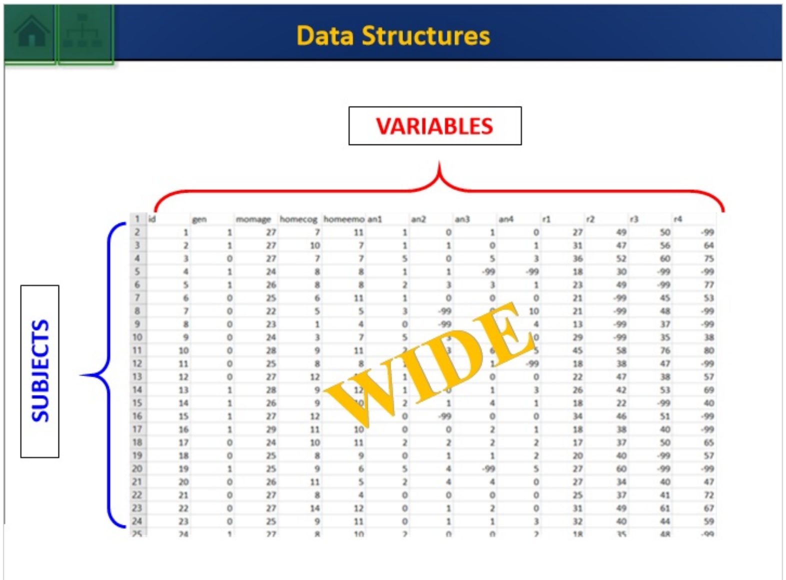
3.24 Not Recommended



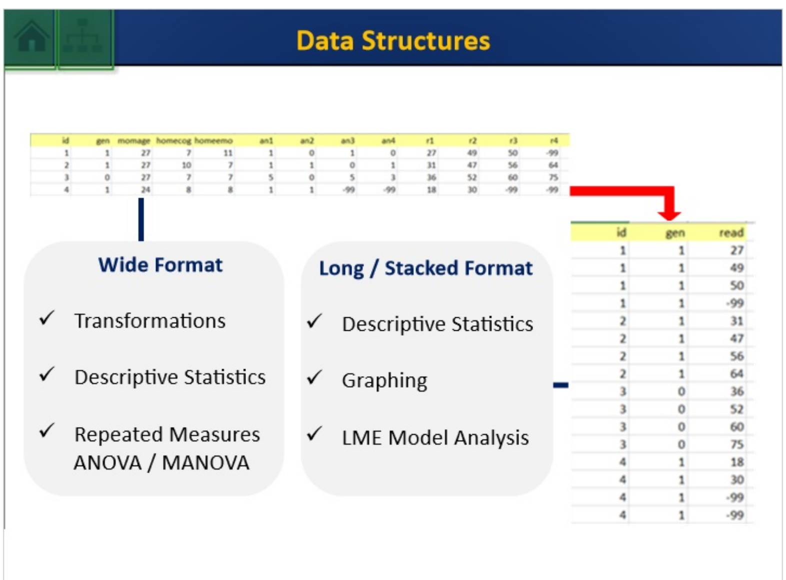
3.25 Recommended



3.26 Data Structures I

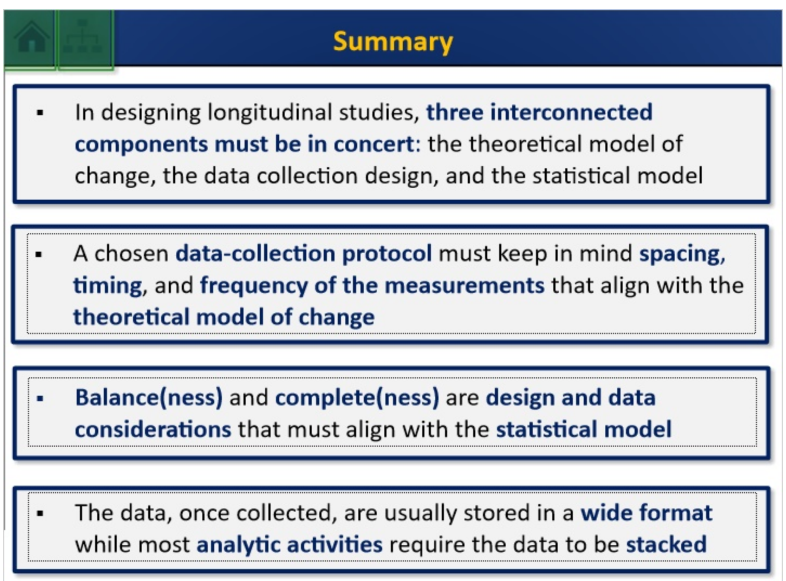


3.27 Data Structures II

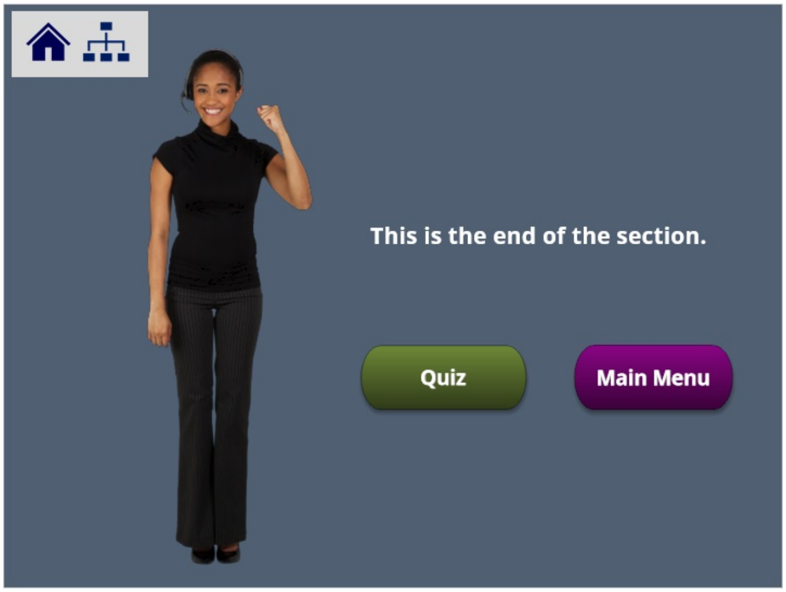


3.28 Bookend: Handling Data Issues

3.29 Summary



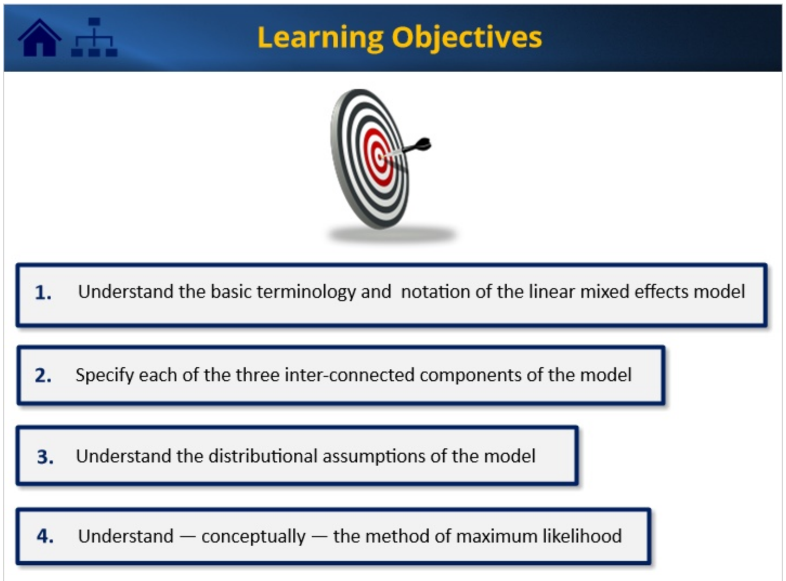
3.30 Bookend: Section 2



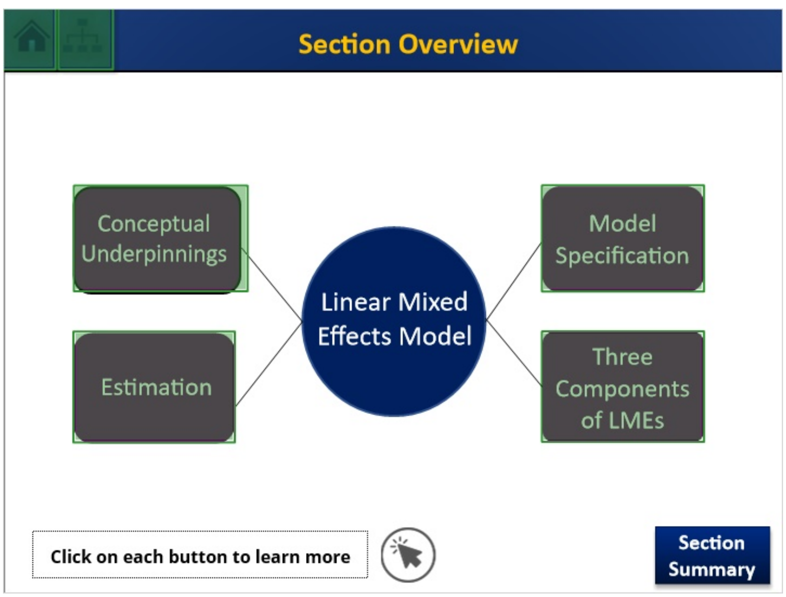
4. Section 3: Linear Mixed Effects Models

4.1 Cover: Section 3

4.2 Learning Objectives: Section 3

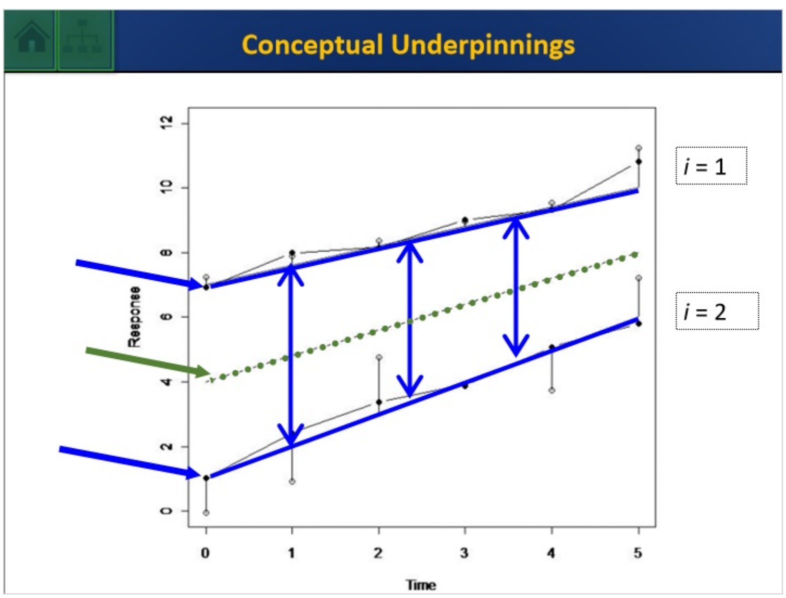


4.3 Topic Selection

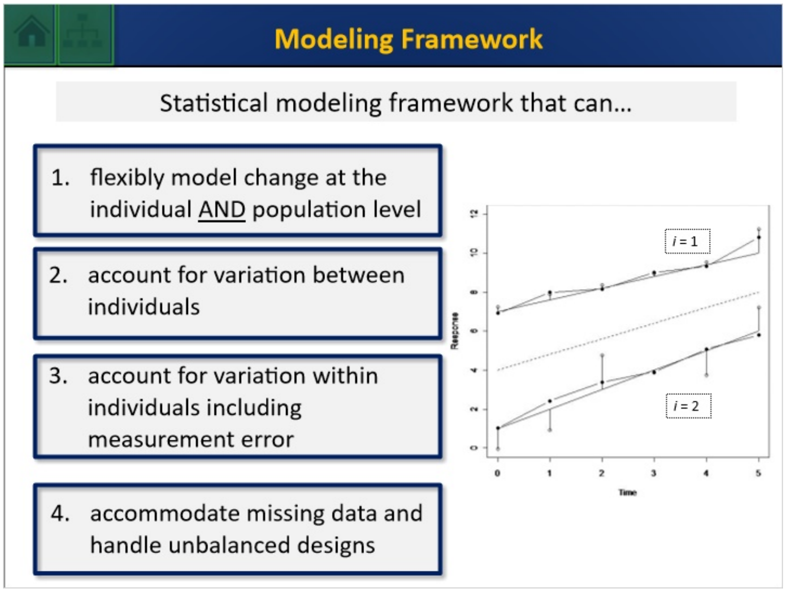


4.4 Bookmark: Conceptual Underpinnings

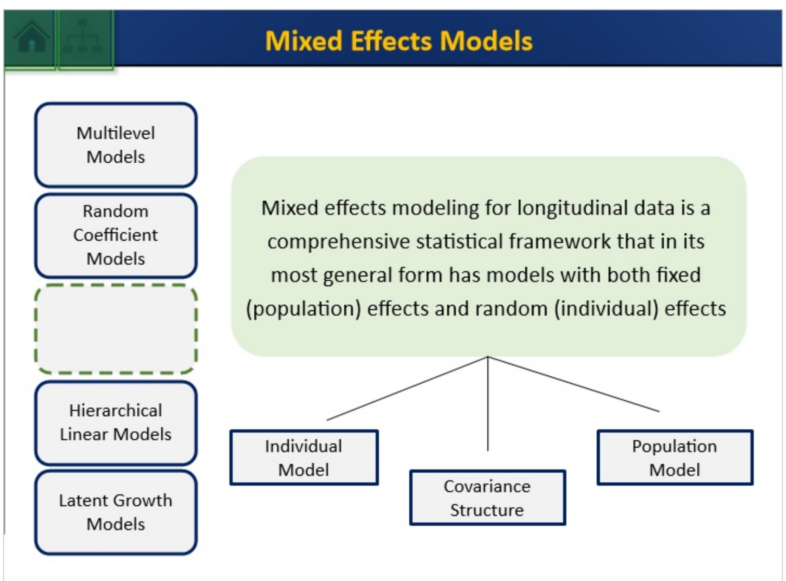
4.5 Conceptual Underpinnings



4.6 Modeling Framework



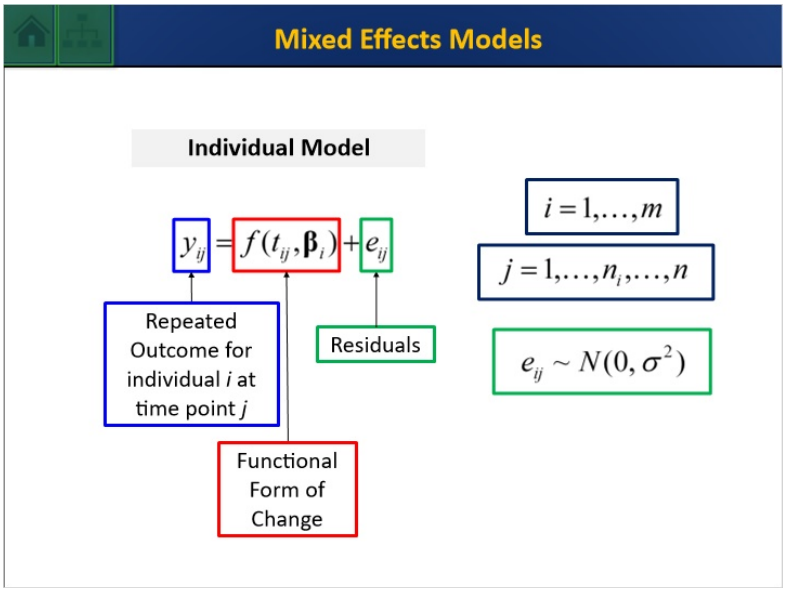
4.7 Mixed Effects Models I



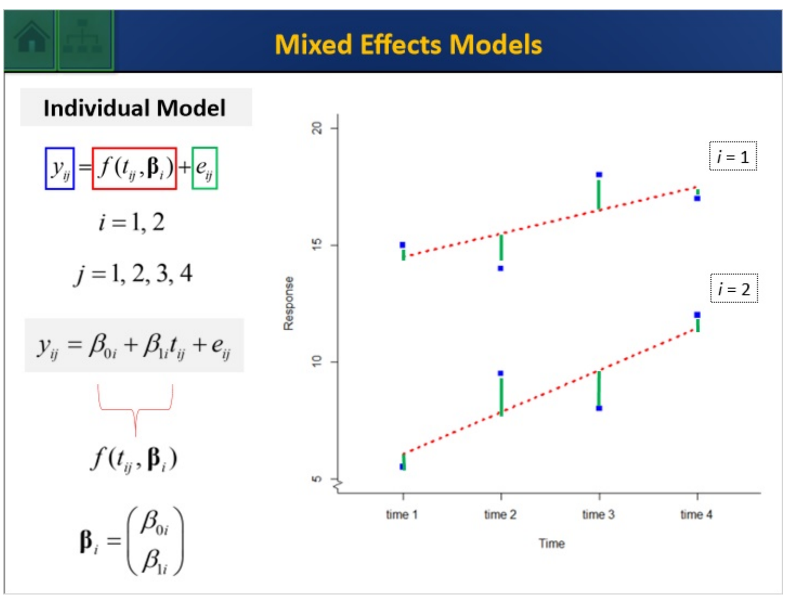
4.8 Bookend: Conceptual Underpinnings

4.9 Bookmark: Model Specification

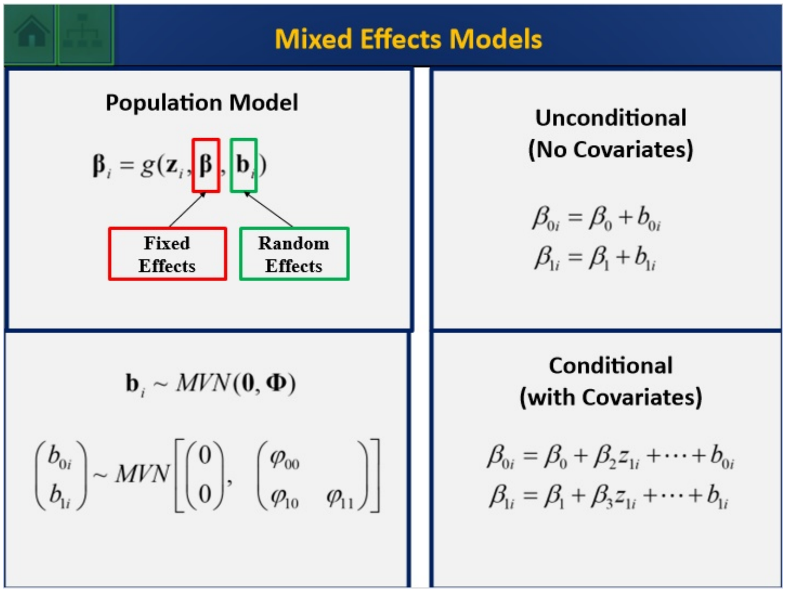
4.10 Mixed Effects Models II



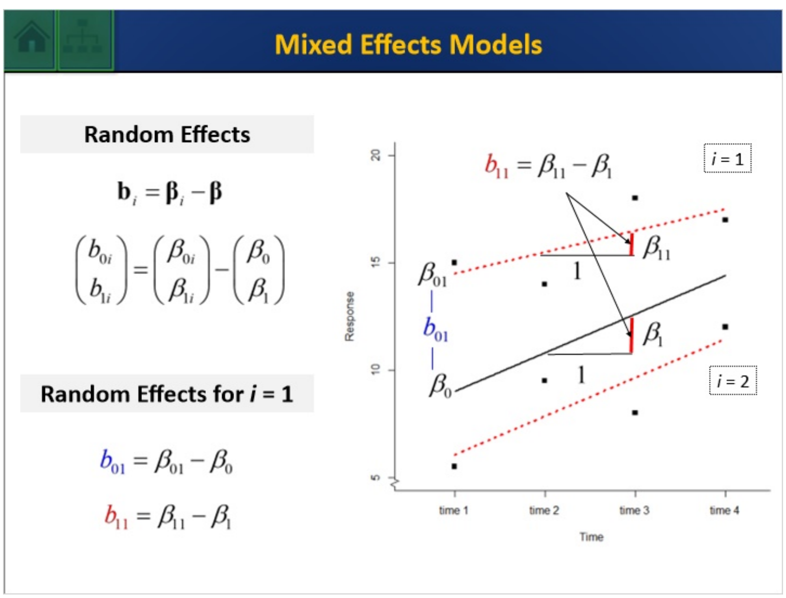
4.11 Mixed Effects Models III



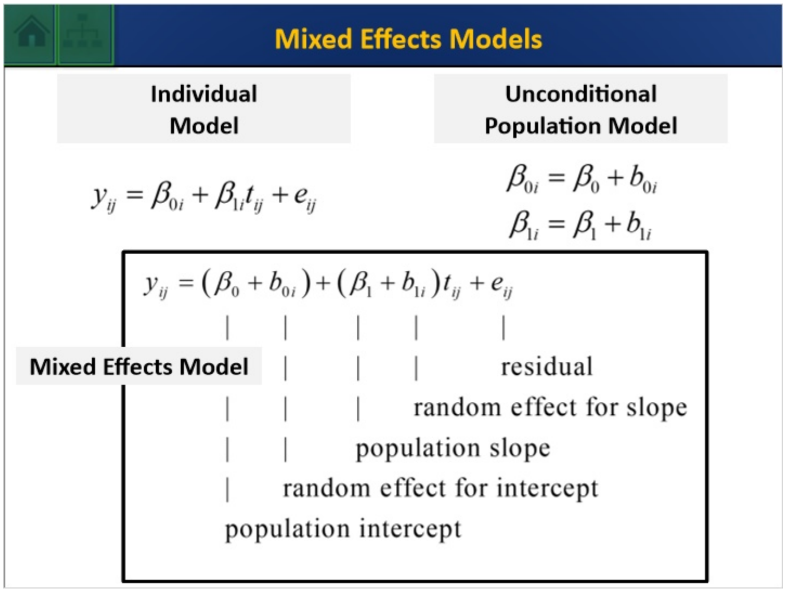
4.12 Mixed Effects Models IV



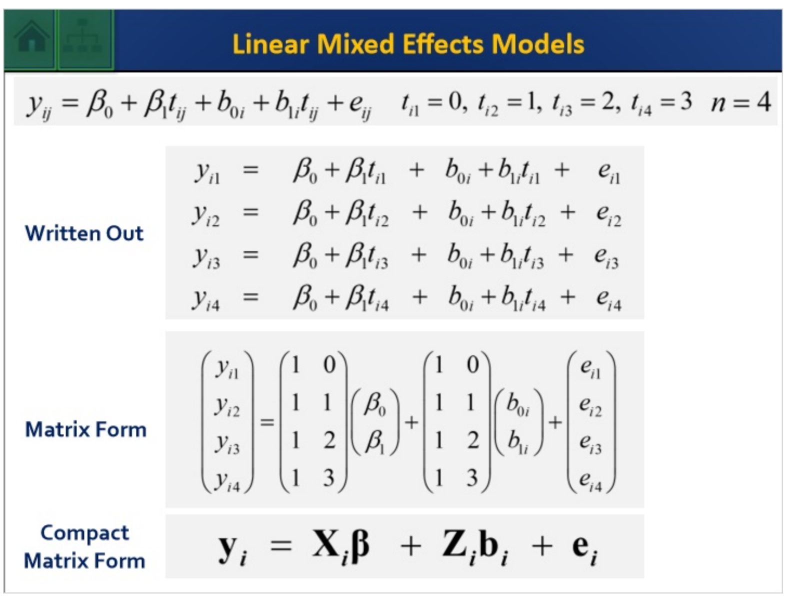
4.13 Mixed Effects Models V



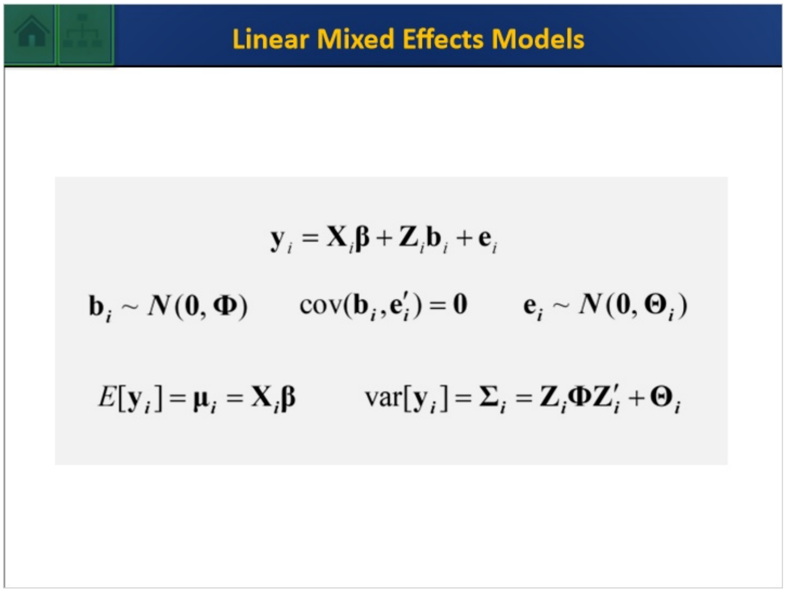
4.14 Mixed Effects Models VI



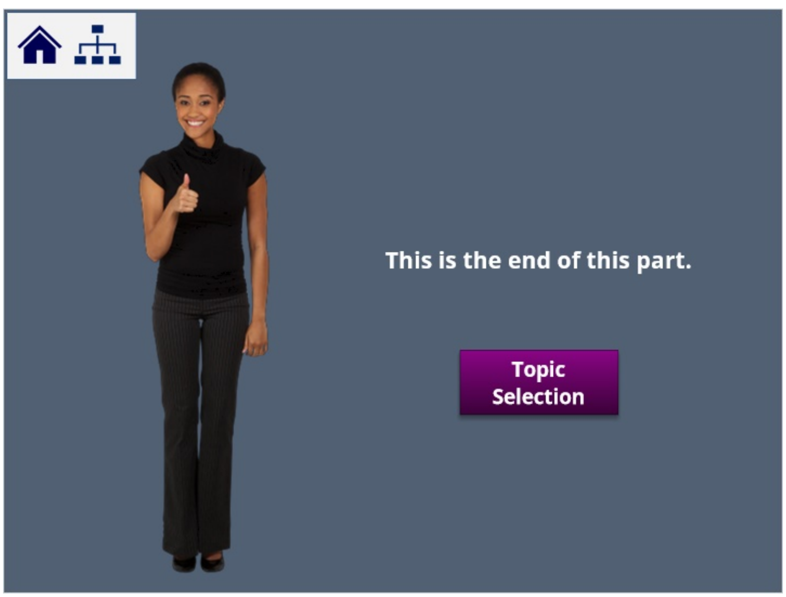
4.15 Linear Mixed Effects Models I



4.16 Linear Mixed Effects Models II

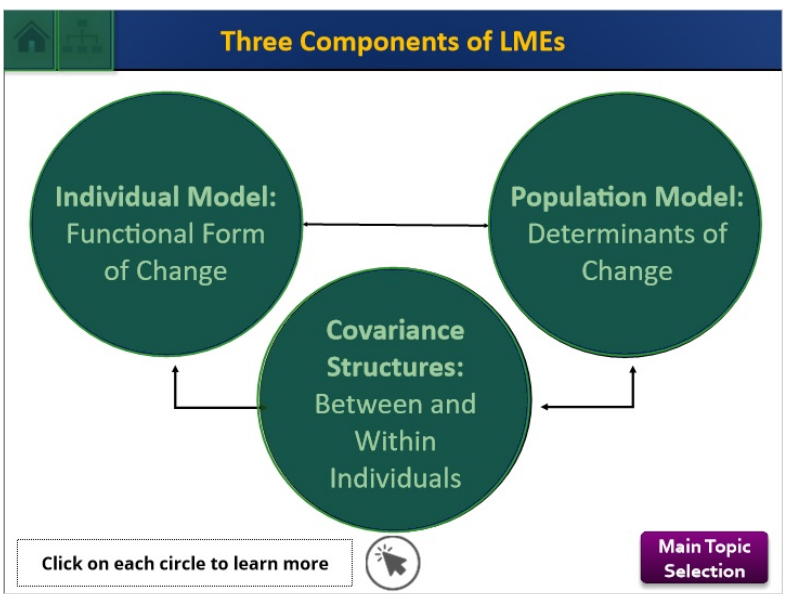


4.17 Bookend: Model Specification



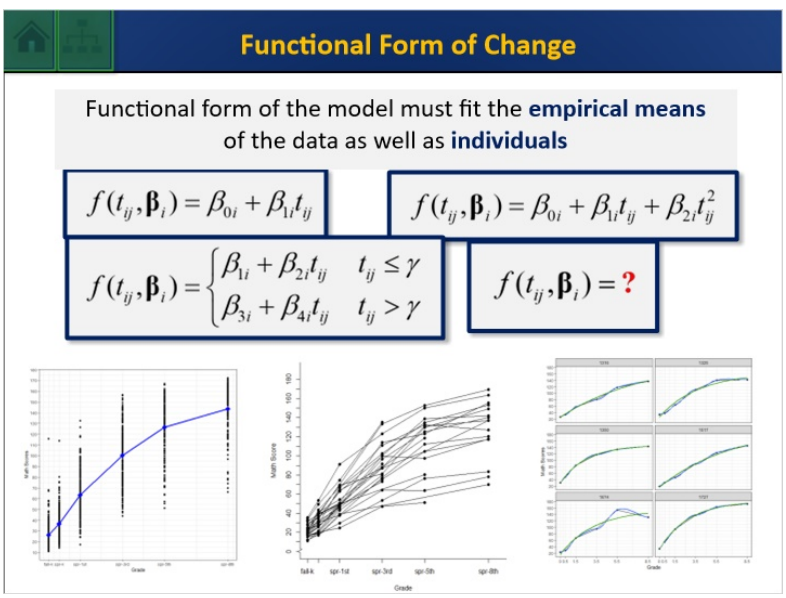
4.18 Bookmark: Three Components of LMEs

4.19 Component Selection

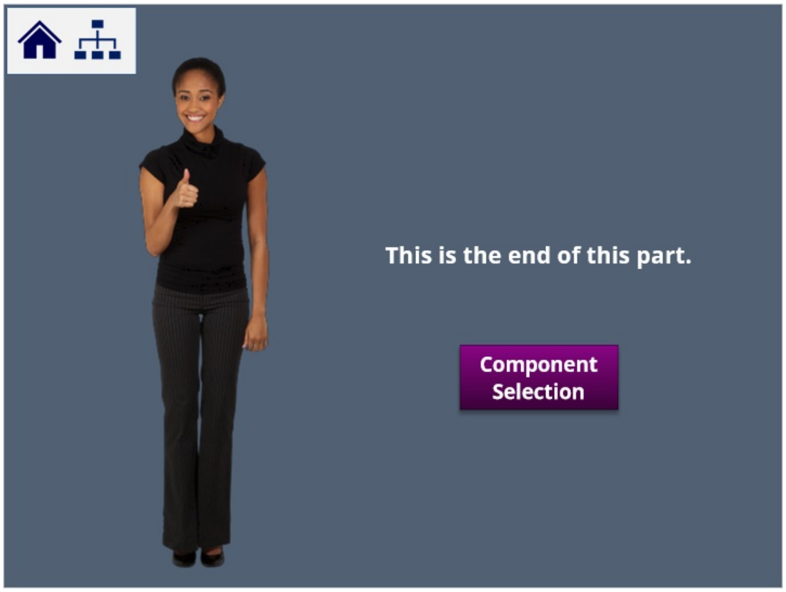


4.20 Bookmark: Functional Form

4.21 Functional Form of Change

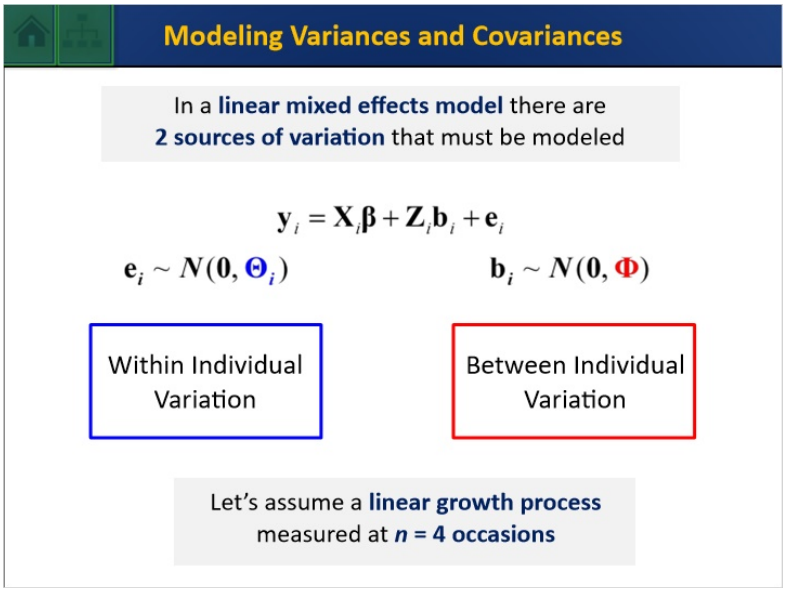


4.22 Bookend: Functional Form

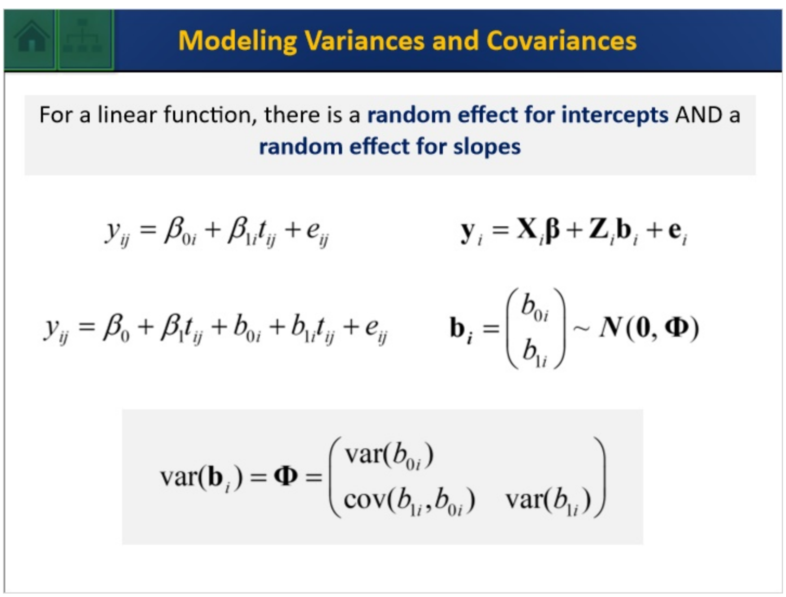


4.23 Bookmark: Variances and Covariances

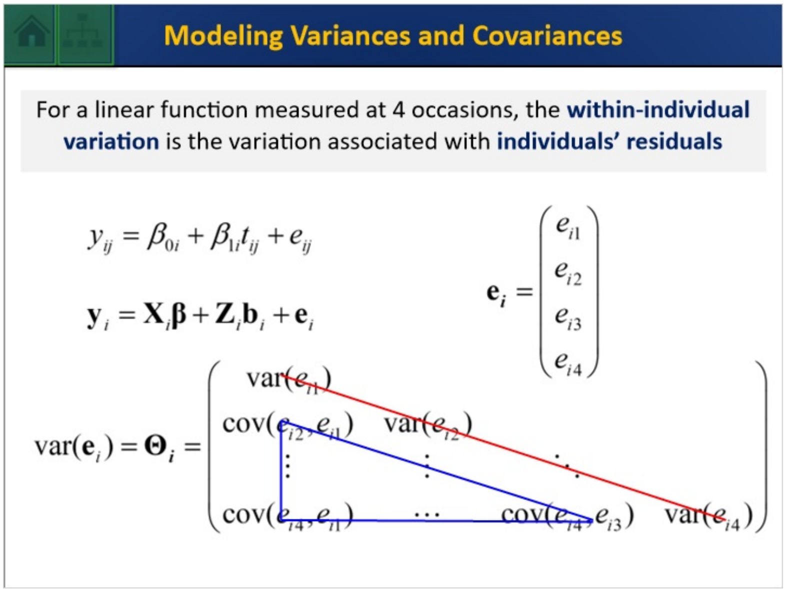
4.24 Modeling Variances and Covariances I



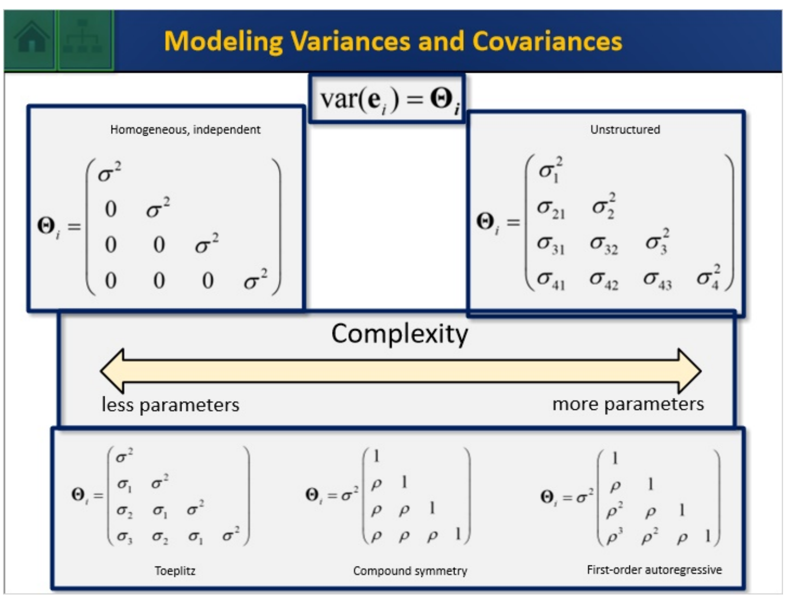
4.25 Modeling Variances and Covariances II



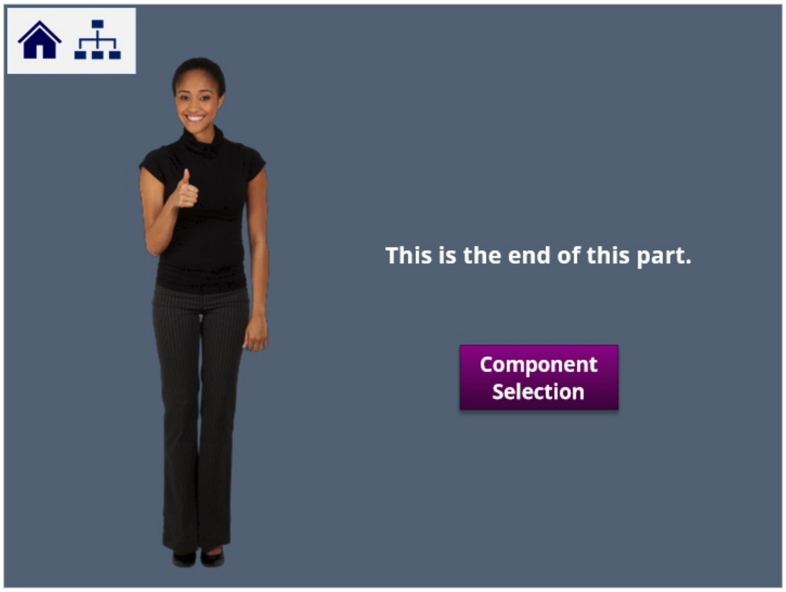
4.26 Modeling Variances and Covariances III



4.27 Modeling Variances and Covariances IV

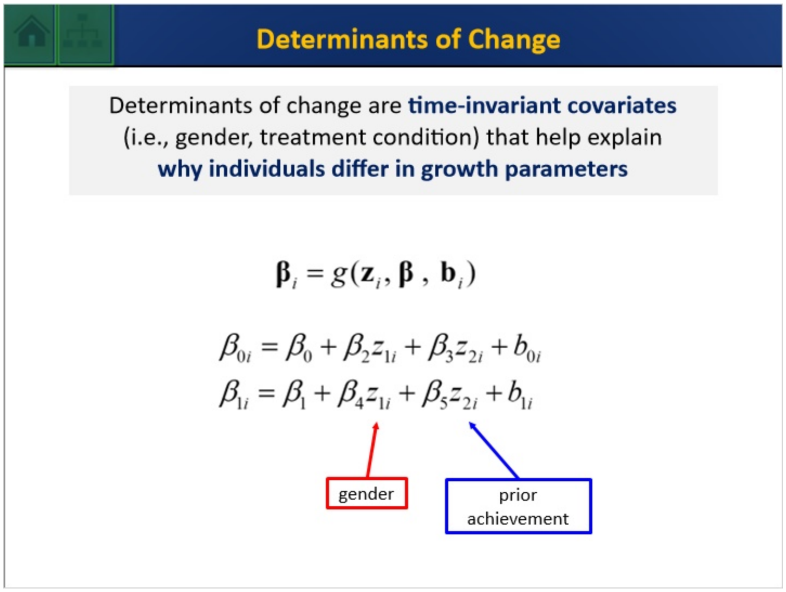


4.28 Bookend: Variances and Covariances

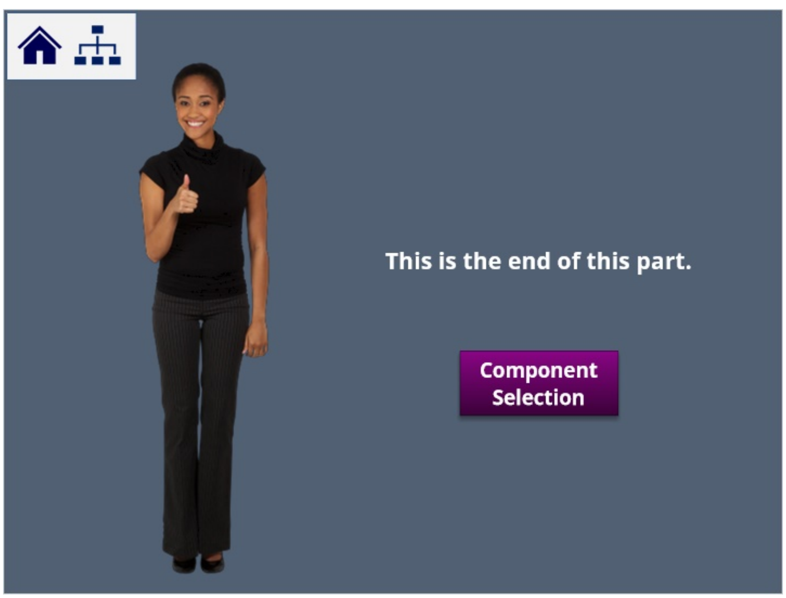


4.29 Bookmark: Determinants of Change

4.30 Determinants of Change

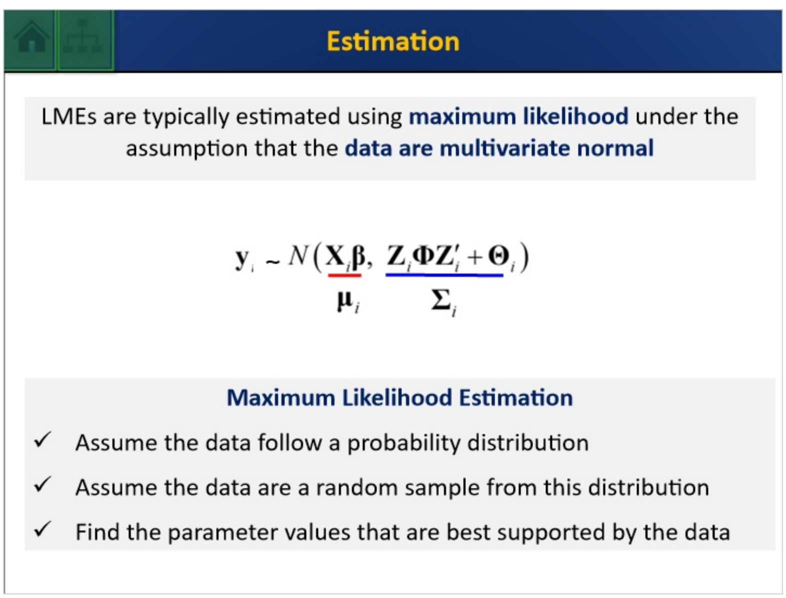


4.31 Bookend: Determinants of Change

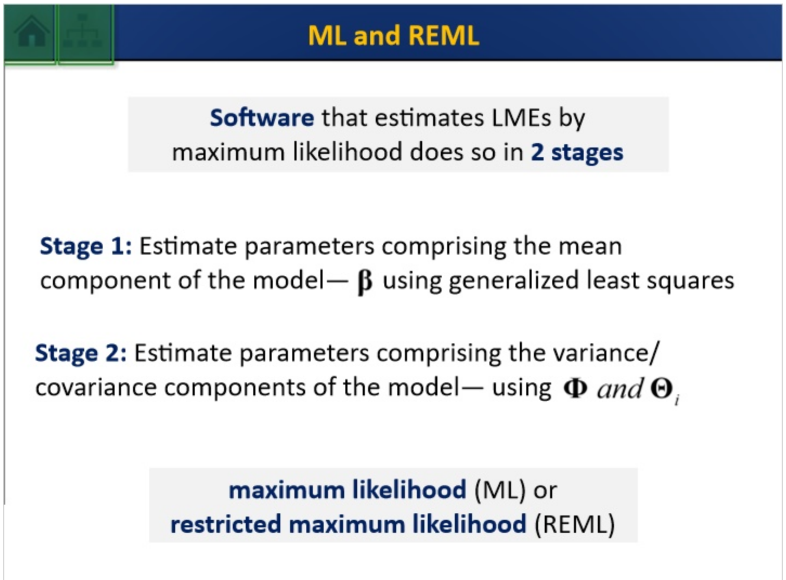


4.32 Bookmark: Estimation

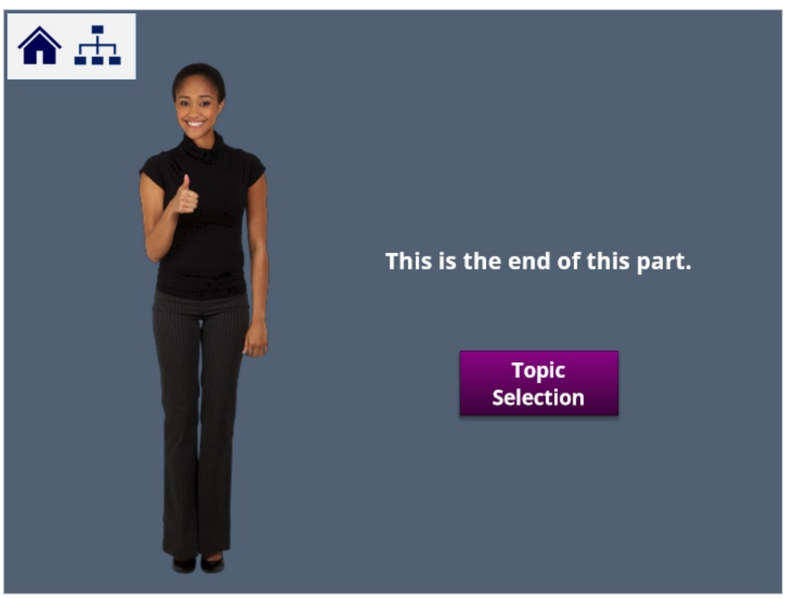
4.33 Estimation



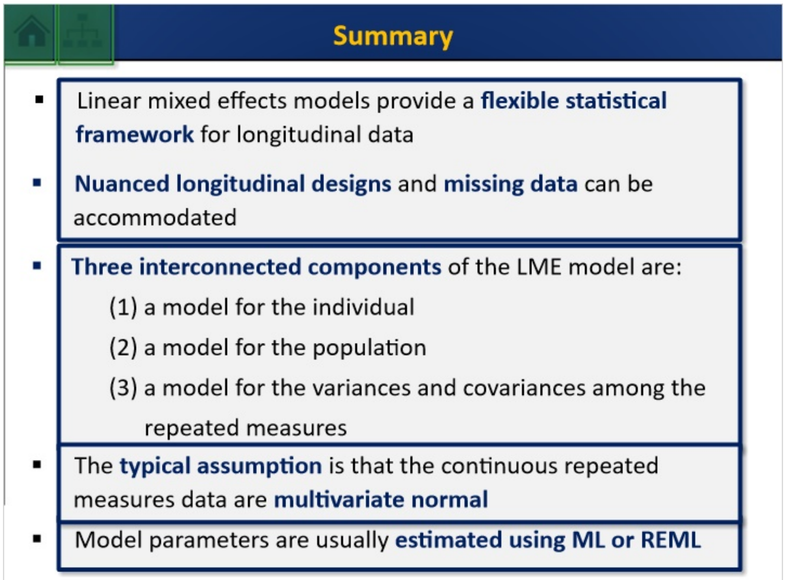
4.34 ML and REML



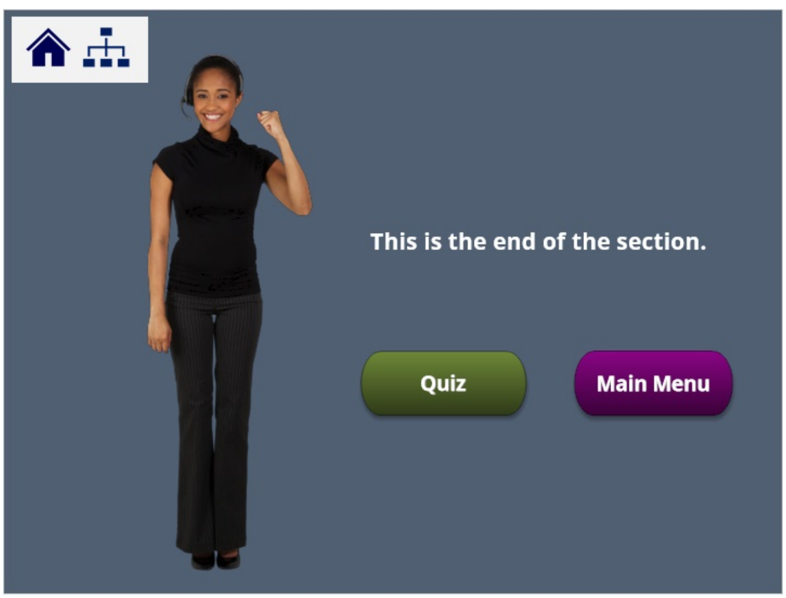
4.35 Bookend: Estimation



4.36 Summary



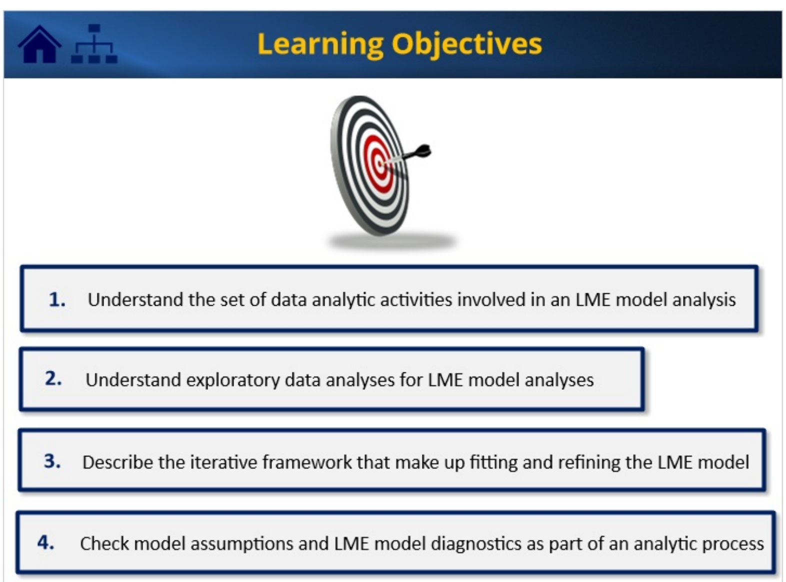
4.37 Bookend: Section 3



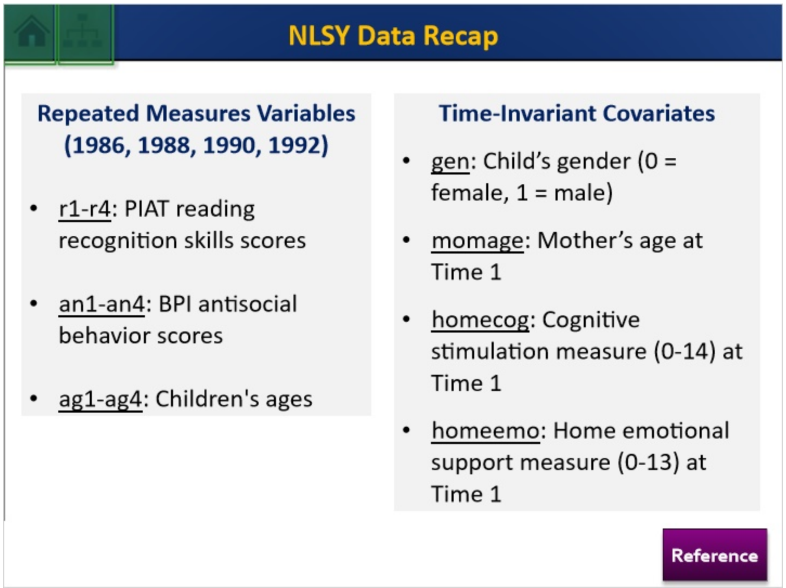
5. Section 4: LME Analyses

5.1 Cover: Section 4

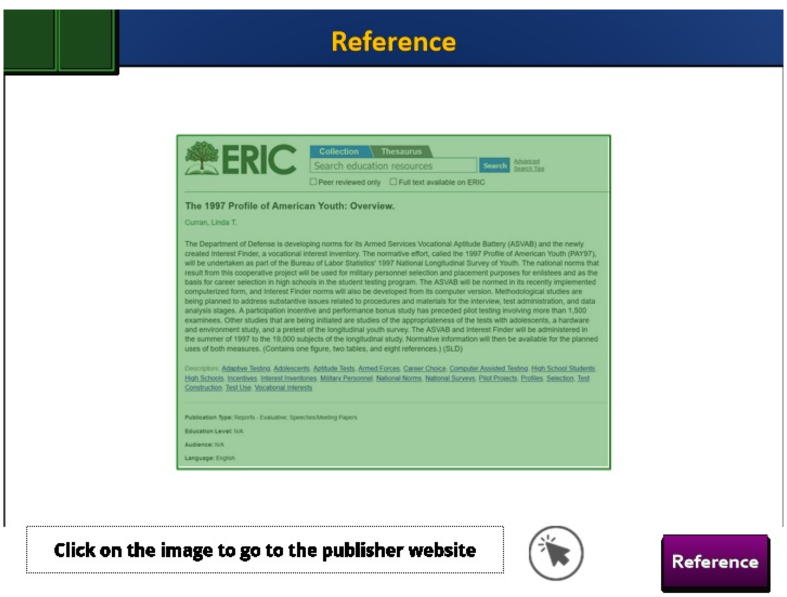
5.2 Learning Objectives: Section 4



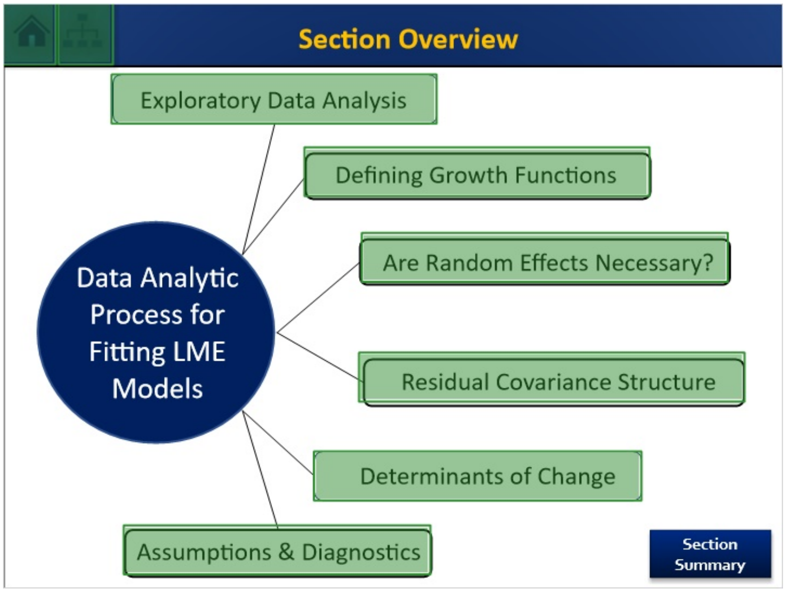
5.3 NLSY Data Recap



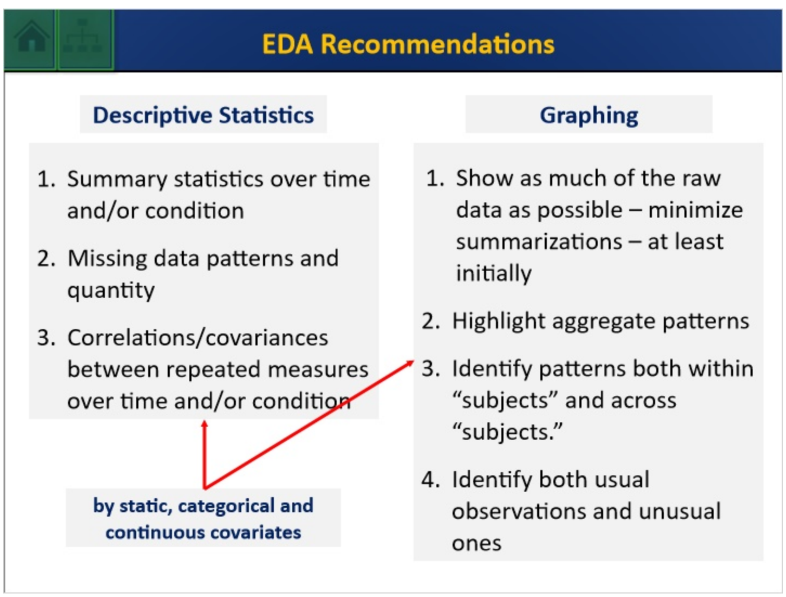
Reference (Slide Layer)



5.4 Topic Selection



5.5 EDA Recommendations



5.6 Descriptive Summaries I

Descriptive Summaries

Means

r1	r2	r3	r4
25.22716	40.76000	50.05091	57.74074

SDs

r1	r2	r3	r4
9.249445	10.836461	11.609725	12.480446

Corr

	r1	r2	r3	r4
r1	1.0000000	0.6246212	0.5324771	0.4513588
r2	0.6246212	1.0000000	0.8085688	0.7520729
r3	0.5324771	0.8085688	1.0000000	0.8134315
r4	0.4513588	0.7520729	0.8134315	1.0000000

Summary Statistics Across Time

5.7 Descriptive Summaries II

Descriptive Summaries

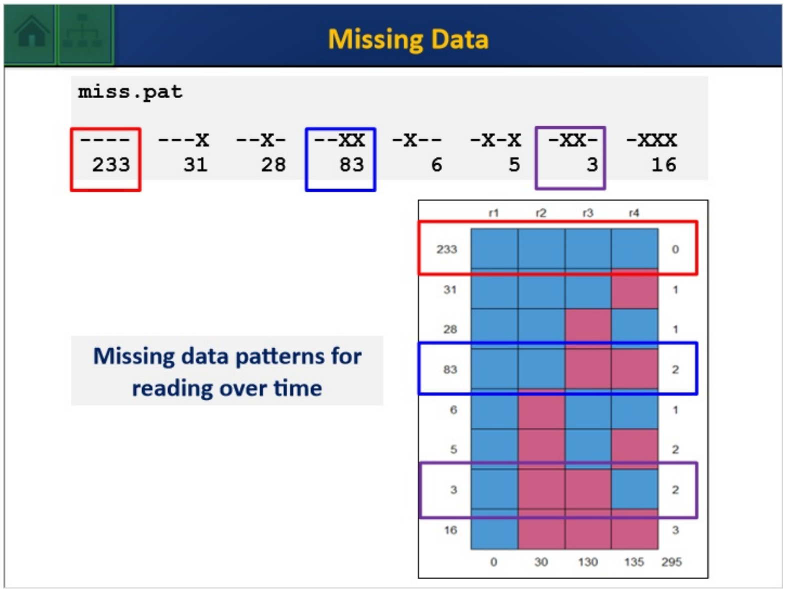
year	gender	read
0	0	25.75743
0	1	24.69951
2	0	41.42391
2	1	40.12042
4	0	50.87218
4	1	49.28169
6	0	57.70677
6	1	57.77372

by gender across time

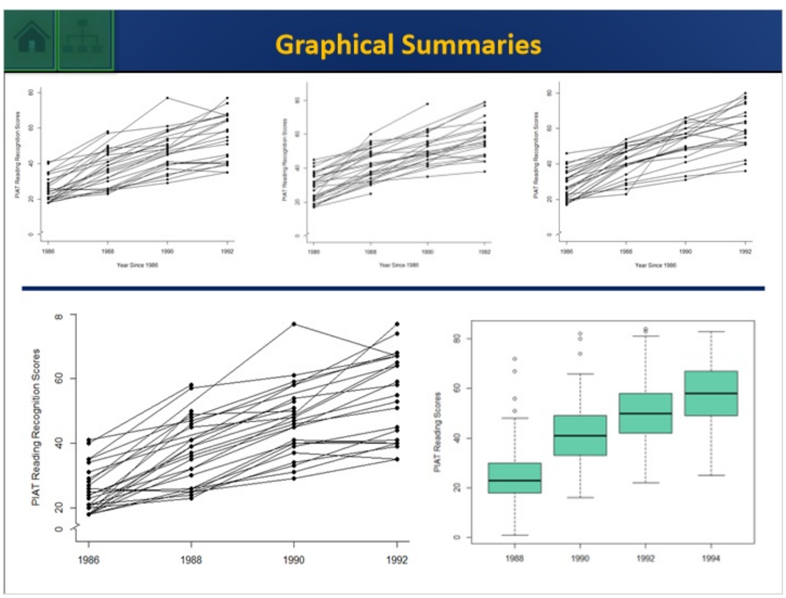
year	(homeemo, g=3)	read
0	[0, 9)	25.20438
0	[9,12)	25.19024
0	[12,13]	25.39683
2	[0, 9)	39.62400
2	[9,12)	40.52062
2	[12,13]	44.12500
4	[0, 9)	47.59091
4	[9,12)	51.08904
4	[12,13]	51.63415
6	[0, 9)	54.27586
6	[9,12)	58.86525
6	[12,13]	61.14286

by continuous covariate across time

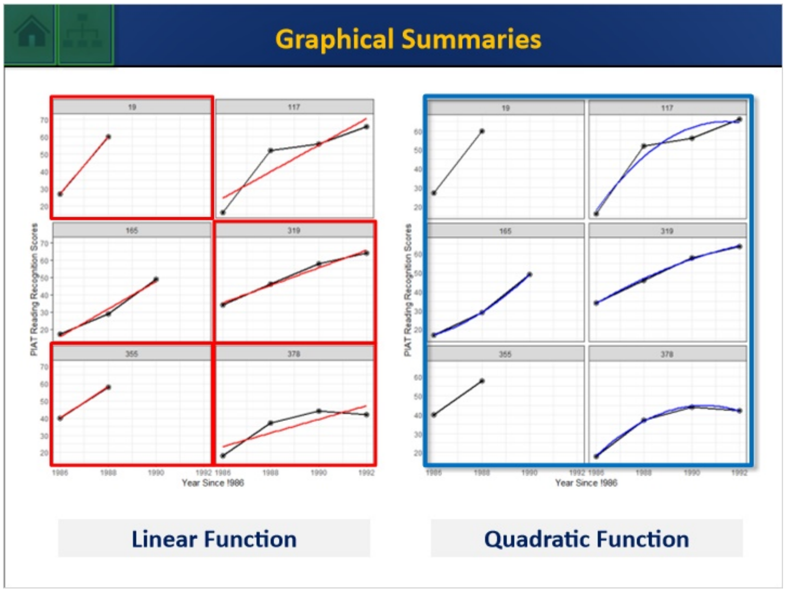
5.8 Missing Data



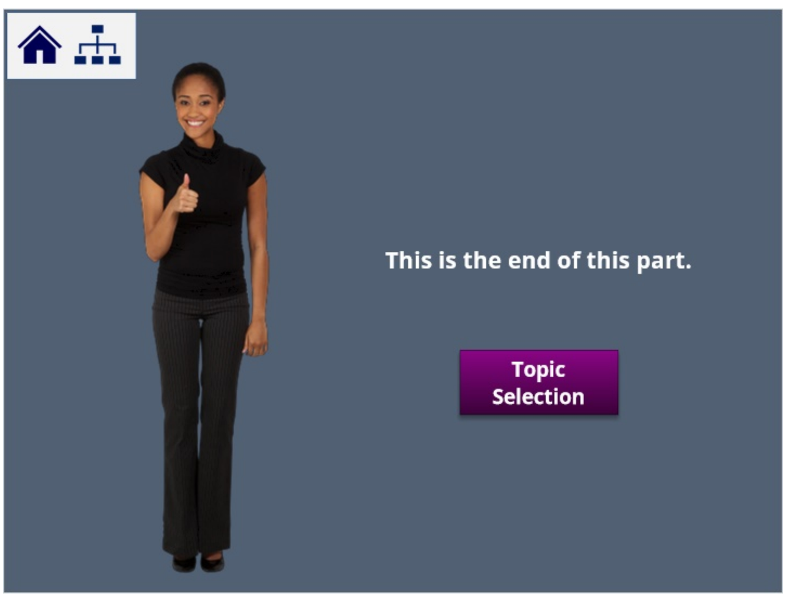
5.9 Graphical Summaries I



5.10 Graphical Summaries II

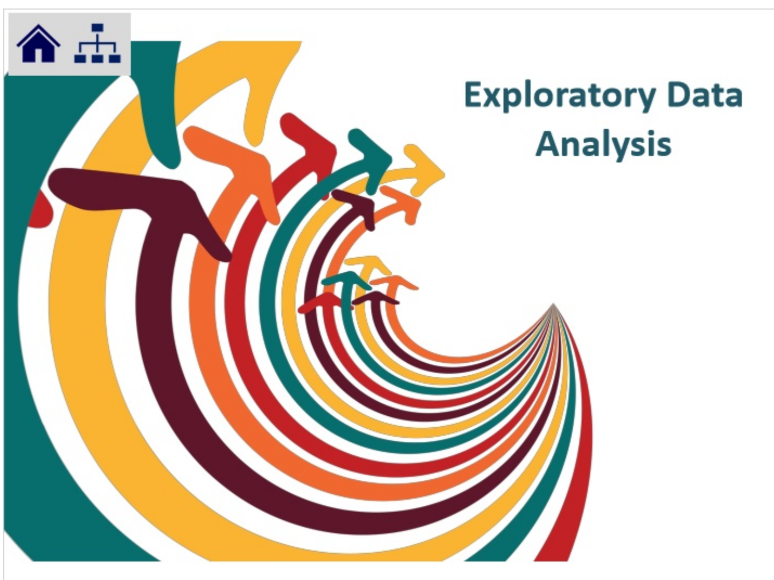


5.11 Bookend: Exploratory Data Analysis

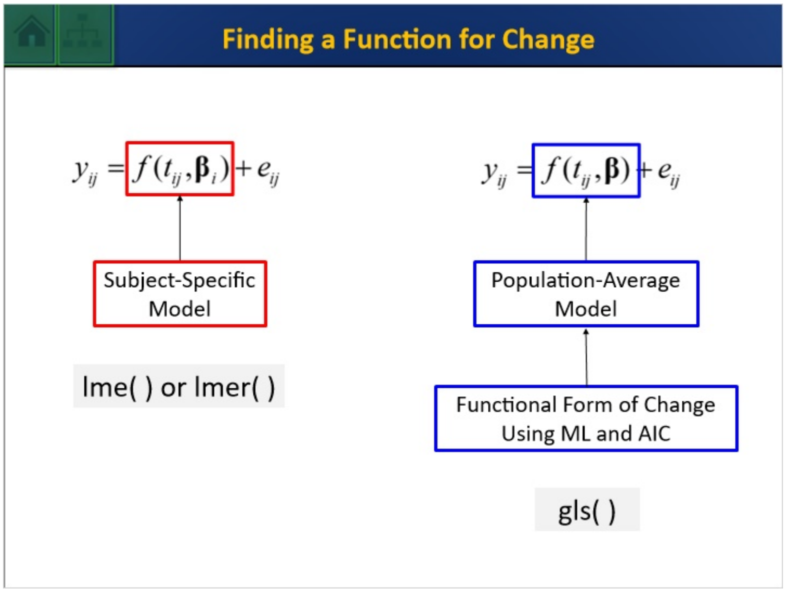


5.12 Bookmark: Defining Growth Functions

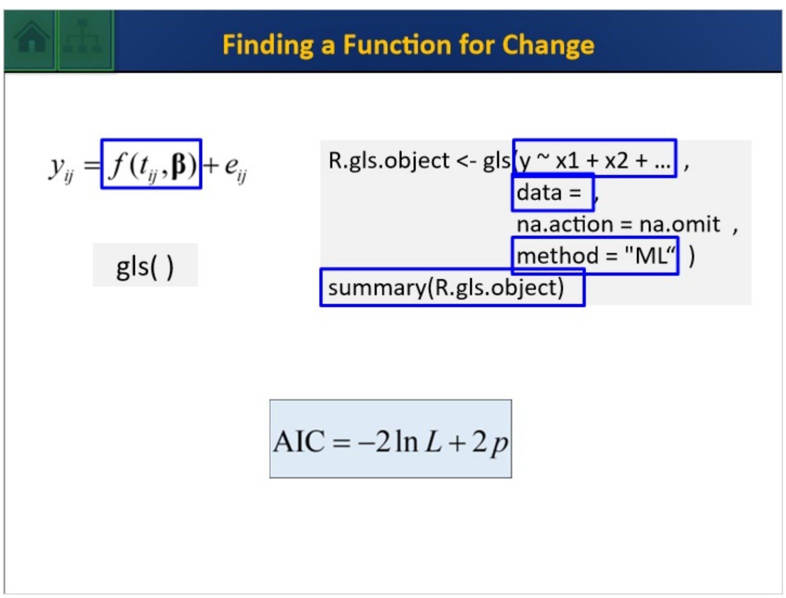
5.13 Bookmark: Exploratory Data Analysis



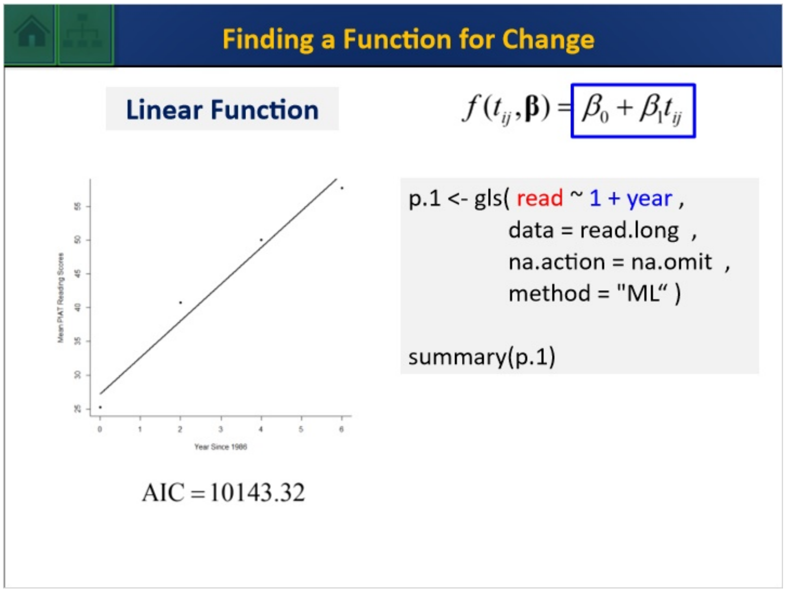
5.14 Finding a Function for Change I



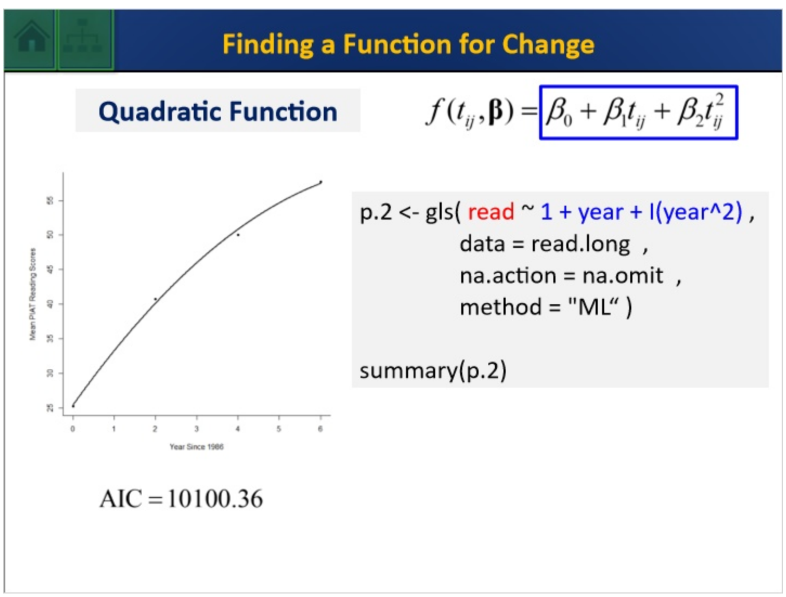
5.15 Finding a Function for Change II



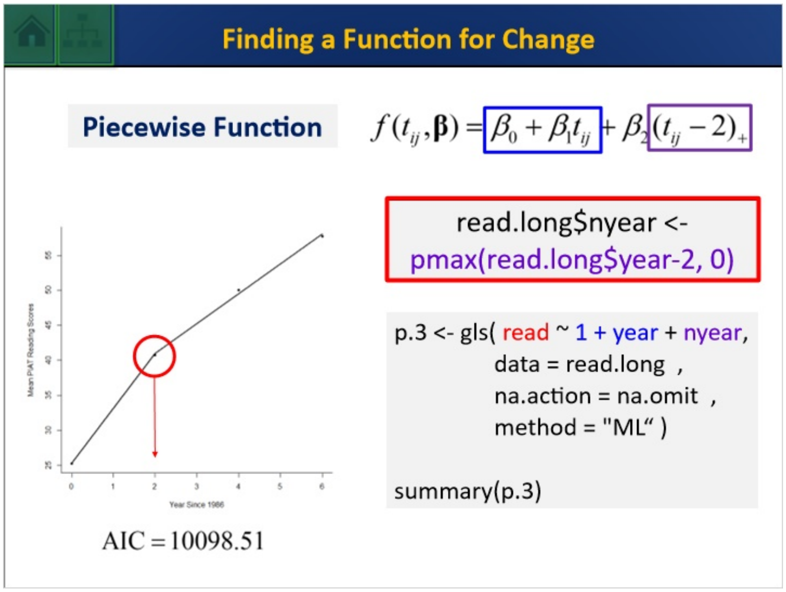
5.16 Finding a Function for Change III



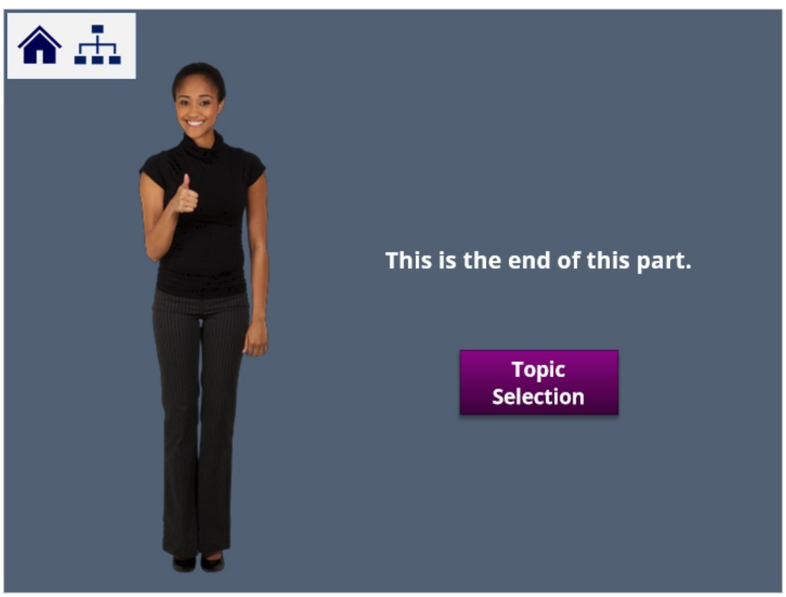
5.17 Finding a Function for Change IV



5.18 Finding a Function for Change V

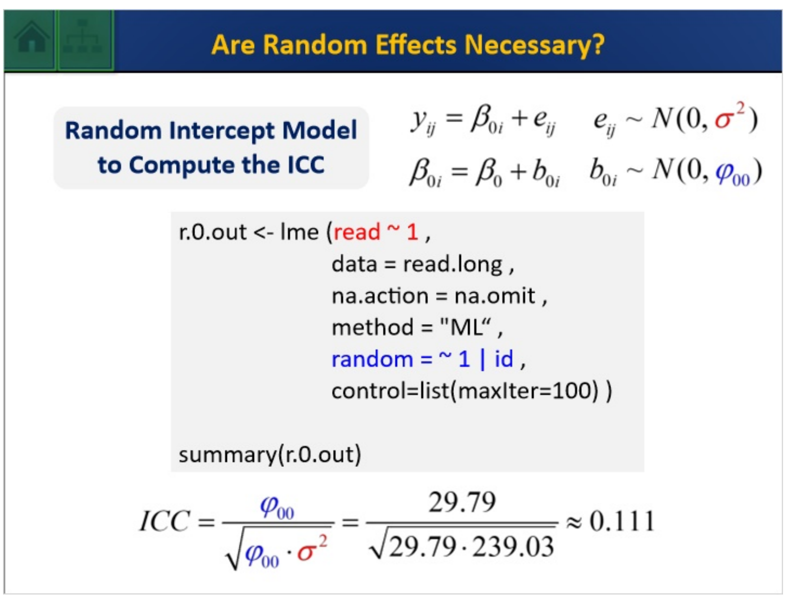


5.19 Bookend: Defining Growth Functions

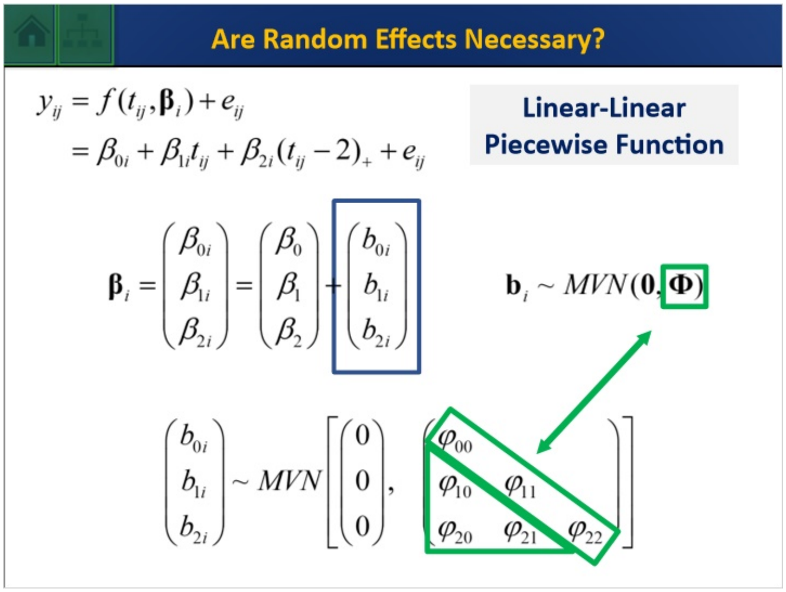


5.20 Bookmark: Are Random Effects Necessary

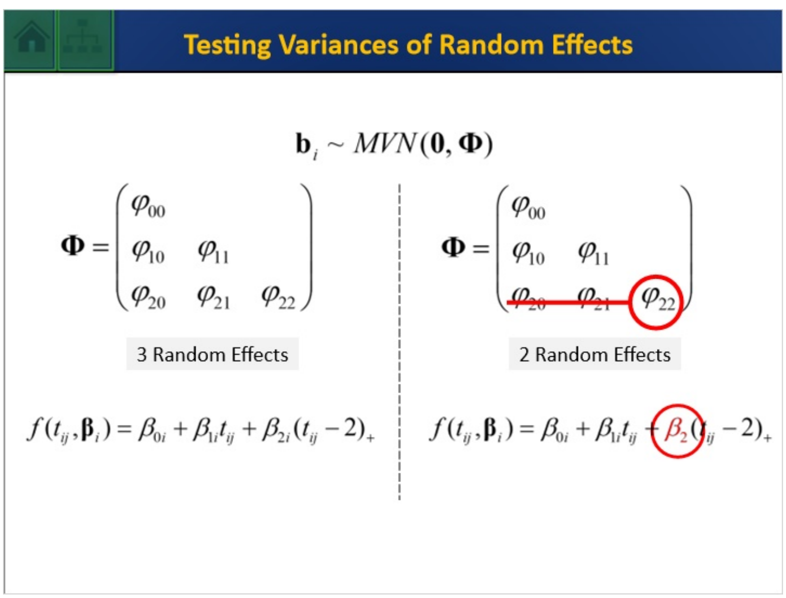
5.21 Are Random Effects Necessary I



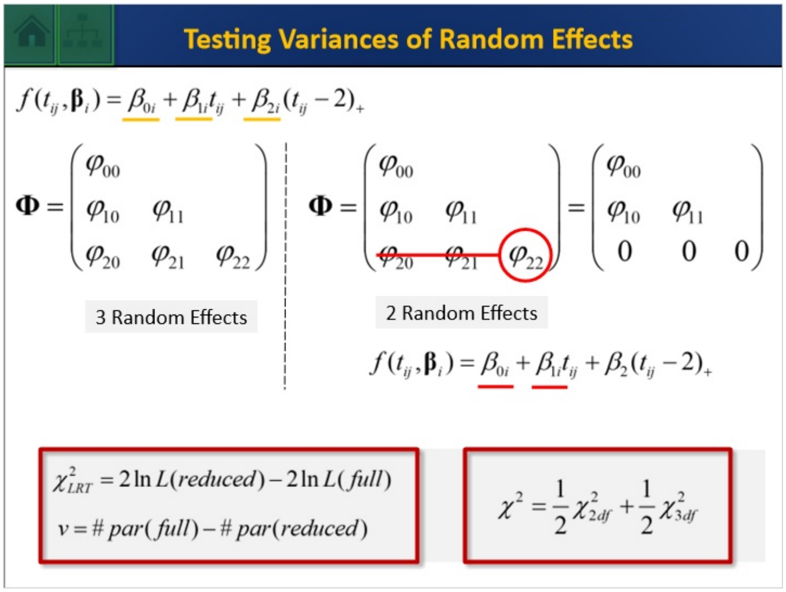
5.22 Are Random Effects Necessary II



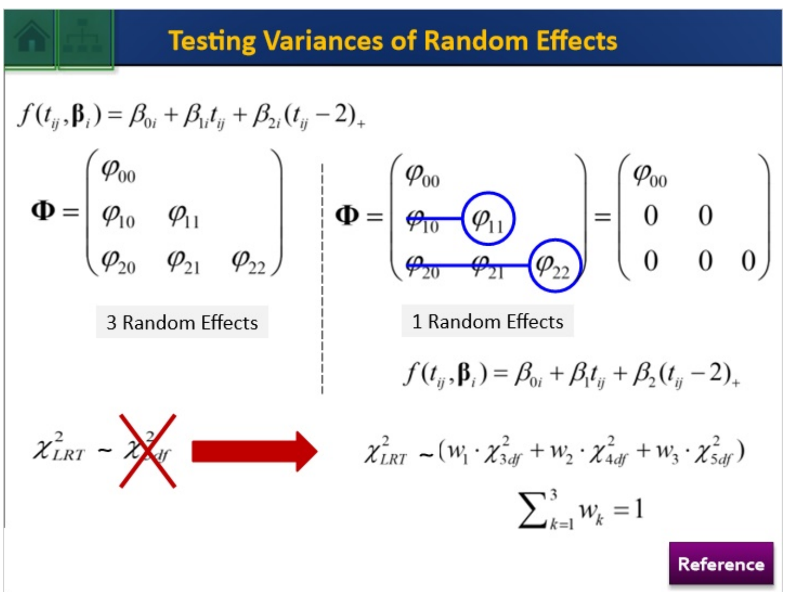
5.23 Testing Variances of Random Effects I



5.24 Testing Variances of Random Effects II

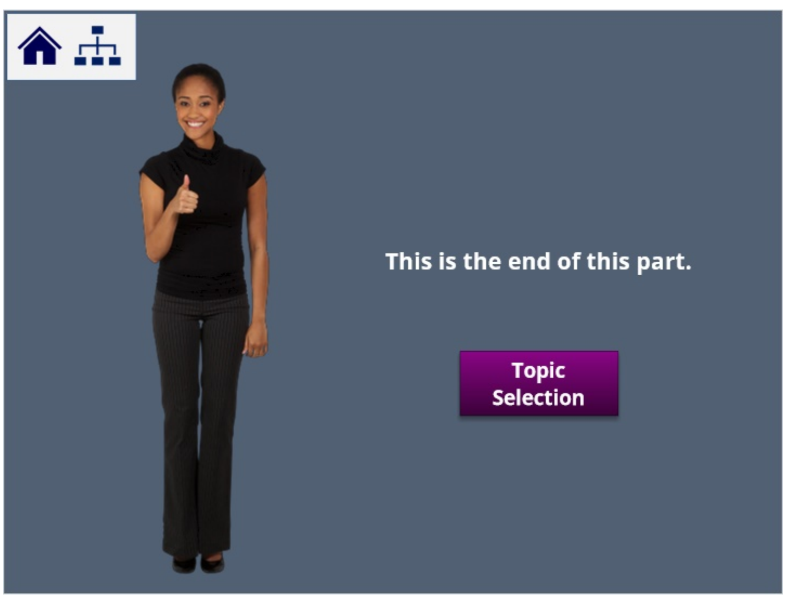


5.25 Testing Variances of Random Effects III



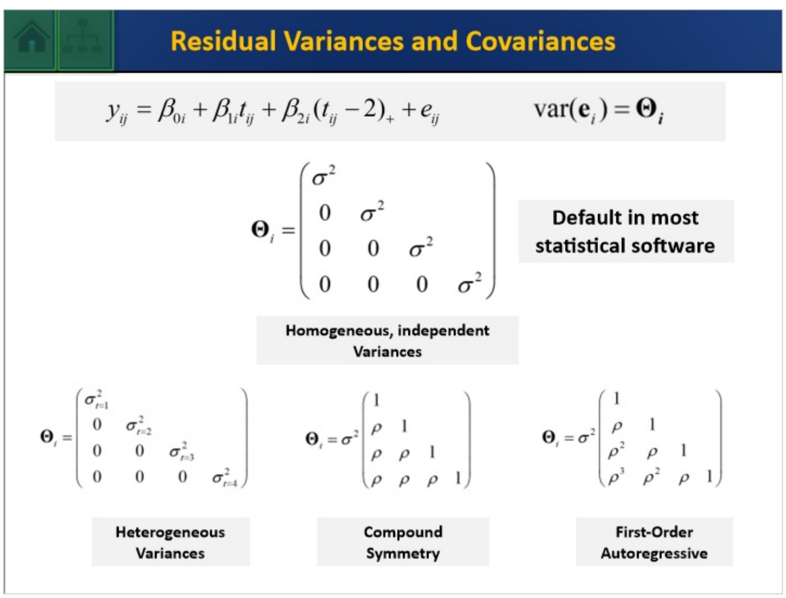
Reference (Slide Layer)

5.26 Bookend: Random Effects

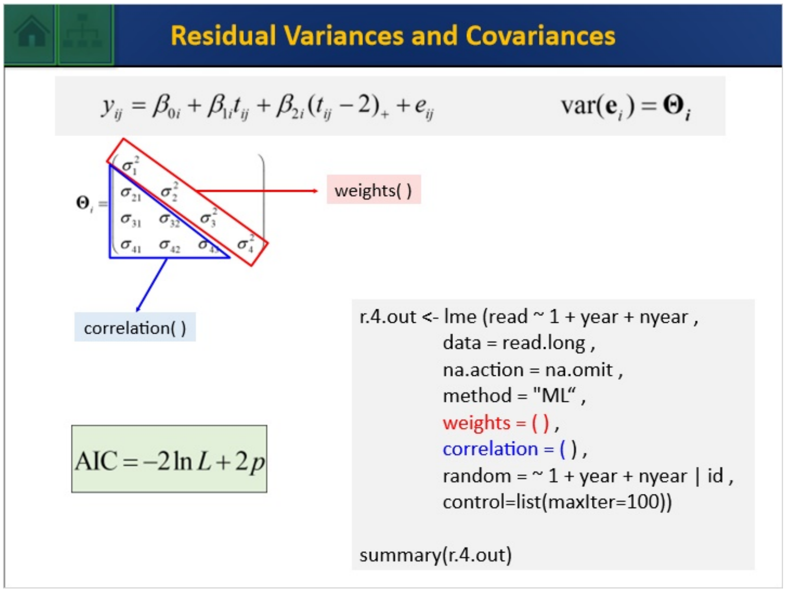


5.27 Bookmark: Residual Covariance Structure

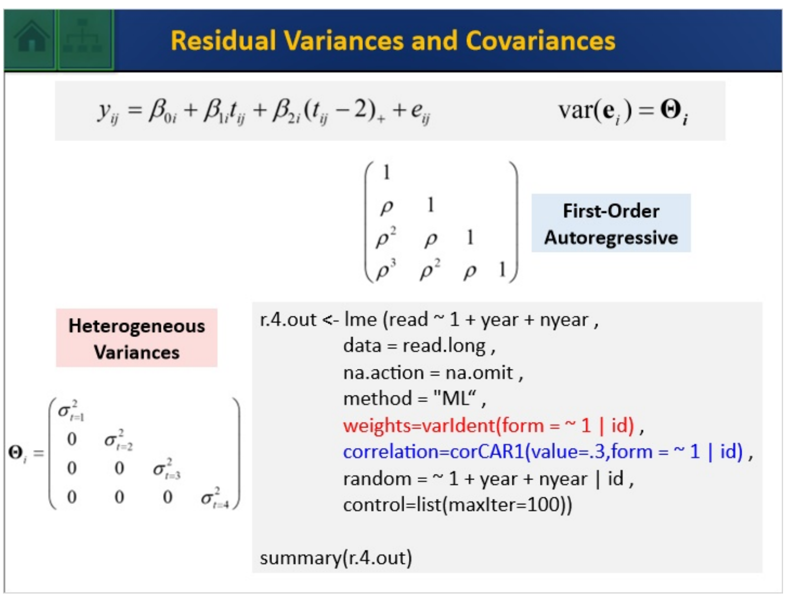
5.28 Residual Variances and Covariances I



5.29 Residual Variances and Covariances II



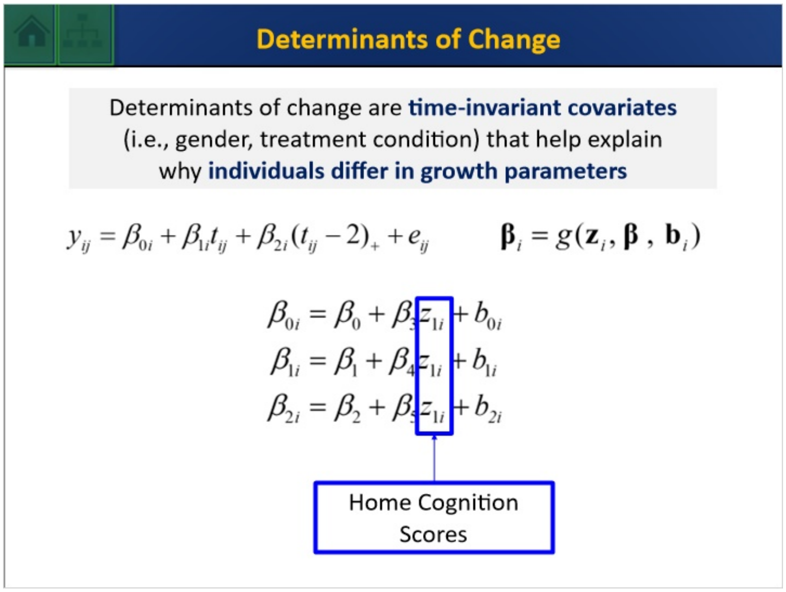
5.30 Residual Variances and Covariances III



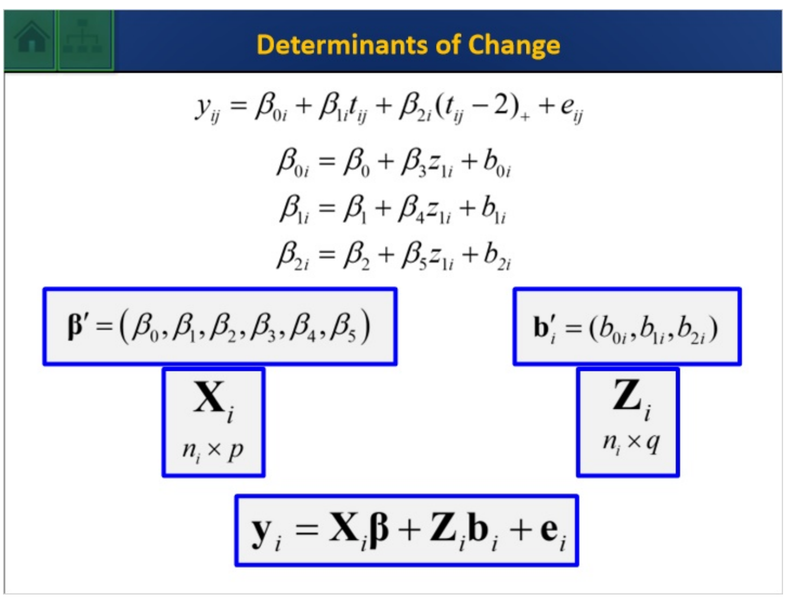
5.31 Bookend: Residual Covariances

5.32 Bookmark: Determinants of Change

5.33 Determinants of Change I



5.34 Determinants of Change II



5.35 Determinants of Change III

Determinants of Change

$$\mathbf{y}_i = \mathbf{X}_i\boldsymbol{\beta} + \mathbf{Z}_i\mathbf{b}_i + \mathbf{e}_i$$

$$\beta_{0i} = \beta_0 + \beta_3 z_{1i} + b_{0i}$$
$$\beta_{1i} = \beta_1 + \beta_4 z_{1i} + b_{1i}$$
$$\beta_{2i} = \beta_2 + \beta_5 z_{1i} + b_{2i}$$

```
r.9.out <- lme (read ~ 1 + year + nyear +
                homecog + year:homecog + nyear:homecog ,
                data = read.long ,
                na.action = na.omit ,
                method = "ML" ,
                random = ~ 1 + year + nyear | id ,
                control=list(maxIter=100))

summary(r.9.out)
```

5.36 Determinants of Change IV

Determinants of Change

Parameter	Unconditional Model	Conditional Model
β_0	25.23	25.23
β_1	7.81	7.81
β_2	-3.41	-3.43
β_3	n/a	0.31
β_4	n/a	0.24
β_5	n/a	-0.13
φ_{00}	60.90	60.23
φ_{10}	1.96	1.50
φ_{11}	5.96	5.55
φ_{20}	-3.18	-2.93
φ_{21}	-3.43	-3.18
φ_{22}	2.32	2.16
σ^2	24.72	24.73

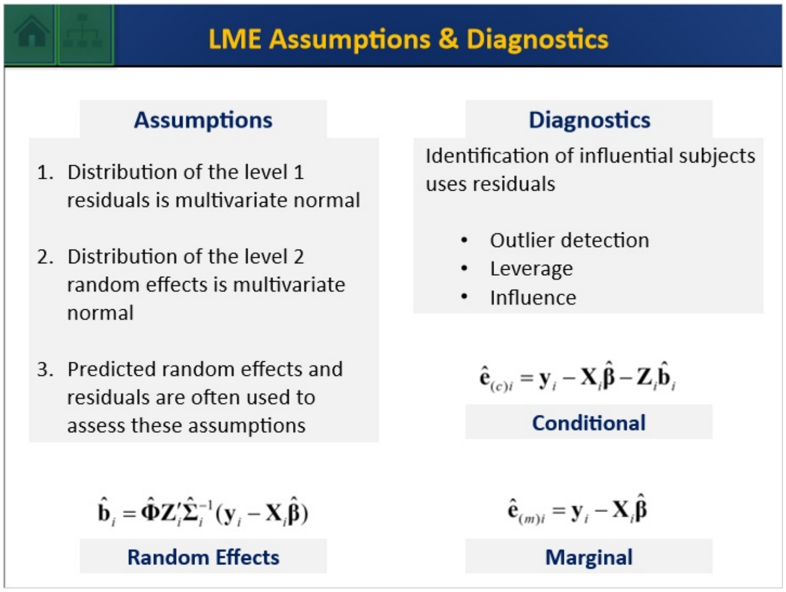
$$\text{var}_{slpdiff} = 100 \times \left(\frac{2.32 - 2.16}{2.32}\right) = 6.90\%$$

Explained Variance Intercept, Slope, and Slope Difference

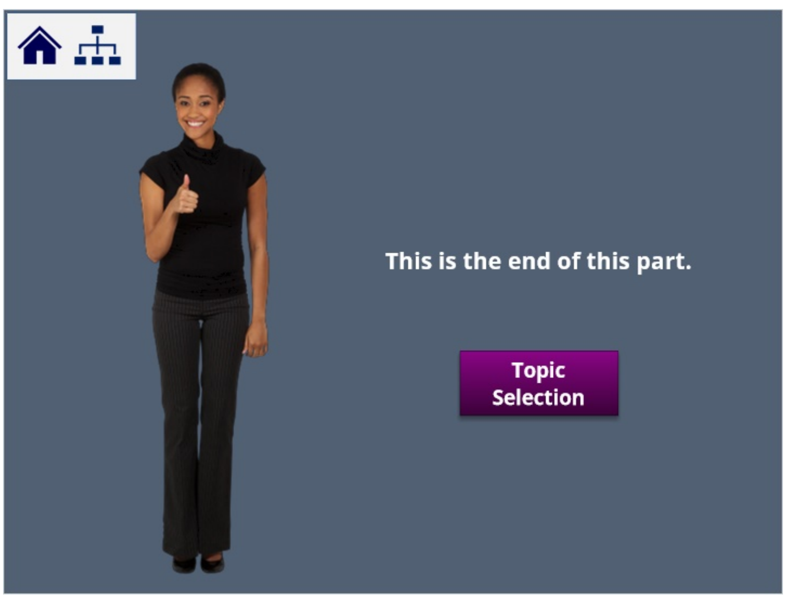
5.37 Bookend: Determinants of Change

5.38 Bookmark: Assumptions and Diagnostics

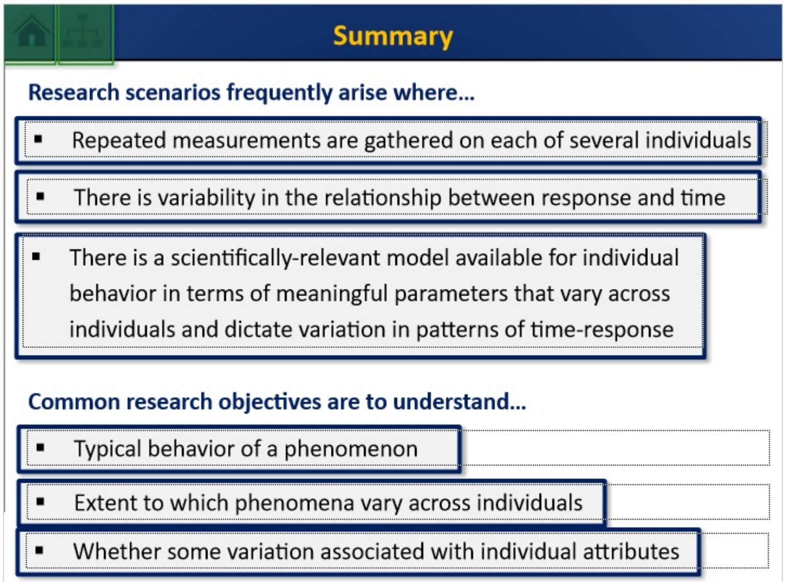
5.39 LME Assumptions & Diagnostics



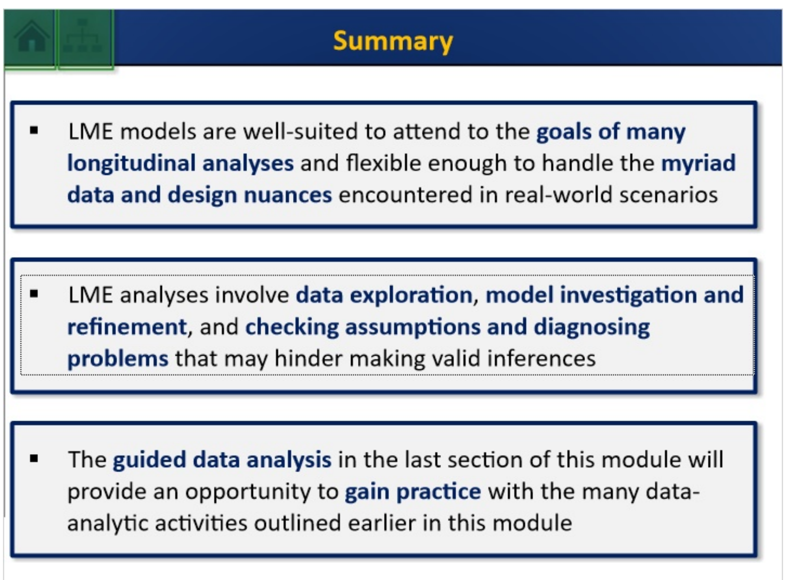
5.40 Bookend: Assumptions & Diagnostics



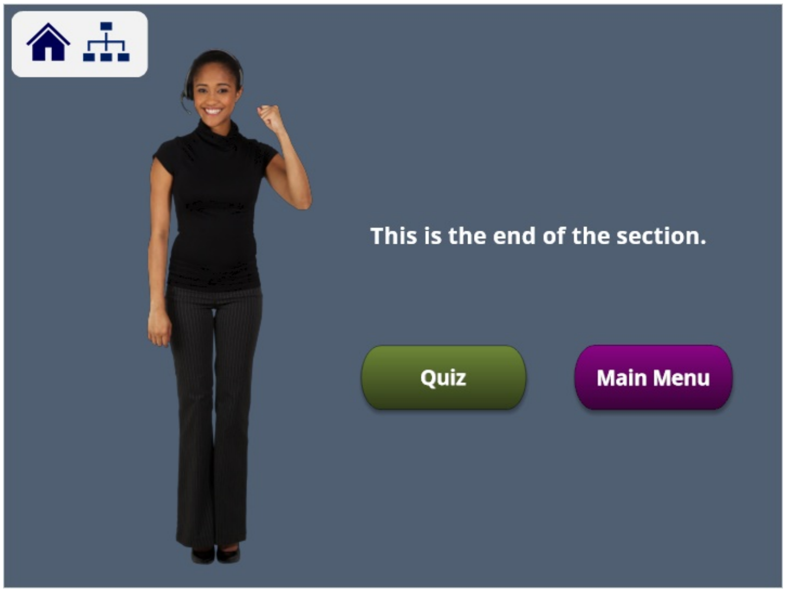
5.41 Summary I



5.42 Summary II



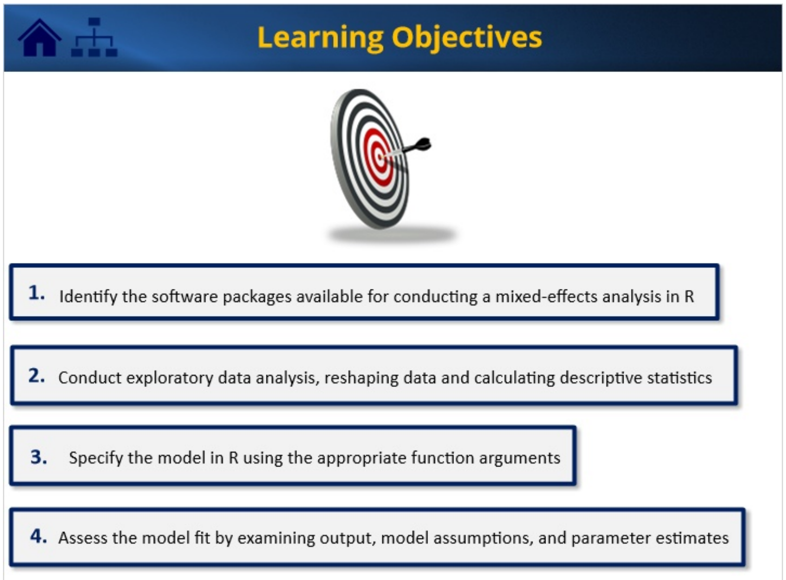
5.43 Bookend: Section 4



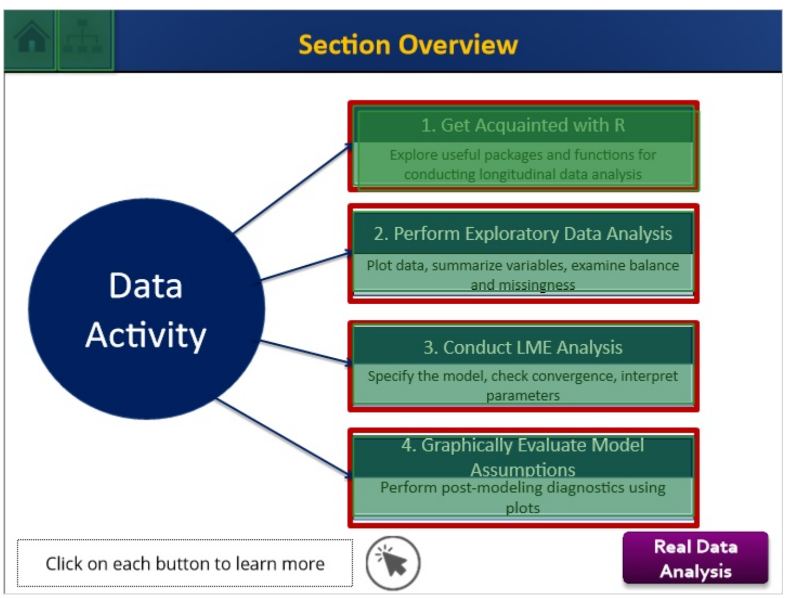
6. Section 5: Data Activity

6.1 Cover: Section 5

6.2 Learning Objectives

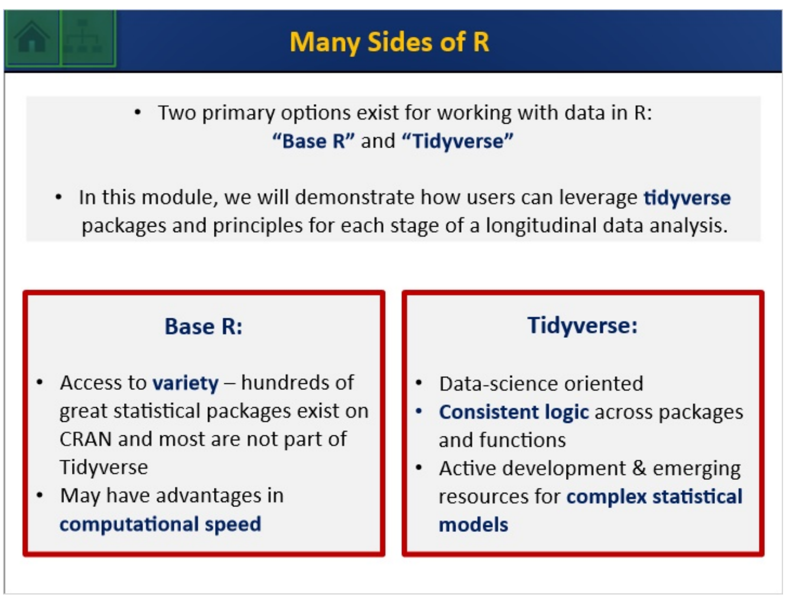


6.3 Topic Selection

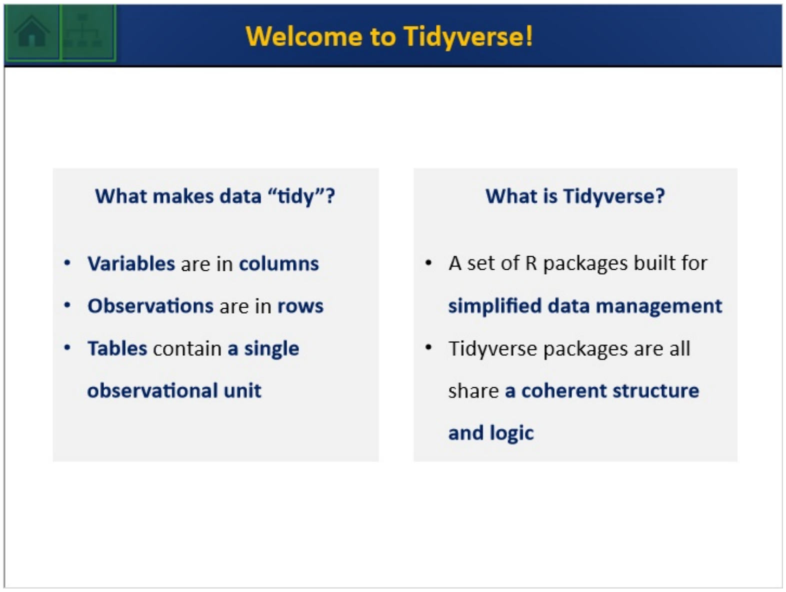


6.4 Bookmark: Get Acquainted with R

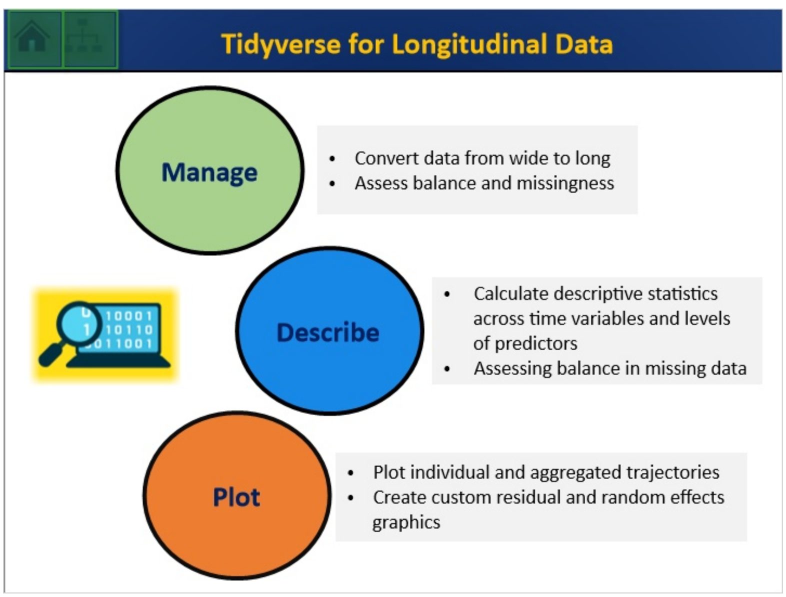
6.5 Many Sides of R



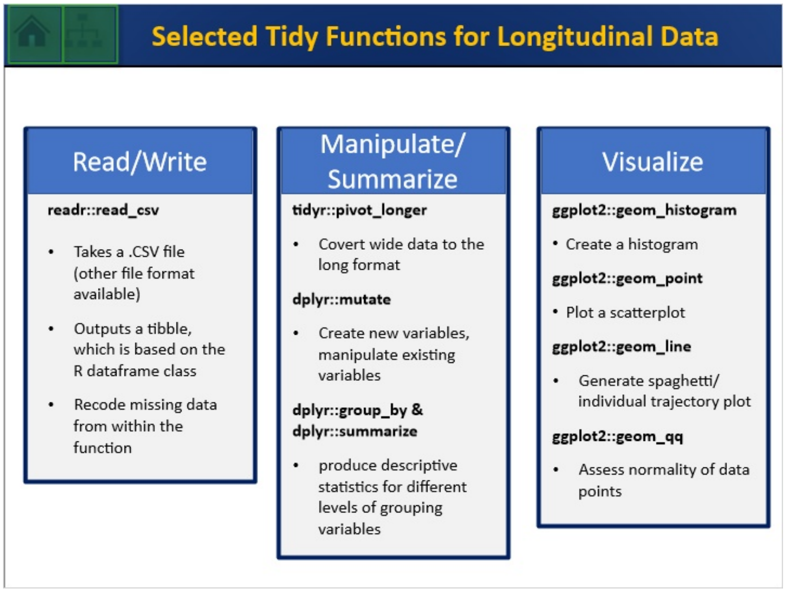
6.6 Welcome to Tidyverse



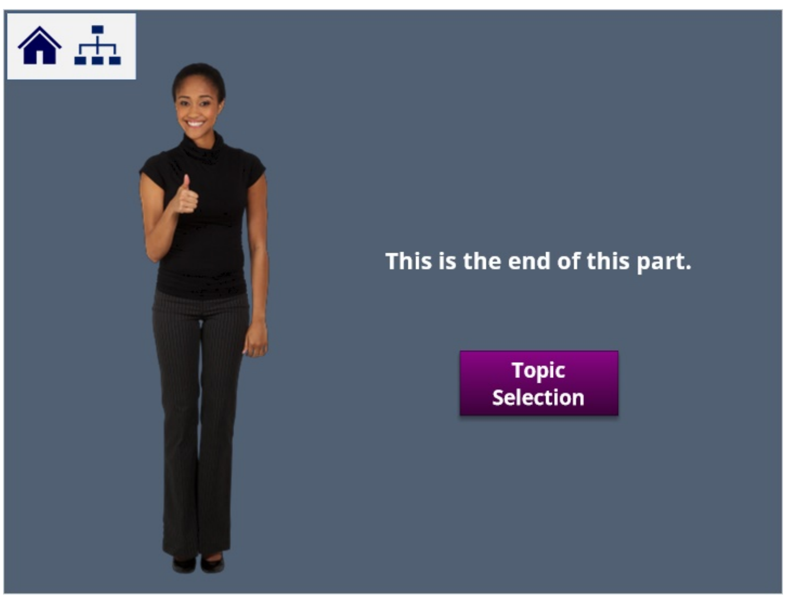
6.7 Tidyverse for Longtitudinal Data



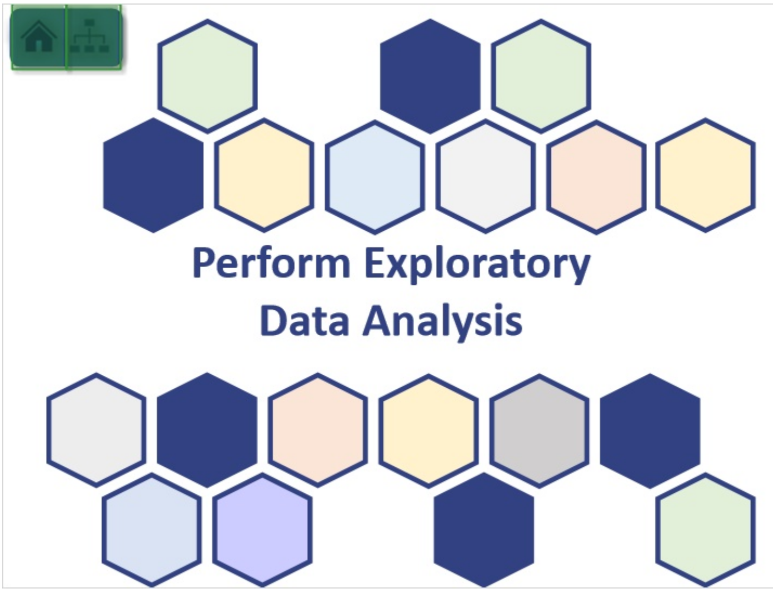
6.8 Selected Tidy Functions for Longitudinal Data



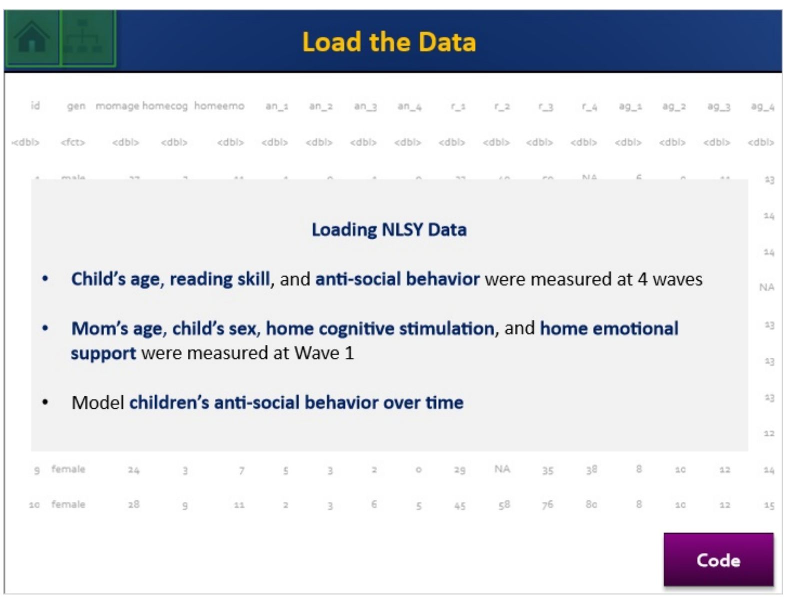
6.9 Bookend: Get Acquainted with R



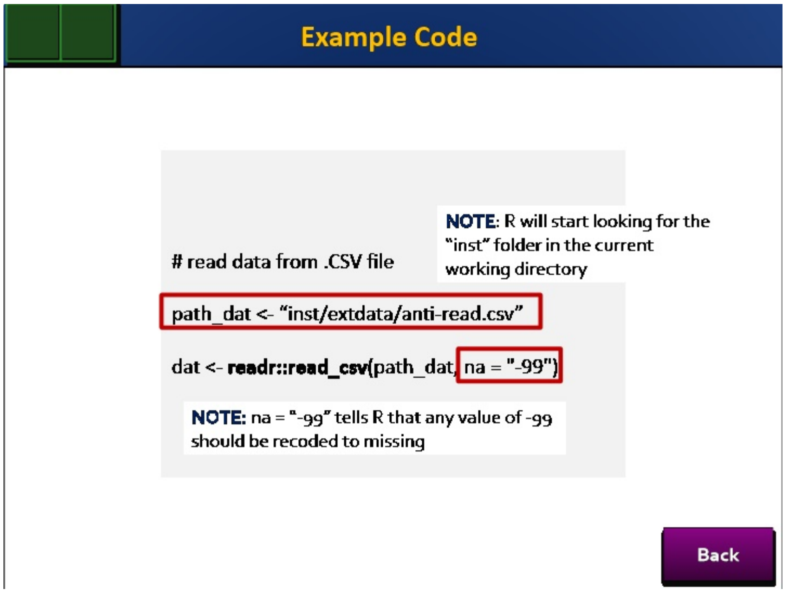
6.10 Bookmark: Perform Exploratory Data Analysis



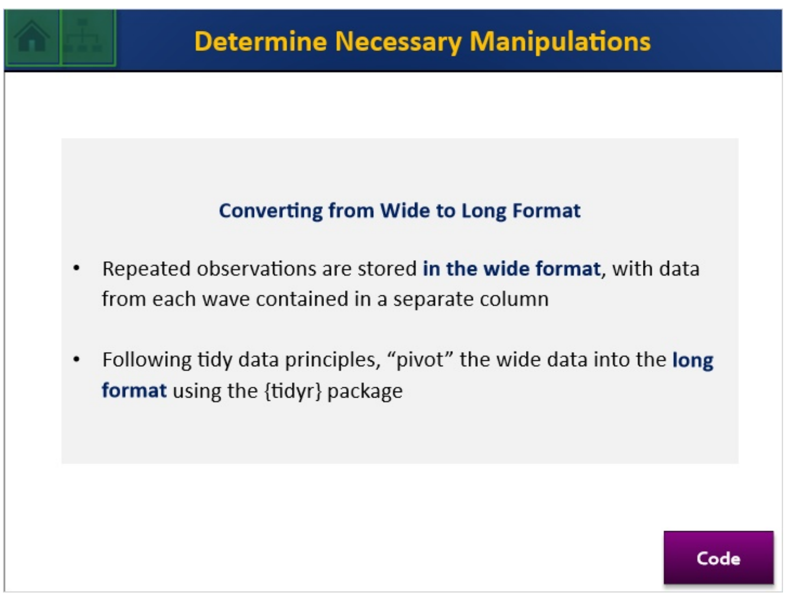
6.11 EDA1:Load the Data



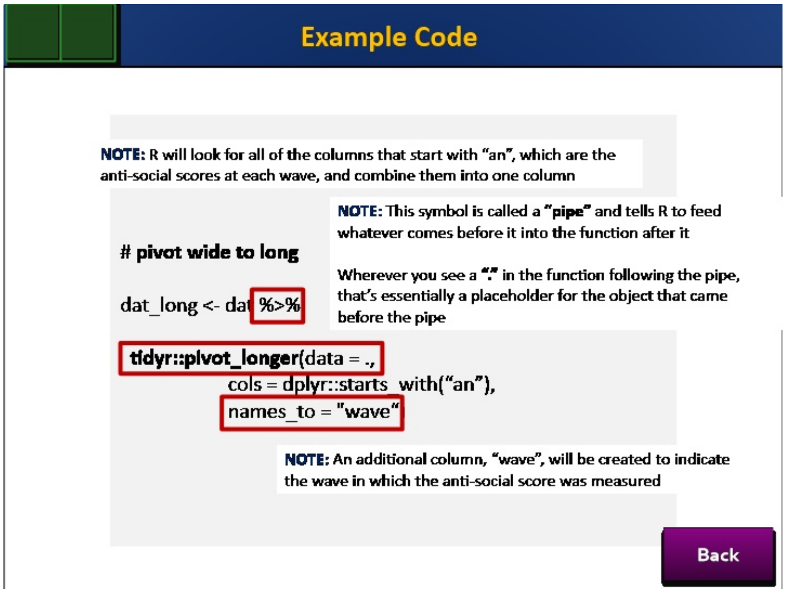
Code (Slide Layer)



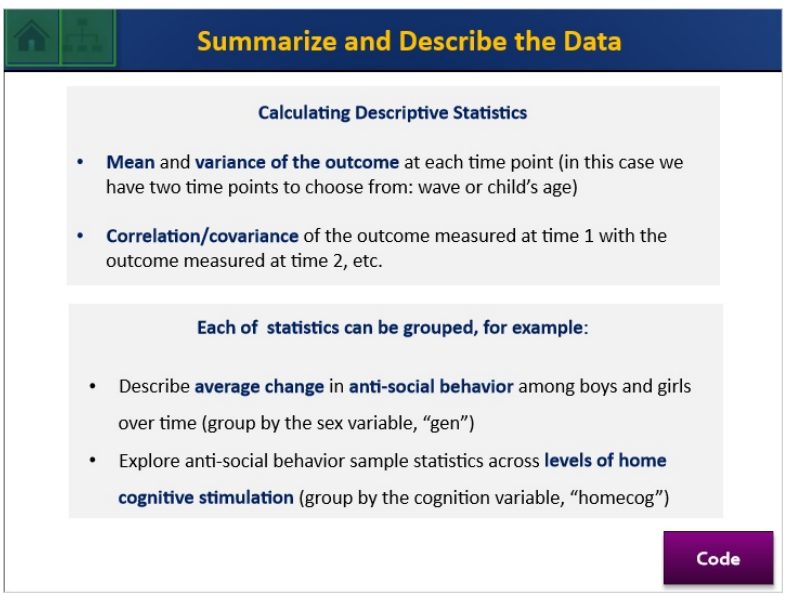
6.12 EDA 2: Determine Necessary Manipulations



Code (Slide Layer)



6.13 EDA 3: Summarize and Describe the Data



Code (Slide Layer)

Example Code

```
dat_long %>%
dplyr::group_by(., ag) %>%
dplyr::summarize(.,
        mean = round(mean(anti_score, na.rm = TRUE), 2),
        var = round(var(anti_score, na.rm = TRUE), 2),
        n = dplyr::n())
```

NOTE: We use the dplyr::group_by function to tell R to calculate the statistics we request in the next step within each level of the grouping variable. Here, we choose to group by "ag", or the age of the child, rather than the "wave" of data collection.

To also group by a predictor, e.g., child's sex, add the grouping variable of interest after "ag", like so: dplyr::group_by(., ag, gen).

NOTE: Using dplyr::n() tells R to calculate the sample size in each group. This is especially important in our case because we have chosen to group by age rather than wave.

Back

6.14 EDA 3: Example Table

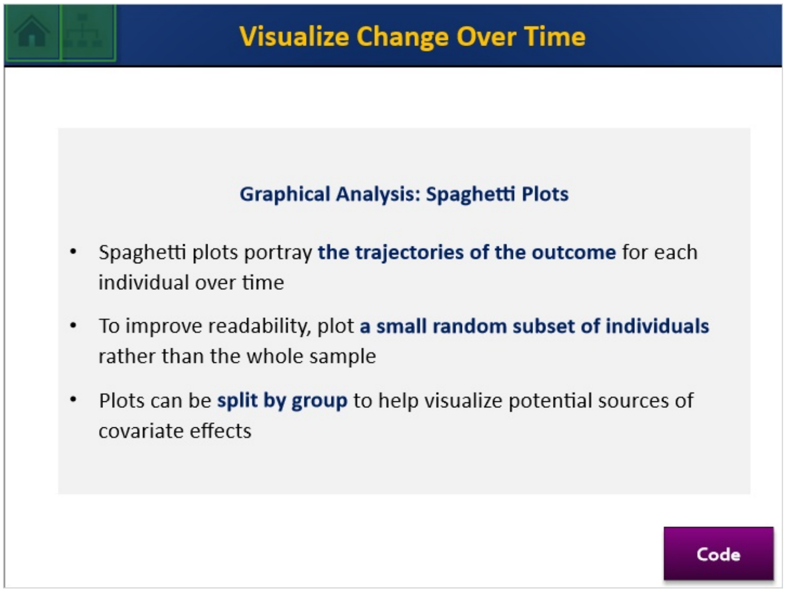
Example Table

Anti-Social Behavior Descriptives

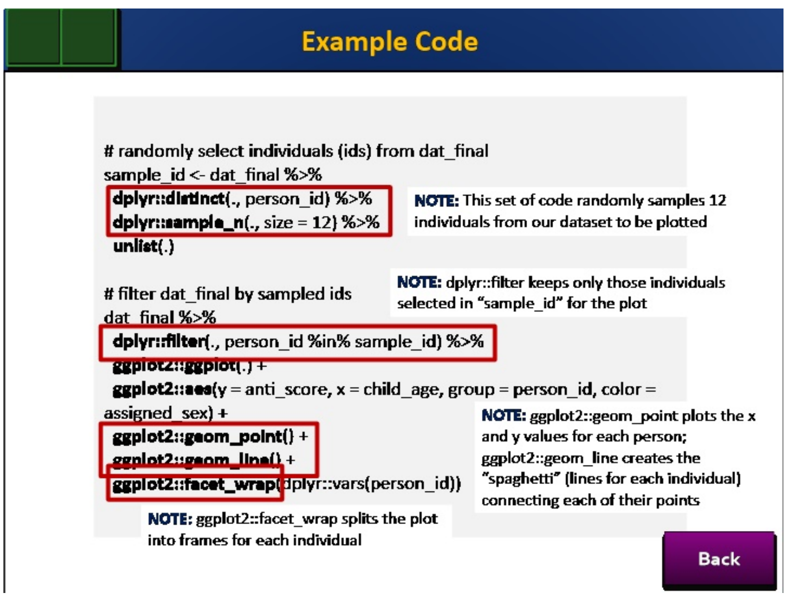
Sample size, means, & variances of anti-social scores across ages.

	Anti-Social Scores by Age		
Child Age	Sample Size	Mean	Variance
6	122	1.57	2.78
7	168	1.55	2.42
8	146	1.97	3.23
9	192	1.89	3.82
10	151	2.14	4.56
11	174	1.79	3.80
12	135	1.84	3.17
13	173	2.24	5.16
14	101	1.96	4.36
15	8	1.12	3.55
NA	250	—	—

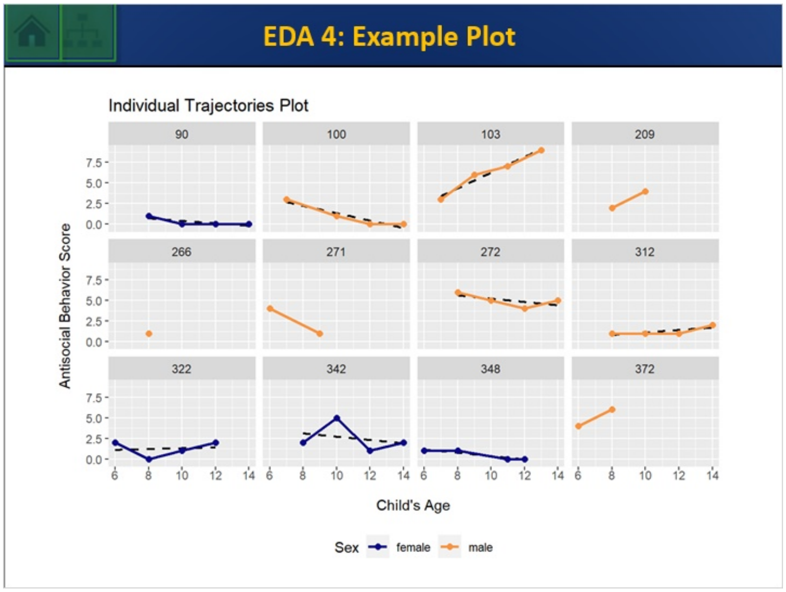
6.15 EDA 4: Visualize Change Over Time



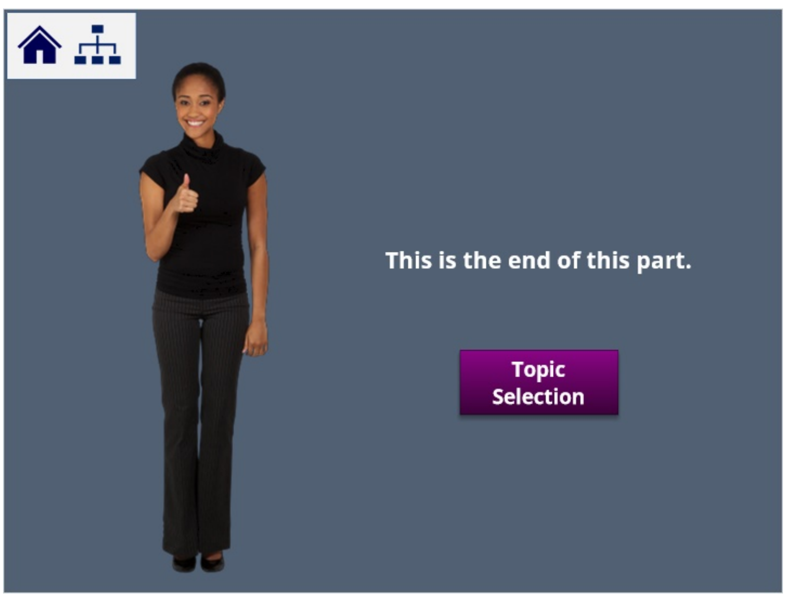
Code (Slide Layer)



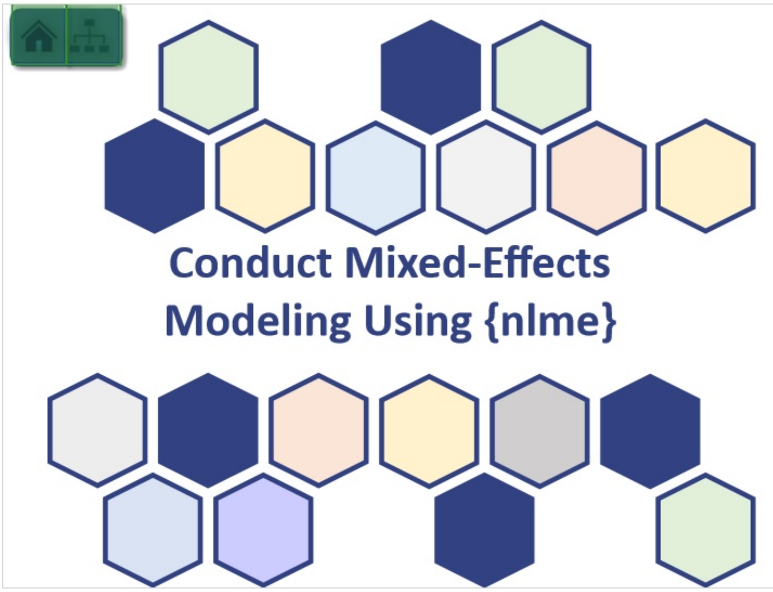
6.16 EDA 4: Example Plot



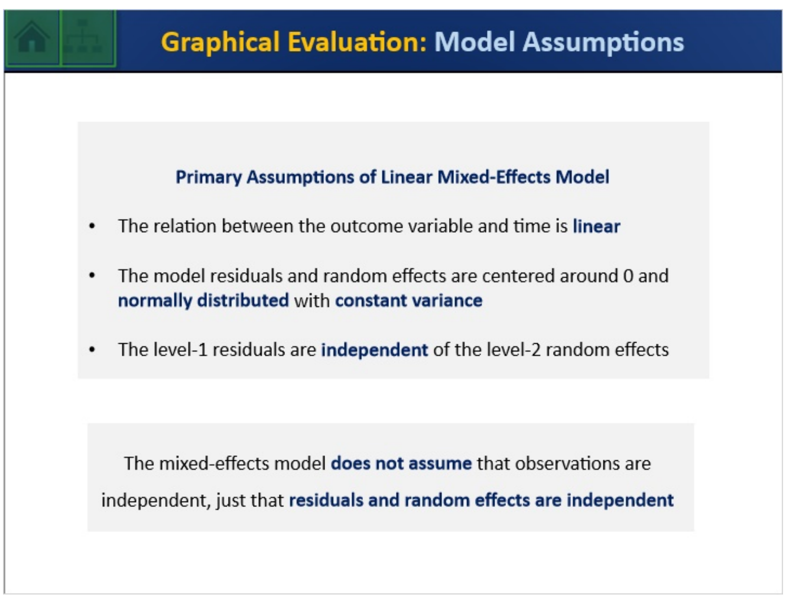
6.17 Bookend: Perform Exploratory Data Analysis



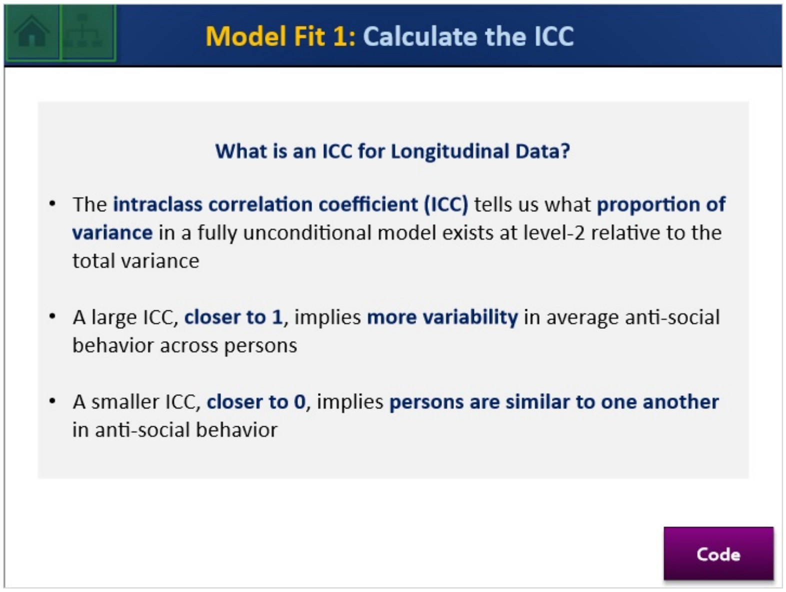
6.18 Bookmark: Conduct Mixed-Effects Modeling Using {nlme}



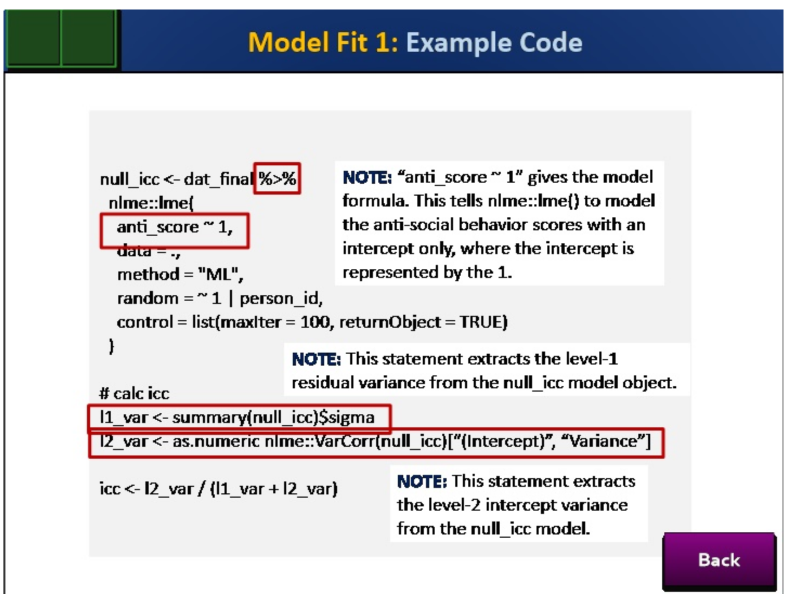
6.19 Graphical Eval: Model Assumptions



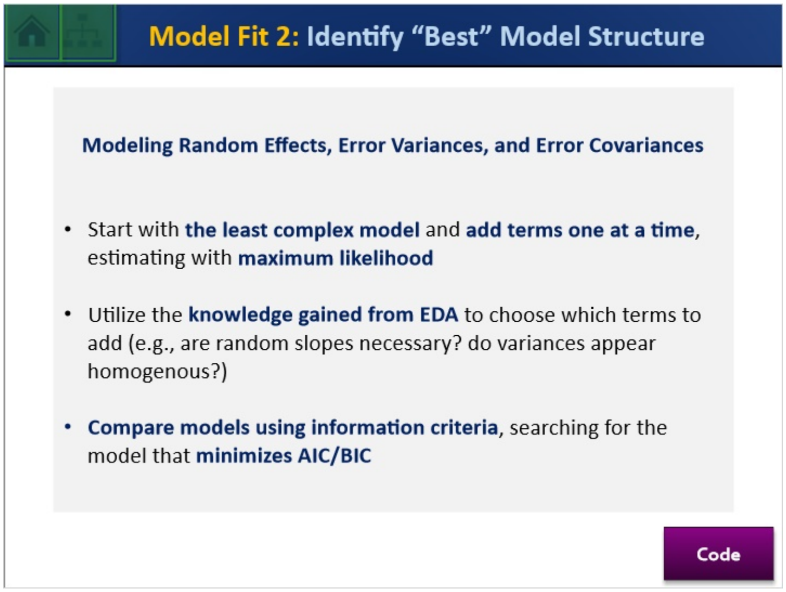
6.20 Model Fit 1: Calculate the ICC



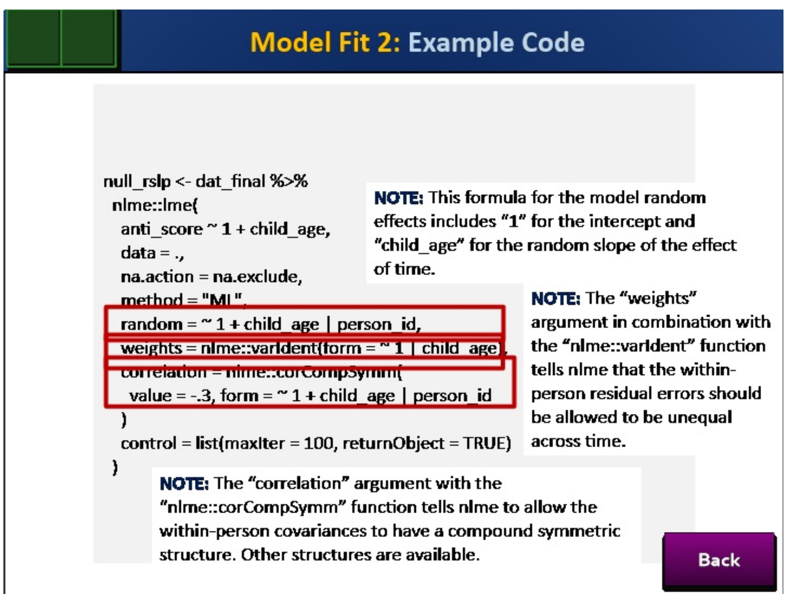
Code (Slide Layer)



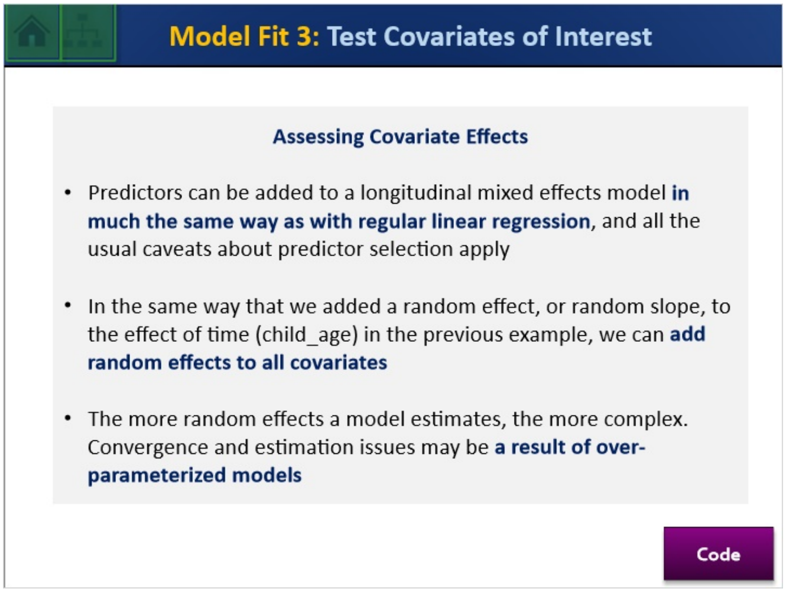
6.21 Model Fit 2: Identify "Best" Model Structure



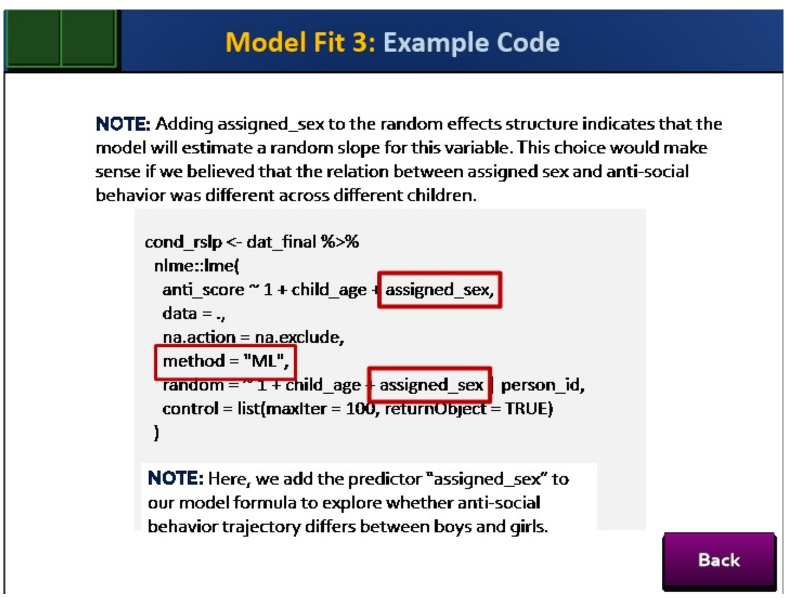
Code (Slide Layer)



6.22 Model Fit 3: Test Covariates of Interest

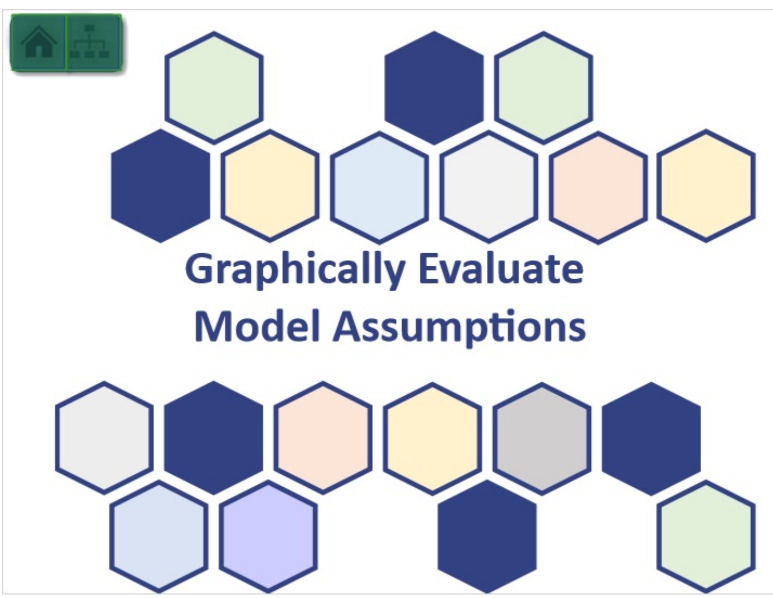


Code (Slide Layer)

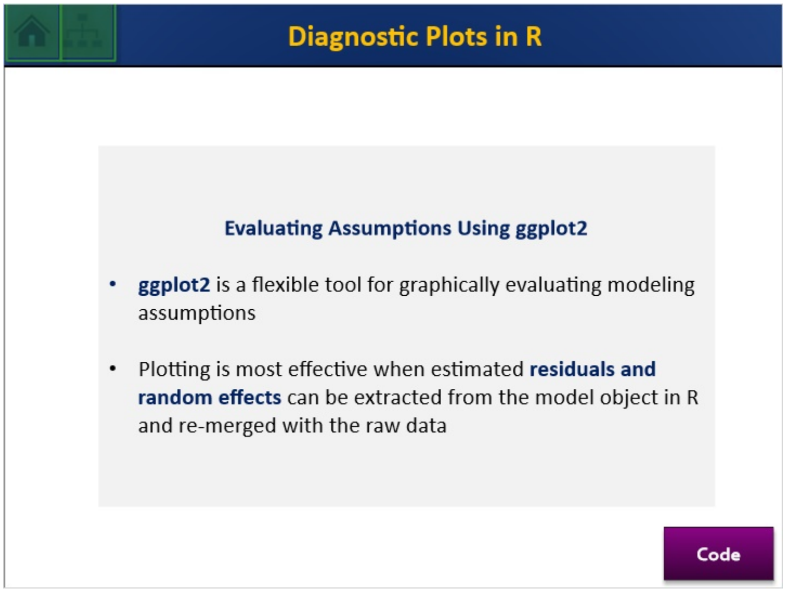


6.23 Bookend: Conduct Mixed-Effects Modeling Using {nlme}

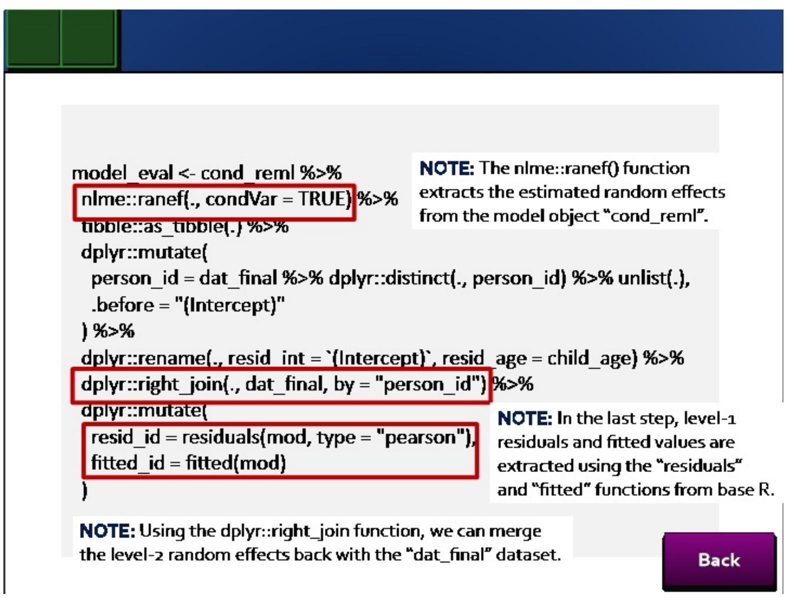
6.24 Bookmark: Graphically Evaluate Model Assumptions



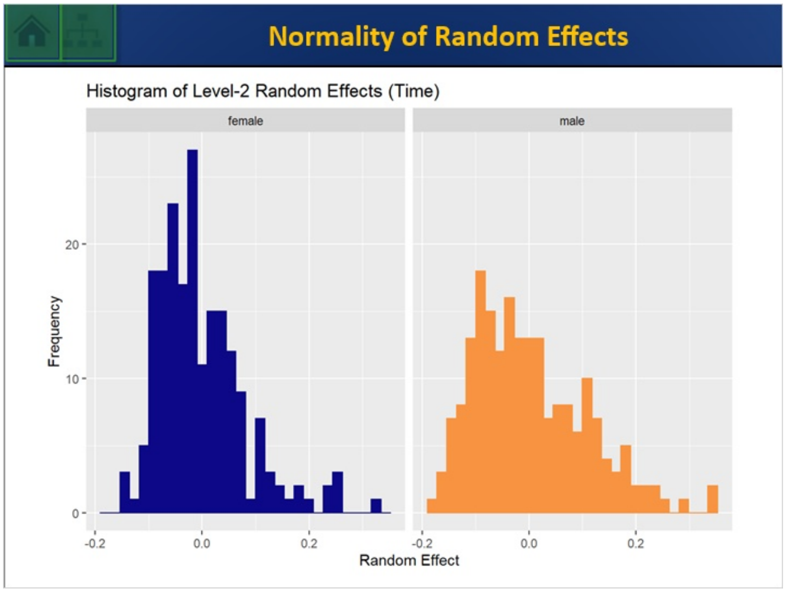
6.25 Graphical Eval: Diagnostic Plots in R



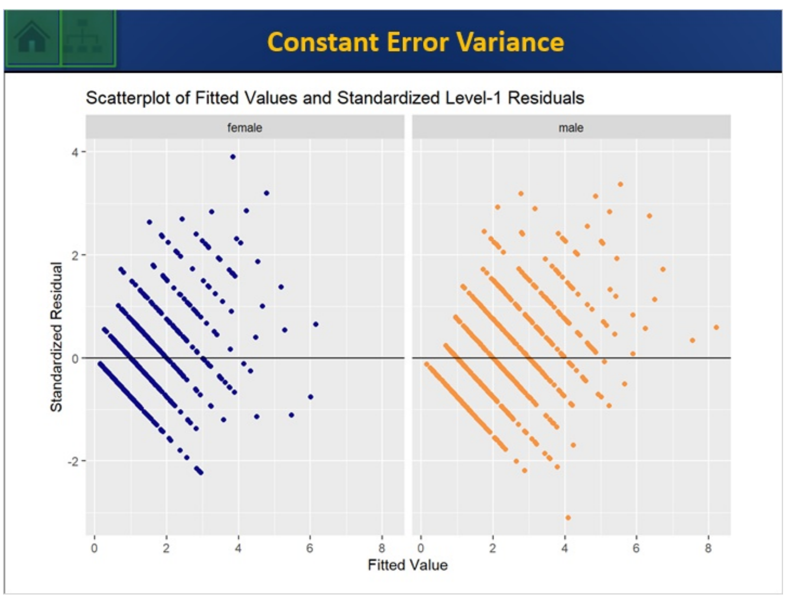
Code (Slide Layer)



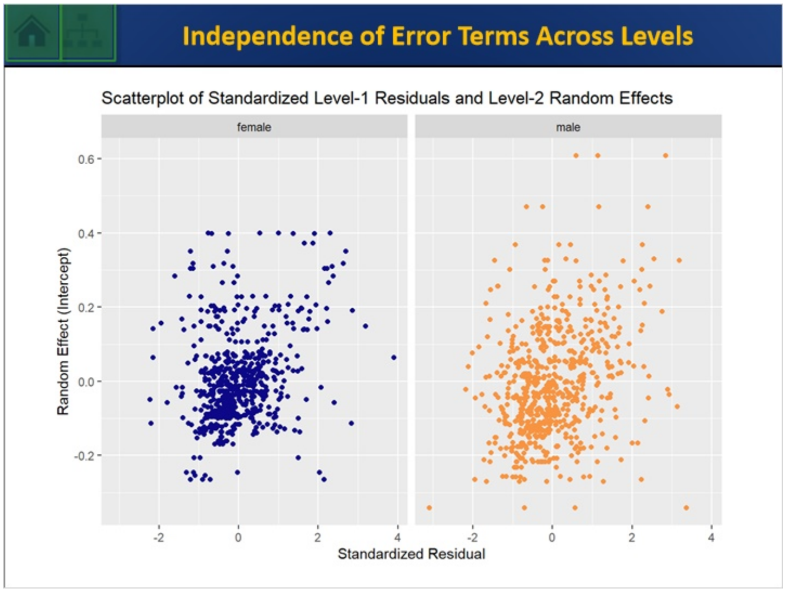
6.26 Graphical Eval: Normality of Random Effects



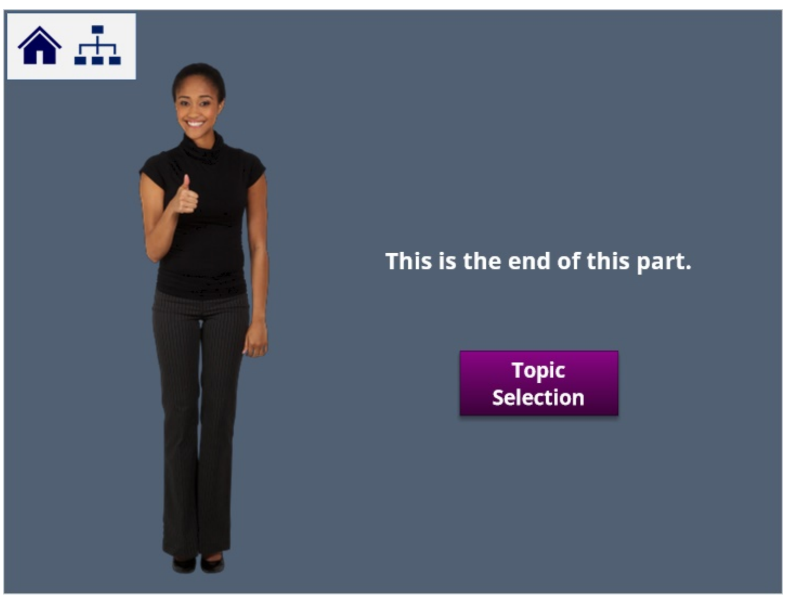
6.27 Graphical Eval: Constant Error Variance



6.28 Graphical Eval: Independence of Error Terms Across Levels

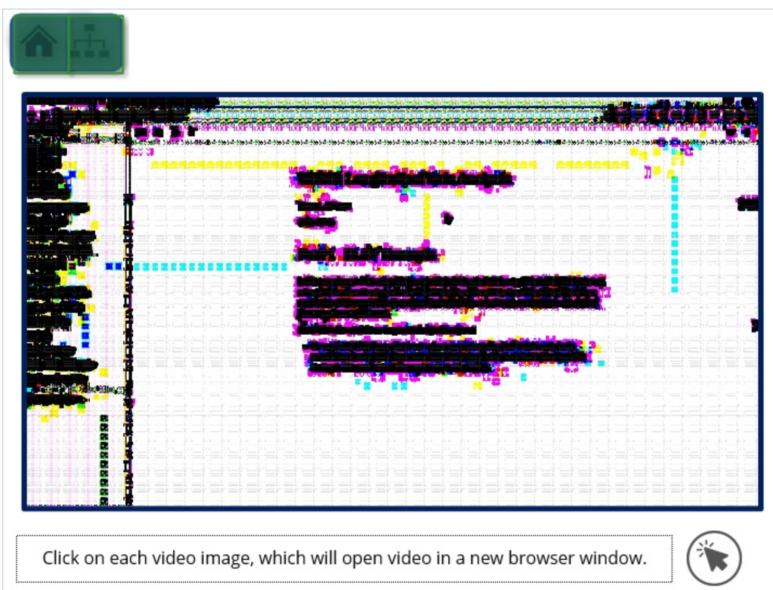


6.29 Bookend: Graphical Evaluation



6.30 Bookmark: Real Data Analysis

6.31 Example 1



6.32 Graphical Evaluation

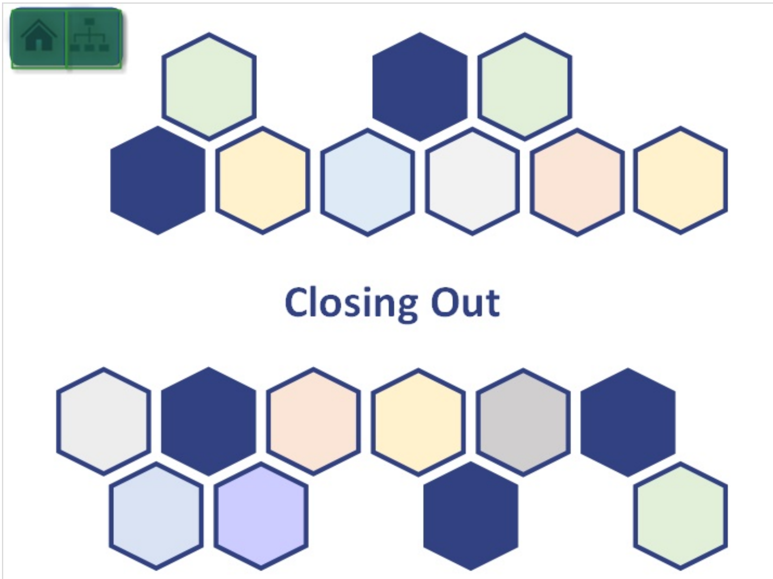
Graphical Evaluation

- Linear mixed-effects models for longitudinal data are **similar to linear regression models** in that they impose several assumptions
- With increasing model complexity, there are both more assumptions and more opportunities to **"relax" assumptions that are untenable**

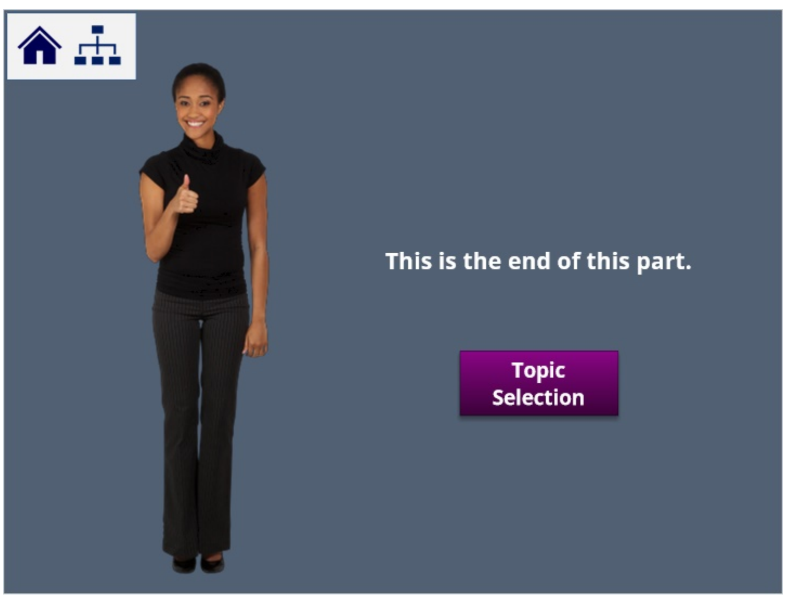
6.33 Example 2

Click on each video image, which will open video in a new browser window.

6.34 End of Section



6.35 Bookend: Data Activity



6.36 Module Cover (END)