

CONTENTS

<i>Preface</i>	<i>xiii</i>
1 Introduction	1
Chapter Objectives	1
Introduction	1
Providing a Conceptual Overview	2
Analysis of Multilevel Data Structures	5
Contrasting Linear Models	6
Univariate Analysis	9
<i>Multiple Regression</i>	10
<i>Analysis of Variance</i>	10
Multivariate Analysis	11
<i>Multivariate Analysis of Variance</i>	11
<i>Structural Equation Modeling</i>	13
Multilevel Data Structures	15
<i>Multilevel Multivariate Model</i>	17
<i>Multilevel Structural Model</i>	18
Summary	20
References	21
2 Getting Started With Multilevel Analysis	23
Chapter Objectives	23
Introduction	23
From Single-Level to Multilevel Analysis	25
<i>Summarizing Some Differences</i>	29
Developing a General Multilevel Modeling Strategy	31

	Step 1: Partitioning the Variance in an Outcome	33
	Step 2: Adding Level-1 Predictors to Explain Intercept Variability	37
	Step 3: Specifying Level-2 Predictors to Explain Intercept Variability	38
	Step 4: Examining Possible Variation in Slopes	40
	Step 5: Adding Predictors to Explain Variation in Slopes	41
	Specifying Random Effects at Level 2	43
	Methods for Estimating Model Parameters	44
	Maximum Likelihood Estimation	45
	Full Information ML	48
	Model Convergence	51
	Considerations for ML Estimation	52
	Other Model Estimation Approaches in Mplus	54
	WLS Estimation	55
	Bayesian Estimation	56
	A Comparison of Estimation Approaches With Small Numbers of Level-2 Units	57
	Summary	60
	References	62
3	Multilevel Regression Models	67
	Chapter Objectives	67
	Introduction	67
	Overview of Multilevel Regression Models	69
	Building a Model to Explain Employee Morale	70
	Model 1: One-Way ANOVA model	74
	Model 1 Statements	75
	Model 1 Output	77
	Model 2: Level-1 Random-Intercept Model	79
	Model 2 Statements	81
	Model 2 Output	82
	Model 3: Specifying a Level-1 Random Slope	83
	Model 3 Statements	83
	Model 3 Output	84
	Model 4: Explaining Variation in the Level-2 Intercept and Slope	85
	Model 4 Statements	85
	Model 4 Output	86
	Centering Predictors	87
	Centering Predictors in Models With Random Slopes	91
	Summary	93
	References	94
4	Extending the Two-Level Regression Model	97
	Chapter Objectives	97
	Introduction	97

Three-Level Univariate Model	98
<i>Developing a Three-Level Univariate Model</i>	99
<i>Research Questions</i>	100
<i>Data</i>	100
<i>Model 1: Null (No Predictors) Model</i>	101
<i>Model 1 Statements</i>	101
<i>Model 1 Output</i>	102
<i>Model 2: Defining Predictors at Each Level</i>	103
<i>Grand-Mean Centering</i>	103
<i>Model 2 Statements</i>	105
<i>Model 2: Grand-Mean Centered Output</i>	105
<i>Group-Mean Centering</i>	107
<i>Model 2 Statements</i>	107
<i>Model 2: Group-Mean Centered Output</i>	108
<i>Model 3: Does the Slope Vary Randomly Across Schools?</i>	109
<i>Model 3 Statements</i>	110
<i>Model 3 Output</i>	111
<i>Model 4: Developing a Model to Explain Variability in Slopes</i>	111
<i>Model 4 Statements</i>	112
<i>Model 4 Output</i>	112
Defining Path Models	113
<i>Single-Level Path Model</i>	114
<i>Multilevel Path Model</i>	115
<i>Model 1: Two-Level Model With Multivariate Outcomes</i>	117
<i>Model 1 Statements</i>	119
<i>Model 1 Output</i>	120
<i>Model 2: Specifying a Mediating Variable Between Groups</i>	122
<i>Model 2 Statements</i>	123
<i>Model 2 Output</i>	124
<i>Model 3: Revised Model Removing Nonsignificant Paths</i>	127
<i>Examining an Indirect Effect</i>	128
<i>Model 3 Statements</i>	128
<i>Model 3 Output</i>	129
<i>Final R-Square Estimates</i>	129
Summary	131
References	131

5	Defining Multilevel Latent Variables	133
	Chapter Objectives	133
	Introduction	133
	Latent Variables	135
	The Measurement Model	136
	Structural Model	139
	Proposing a CFA Model	140

Model Identification 143
Model Fit Indices 145
Model 1: Examining a Single-Level CFA Model 148
 Model 1 Output 149
Model 2: Freeing an Error Covariance 153
 Model 2 Output 153
Extending the Generalizability of a Model 154
Multilevel Measurement Models 155
 Multilevel Factor Variance Components 158
 Estimating ML-CFA Models 159
 Model 3: Defining a Two-Level CFA Model 162
 Examining the Fit Indices 166
 Examining the Model Parameters 167
 Model 4: Applying Equality Constraints on Factor Loadings 168
 Model 4 Output 169
Standardized Estimates 171
 Comparing Model 3 and Model 4 172
Extending the CFA Model to Three Levels 174
 Model 5: Invariant Loadings at Levels 1 and 2 174
 Model 5 Fit Indices 175
 Model 6: Including Equality Constraints at Level 3 176
 Model 6 Fit Indices 176
 Model 7: Restricting Errors to Zero at Level 2 177
 Model 7 Fit Indices 177
 Comparing Models 6 and 7 177
 Model 7 Parameter Estimates 178
Summary 179
References 179

6 Multilevel Structural Equation Models 183

Chapter Objectives 183
Introduction 183
Multilevel Models With Latent Variables and Covariates 184
 Model 1: Two-Level CFA With Observed Predictors 185
 Model 1 Statements 187
 Model 1 Output 189
 Model 2: Specifying a Random Level-1 Slope 198
 Model 2 Statements 199
 Model 2 Output 200
 Model 3: Specifying Female as Having Within- and Between-Group Components 200
 Model 3 Statements 200
 Model 3 Output 202
 Model 4: Adding a Latent Factor Between Groups 202

<i>Model 4 Statements</i>	205
<i>Model 4 Output</i>	206
<i>Model 5: Testing an Indirect Effect</i>	206
<i>Model 5 Statements</i>	209
<i>Model 5 Output</i>	210
<i>Model 6: Adding a Relationship Between the Latent Outcomes</i>	211
<i>Model 6 Statements</i>	211
<i>Model 6 Output</i>	212
<i>Model 7: Specifying a Reciprocal Relationship Between Outcomes</i>	213
<i>Model 7 Statements</i>	216
<i>Model 7 Output</i>	218
Summary	219
References	220
7 Methods for Examining Individual and Organizational Change	221
Chapter Objectives	221
Introduction	221
Analyzing Longitudinal Data	223
<i>Repeated-Measures ANOVA</i>	223
<i>Growth Modeling and Other Approaches</i>	224
<i>Random-Coefficients Growth Modeling</i>	225
<i>Defining the Level-1 Model</i>	226
<i>Defining the Level-2 Model</i>	228
Extending the Model to Examine Changes Between Organizations	229
<i>Defining the Level-3 Model</i>	229
Examining Changes in Institutions' Graduation Rates	229
<i>Model 1: Within-Individuals (Level-1) Model</i>	231
<i>Between-Individuals (Level-2) Model</i>	232
<i>Coding the Time Variable</i>	232
<i>Model 1 Statements</i>	234
<i>TECH1 Specification Output</i>	235
<i>Model 1 Output</i>	236
<i>Model 2: Explaining Differences in Random Growth Parameters Between Institutions</i>	238
<i>Model 2 Statements</i>	238
<i>TECH1 Output</i>	239
<i>Model 2 Output</i>	240
<i>Other Types of Random-Coefficients Models</i>	241
Examining Individual Change With SEM	241
<i>Intercept and Slope (IS) and Level and Shape (LS) Models</i>	242
Defining the Latent Curve Model	244
<i>The Measurement Model</i>	244
<i>The Structural Model</i>	246

<i>Model 1: Specifying the IS Model</i>	247
<i>Model 1: IS Model Statements</i>	247
<i>Model 2: Specifying the LS Model</i>	248
<i>Model 2: LS Model Statements</i>	249
<i>Model Identification</i>	249
<i>Model 1 IS Output</i>	250
<i>Model 2 LS Output</i>	252
<i>Comparing the Fit of the IS and LS Models</i>	253
<i>Nested Models</i>	254
<i>Model 3: Adding Covariates to the IS Model</i>	255
<i>Model 3 Statements</i>	256
<i>Model 3 Output</i>	256
<i>Extending the Latent Curve Model</i>	256
Multilevel Latent Curve Analysis	258
<i>Examining Variables That Influence Student Growth in Math</i>	258
<i>Data and Variables</i>	259
<i>Defining the Proposed Model</i>	259
<i>Model Statements</i>	259
<i>Model Output</i>	261
Developing a Piecewise Growth Model	262
<i>Specifying the Piecewise Latent Curve Model</i>	264
<i>Model 1 Statements</i>	265
<i>Model 1 Output</i>	266
<i>Imposing Equality Constraints</i>	266
<i>Model 2: Adding the Covariates</i>	268
<i>Model 2 Statements</i>	268
<i>Model 2 Output</i>	268
Summary	269
References	271

8 Multilevel Models With Categorical Variables

273

Chapter Objectives	273
Introduction	273
Multilevel Models With Categorical Observed Outcomes	278
<i>Specifying Models for Binary, Ordinal, and Nominal Outcomes</i>	278
<i>Binary Outcome</i>	278
<i>Logit Link Function</i>	279
<i>Probit Link Function</i>	281
<i>Ordinal Outcome</i>	283
<i>Ordered Probit Model</i>	286
<i>Unordered Categorical (Nominal) Outcome</i>	287
Mplus Latent Response Formulation	288
Explaining Student Persistence	290
<i>Binary Outcome</i>	291

<i>Model 2 Statements</i>	292	
<i>Ordinal Outcome</i>	294	
<i>Estimating Probabilities From Probit Coefficients</i>	294	
<i>Estimating Probabilities From Logit Coefficients</i>	296	
<i>Adding Level-1 and Level-2 Predictors</i>	296	
<i>Model Statements</i>	297	
<i>Examining a Cross-Level Interaction</i>	300	
<i>Model Statements</i>	301	
Count Data	303	
<i>Building a Level-1 and Level-2 Model</i>	306	
<i>Model Statements</i>	306	
<i>Level-1 and Level-2 Model Output</i>	307	
<i>Negative Binomial Results</i>	308	
Multilevel CFA With Ordinal Observed Indicators	310	
<i>Developing a CFA Model</i>	312	
<i>Model Statements</i>	315	
<i>Model Output</i>	317	
Summary	320	
References	321	
9	Multilevel Mixture Models	323
	Chapter Objectives	323
	Introduction	323
	Defining Latent Classes	324
	<i>An Example Latent Profile Analysis</i>	328
	<i>Model Statements</i>	330
	<i>Model Output</i>	330
	<i>Examining Heterogeneity in Intercepts</i>	331
	<i>Model Statements</i>	333
	<i>Model Output</i>	335
	<i>Investigating Latent Classes for Random Slopes at Level 2</i>	339
	<i>Model Statements</i>	341
	<i>Model Output</i>	342
	<i>Alternative Model Specification</i>	344
	<i>Defining a Two-Level Mixture Model for Math</i>	345
	<i>Model Statements</i>	349
	<i>Model Output</i>	350
	<i>Model Modifications</i>	352
	<i>Two-Level CFA Mixture Model With Continuous Indicators</i>	352
	<i>Model Statements</i>	354
	<i>Model Output</i>	355
	Latent Growth Mixture Models	357
	<i>Examining Latent Classes in Students' Growth in Science</i>	359
	<i>Model Statements</i>	360

<i>Model Output</i>	361
<i>Two-Level LGMM</i>	364
<i>Model Statements</i>	366
<i>Model Output</i>	367
Summary	370
References	370
10 Data Considerations in Examining Multilevel Models	373
Chapter Objectives	373
Introduction	373
Complex Samples, Design Effects, and Sample Weights	373
<i>An Example Using Multilevel Weights</i>	379
<i>Model Statements</i>	379
<i>Model Output</i>	382
Parameter Bias and Statistical Power	384
<i>Bias</i>	384
<i>Power</i>	385
<i>An Example</i>	386
<i>Anticipated Effect Size and Power</i>	389
<i>Mplus Monte Carlo Study</i>	393
<i>Model Statements</i>	395
<i>Model Output</i>	396
Design Complexity	398
Missing Data	399
<i>Missing Data at Level 2</i>	404
<i>Model Statements</i>	404
<i>Initial Summary Output</i>	405
<i>Imputation File</i>	406
<i>Model Estimates</i>	407
<i>Model Output</i>	407
Concluding Thoughts	410
References	413
<i>Glossary</i>	417
<i>Author Index</i>	429
<i>Subject Index</i>	433