

Appendix B - Implement LTA Analyses with MplusAutomation

Rationale for MplusAutomation workflow:

This R-script is intended to provide a template for running LTA and associated tasks in a systematic manner. Using this approach all code for data pre-processing, model estimation, tabulation, and figure processing can be contained within a single script providing clear documentation. It is the authors belief that this dramatically reduces risk of user-error, is conducive to open-science philosophy, and scientific transparency. All models are estimated using **Mplus** (Muthén & Muthén, 1998 - 2017) using the wrapping program **MplusAutomation** (Hallquist & Wiley, 2018). This method requires the user to have the proprietary software **Mplus** installed on their OS.

This approach also relies on the utility of **R-Projects**. This provides a structured framework for organizing all associated data files, Mplus text files, scripts, and figures. Given the high output of Mplus files inherent to LTA modeling, creating a system of project sub-folders greatly improves organization (i.e., folders; ‘data’, ‘mplus_files’ ‘figures’, etc.) Additionally, the communication between R and Mplus requires the specification of file-paths a procedure which is streamlined by use of **R-projects**. Due to the reliance on file-paths the **here** package is utilized for reproducibility, by making all path syntax uniform across operating systems.

Data Source: The data used to illustrate these analyses include elementary school student *Science Attitude* survey items collected during 7th and 10th grades from the **Longitudinal Study of American Youth** (LSAY; Miller, 2015).

Preparation

Download the R-Project

Link to Github repository here: <https://github.com/garberadamc/LTA-FAQ>

For readers **unfamiliar with Github** and version controlled R-projects:

1. On the repository page, click the green **Code** button and in the menu choose option **Download ZIP**
2. Place the un-zipped downloaded folder on your desktop
3. Within this folder open the file with the blue cube icon that is file type **LTA-FAQ-analyses.Rproj**
4. Next open the file containing all analysis code named **LTA-FAQ-analyses.R**.

Note: Alternatively, if preferred users may follow analyses using the Rmarkdown script (**.Rmd**).

Project folder organization

The following sub-folders will be used to contain files:

1. “data”;
2. “enum_LCA_time1”;
3. “enum_LCA_time2”;
4. “LTA_models”;
5. “figures”

Note regarding project location: If the main project folder is located within too many nested folders it may result in a file-path error when estimating models with `MplusAutomation`.

Notation guide

In the following script, three types of comments are included in code blocks in which models are estimated using `MplusAutomation`.

- a. **Annotate in R:** The hashtag symbol `#` identifies comments written in R-language form.
 - b. **Annotate in Mplus input:** Within the `mplusObject()` function all text used to generate Mplus input files is enclosed within quotation marks (green text). To add comments within quotations the Mplus language convention is used (e.g., `!!! annotate Mplus input !!!`).
 - c. **Annotate context-specific syntax:** To signal to the user areas of the syntax which vary based on the particular modeling context the text, `NOTE CHANGE:` is used.
-

To install package `{rhdf5}`

```
if (!requireNamespace("BiocManager", quietly = TRUE))  
  install.packages("BiocManager")  
  
BiocManager::install("rhdf5")
```

Load packages

```
library(MplusAutomation)  
library(rhdf5)  
library(tidyverse)  
library(here)  
library(glue)  
library(janitor)  
library(gt)  
library(reshape2)  
library(cowplot)  
library(PNWColors)  
library(ggrepel)
```

Read in LSAY data file, `lsay_lta_faq_2020.csv`.

```
lsay_data <- read_csv(here("data", "lsay_lta_faq_2020.csv"),
                      na=c("9999", "9999.00"))
```

Enumeration

Enumerate time point 1 (7th grade)

```
# NOTE CHANGE: '1:6' indicates the number of k-class models to estimate.
# User can change this number to fit research context.
# In this example, the code loops or iterates over values 1 through 6 ( '{k}' ).
t1_enum_k_16 <- lapply(1:6, function(k) {
  enum_t1 <- mplusObject(

# The 'glue' function inserts R code within a string or "quoted green text" using the syntax {---}
  TITLE = glue("Class-{k}_Time1"),

  VARIABLE = glue(
    "!!! NOTE CHANGE: List of the five 7th grade science attitude indicators !!!
    categorical = ab39m-ab39x;
    usevar = ab39m-ab39x;

    classes = c({k});"),

  ANALYSIS =
    "estimator = mlr;
    type = mixture;
    !!! NOTE CHANGE: The intial and final start values. Reduce to speed up estimation time. !!!
    starts = 500 100;
    processors=10;",

  OUTPUT = "sampstat residual tech11 tech14;",

  PLOT =
    "type = plot3;
    series = ab39m-ab39x(*);",

  usevariables = colnames(lsay_data),
  rdata = lsay_data)

# NOTE CHANGE: Fix to match appropriate sub-folder name
# See after `here` function (e.g., "enum_LCA_time1")
enum_t1_fit <- mplusModeler(enum_t1,
                             dataout=here("enum_LCA_time1", "t1.dat"),
                             modelout=glue(here("enum_LCA_time1", "c{k}_lca_enum_time1.inp")),
```

```

    check=TRUE, run = TRUE, hashfilename = FALSE)
})

```

NOTE: It is highly recommended that you check the output (.out) files to check for convergence warnings or syntax errors.

Enumerate time point 2 (10th grade)

```

t2_enum_k_16 <- lapply(1:6, function(k) {
  enum_t2 <- mplusObject(

    TITLE = glue("Class-{k}_Time2"),

    VARIABLE =
    glue(
      "!!! NOTE CHANGE: List of the five 10th grade science attitude indicators !!!
      categorical = ga33a-ga33l;
      usevar = ga33a-ga33l;

      classes = c({k});"),

    ANALYSIS =
    "estimator = mlr;
    type = mixture;
    starts = 500 100;
    processors=10;",

    OUTPUT = "sampstat residual tech11 tech14;",

    PLOT =
    "type = plot3;
    series = ga33a-ga33l(*);",

    usevariables = colnames(lsay_data),
    rdata = lsay_data)

  enum_t2_fit <- mplusModeler(enum_t2,
    dataout=here("enum_LCA_time2", "t2.dat"),
    modelout=glue(here("enum_LCA_time2", "c{k}_lca_enum_time2.inp")),
    check=TRUE, run = TRUE, hashfilename = FALSE)
})

```

Create model fit summary table

Read all models for enumeration table

```
output_enum_t1 <- readModels(here("enum_LCA_time1"), quiet = TRUE)
output_enum_t2 <- readModels(here("enum_LCA_time2"), quiet = TRUE)
```

Extract model fit data

```
enum_extract1 <- LatexSummaryTable(output_enum_t1,
  keepCols=c("Title", "Parameters", "LL", "BIC", "aBIC",
    "BLRT_PValue", "T11_VLMR_PValue", "Observations"))

enum_extract2 <- LatexSummaryTable(output_enum_t2,
  keepCols=c("Title", "Parameters", "LL", "BIC", "aBIC",
    "BLRT_PValue", "T11_VLMR_PValue", "Observations"))
```

Calculate indices derived from the Log Likelihood (LL)

```
allFit1 <- enum_extract1 %>%
  mutate(aBIC = -2*LL+Parameters*log((Observations+2)/24)) %>%
  mutate(CIAC = -2*LL+Parameters*(log(Observations)+1)) %>%
  mutate(AWE = -2*LL+2*Parameters*(log(Observations)+1.5)) %>%
  mutate(SIC = -.5*BIC) %>%
  mutate(expSIC = exp(SIC - max(SIC))) %>%
  mutate(BF = exp(SIC-lead(SIC))) %>%
  mutate(cmPk = expSIC/sum(expSIC)) %>%
  select(1:5,9:10,6:7,13,14) %>%
  arrange(Parameters)

allFit2 <- enum_extract2 %>%
  mutate(aBIC = -2*LL+Parameters*log((Observations+2)/24)) %>%
  mutate(CIAC = -2*LL+Parameters*(log(Observations)+1)) %>%
  mutate(AWE = -2*LL+2*Parameters*(log(Observations)+1.5)) %>%
  mutate(SIC = -.5*BIC) %>%
  mutate(expSIC = exp(SIC - max(SIC))) %>%
  mutate(BF = exp(SIC-lead(SIC))) %>%
  mutate(cmPk = expSIC/sum(expSIC)) %>%
  select(1:5,9:10,6:7,13,14) %>%
  arrange(Parameters)

allFit <- full_join(allFit1,allFit2)
```

Format fit table

```
allFit %>%
  mutate(Title = str_remove(Title, "_Time*")) %>%
  gt() %>%
  tab_header(
    title = md("**Model Fit Summary Table**"), subtitle = md("&nbsp;")) %>%
  cols_label(
    Title = "Classes",
    Parameters = md("Par"),
    LL = md("*LL*"),
    T11_VLMR_PValue = "VLMR",
    BLRT_PValue = "BLRT",
    BF = md("BF"),
    cmPk = md("*cmP_k*")) %>%
  tab_footnote(
    footnote = md(
      "*Note.* Par = Parameters; *LL* = model log likelihood;
      BIC = Bayesian information criterion;
      aBIC = sample size adjusted BIC; CAIC = consistent Akaike information criterion;
      AWE = approximate weight of evidence criterion;
      BLRT = bootstrapped likelihood ratio test p-value;
      VLMR = Vuong-Lo-Mendell-Rubin adjusted likelihood ratio test p-value;
      cmPk = approximate correct model probability."),
    locations = cells_title()) %>%
  tab_options(column_labels.font.weight = "bold") %>%
  fmt_number(10, decimals = 2,
    drop_trailing_zeros=TRUE,
    suffixing = TRUE) %>%
  fmt_number(c(3:9,11),
    decimals = 2) %>%
  fmt_missing(1:11,
    missing_text = "--") %>%
  fmt(c(8:9,11),
    fns = function(x)
      ifelse(x<0.001, "<.001",
        scales::number(x, accuracy = 0.01))) %>%
  fmt(10, fns = function(x)
    ifelse(x>100, ">100",
      scales::number(x, accuracy = .1))) %>%
  tab_row_group(
    group = "Time-1",
    rows = 1:6) %>%
  tab_row_group(
    group = "Time-2",
    rows = 7:12) %>%
  row_group_order(
    groups = c("Time-1", "Time-2")
  )
```

Model Fit Summary Table¹

Classes	Par	LL	BIC	aBIC	CIAC	AWE	BLRT	VLMR	BF	cmP _k
Time-1										
C1_LCA1	5	-10,250.60	20,541.34	20,525.45	20,546.34	20,596.47	–	–	–	<.001
C2_LCA1	11	-8,785.32	17,658.92	17,623.97	17,669.93	17,780.22	<.001	<.001	>100	<.001
C3_LCA1	17	-8,693.57	17,523.59	17,469.57	17,540.59	17,711.04	<.001	<.001	>100	0.00
C4_LCA1	23	-8,664.09	17,512.79	17,439.71	17,535.79	17,766.40	<.001	<.001	>100	1.00
C5_LCA1	29	-8,662.39	17,557.54	17,465.39	17,586.54	17,877.31	1.00	0.66	>100	<.001
C6_LCA1	35	-8,661.54	17,604.01	17,492.80	17,639.01	17,989.94	1.00	0.75	>100	<.001
Time-2										
C1_LCA2	5	-7,658.79	15,356.19	15,340.30	15,361.19	15,409.80	–	–	–	<.001
C2_LCA2	11	-6,073.81	12,232.56	12,197.61	12,243.56	12,350.50	<.001	<.001	>100	<.001
C3_LCA2	17	-5,988.36	12,107.99	12,053.98	12,124.99	12,290.27	<.001	<.001	>100	0.32
C4_LCA2	23	-5,964.45	12,106.50	12,033.43	12,129.51	12,353.12	<.001	0.00	2.1	0.68
C5_LCA2	29	-5,961.68	12,147.30	12,055.16	12,176.30	12,458.25	0.31	0.36	>100	<.001
C6_LCA2	35	-5,961.26	12,192.79	12,081.59	12,227.79	12,568.07	1.00	0.50	>100	<.001

¹Note. Par = Parameters; LL = model log likelihood; BIC = Bayesian information criterion; aBIC = sample size adjusted BIC; CAIC = consistent Akaike information criterion; AWE = approximate weight of evidence criterion; BLRT = bootstrapped likelihood ratio test p-value; VLMR = Vuong-Lo-Mendell-Rubin adjusted likelihood ratio test p-value; cmPk = approximate correct model probability.

Compare time 1 & time 2 LCA plots

Read models for plotting (4-class models)

```
model_t1_c4 <- readModels(here("enum_LCA_time1", "c4_lca_enum_time1.out"), quiet = TRUE)
model_t2_c4 <- readModels(here("enum_LCA_time2", "c4_lca_enum_time2.out"), quiet = TRUE)
```

Create a function `plot_lca_function` that requires 5 arguments:

- `model_name`: name of Mplus model object (e.g., `model_t1_c4`)
- `item_num`: the number of items in LCA measurement model (e.g., 5)
- `class_num`: the number of classes (k) in LCA model (e.g., 4)
- `item_labels`: the item labels for x-axis (e.g., `c("Enjoy", "Useful", "Logical", "Job", "Adult")`)
- `plot_title`: include the title of the plot here (e.g., "Time 1 LCA Posterior Probability Plot")

```
plot_lca_function <- function(model_name,item_num,class_num,item_labels,plot_title){
  mplus_model <- as.data.frame(model_name$gh5$means_and_variances_data$estimated_probs$values)
  plot_t1 <- mplus_model[seq(2, 2*item_num, 2),]

  c_size <- as.data.frame(model_name$class_counts$modelEstimated$proportion)
  colnames(c_size) <- paste0("cs")
}
```

```

c_size <- c_size %>% mutate(cs = round(cs*100, 2))
colnames(plot_t1) <- paste0("C", 1:class_num, glue(" ({c_size[1:class_num,]}%)"))

plot_t1 <- cbind(Var = paste0("U", 1:item_num), plot_t1)
plot_t1$Var <- factor(plot_t1$Var,
  labels = item_labels)
plot_t1$Var <- fct_inorder(plot_t1$Var)
pd_long_t1 <- melt(plot_t1, id.vars = "Var")

p <- pd_long_t1 %>%
  ggplot(aes(x = as.integer(Var), y = value,
    shape = variable, colour = variable, lty = variable)) +
  geom_point(size = 4) + geom_line() +
  scale_x_continuous("", breaks = 1:5, labels = plot_t1$Var) +
  scale_colour_grey() +
  labs(title = plot_title, y = "Probability") +
  theme_cowplot() +
  theme(legend.title = element_blank(),
    legend.position = "top")

p
return(p)
}

```

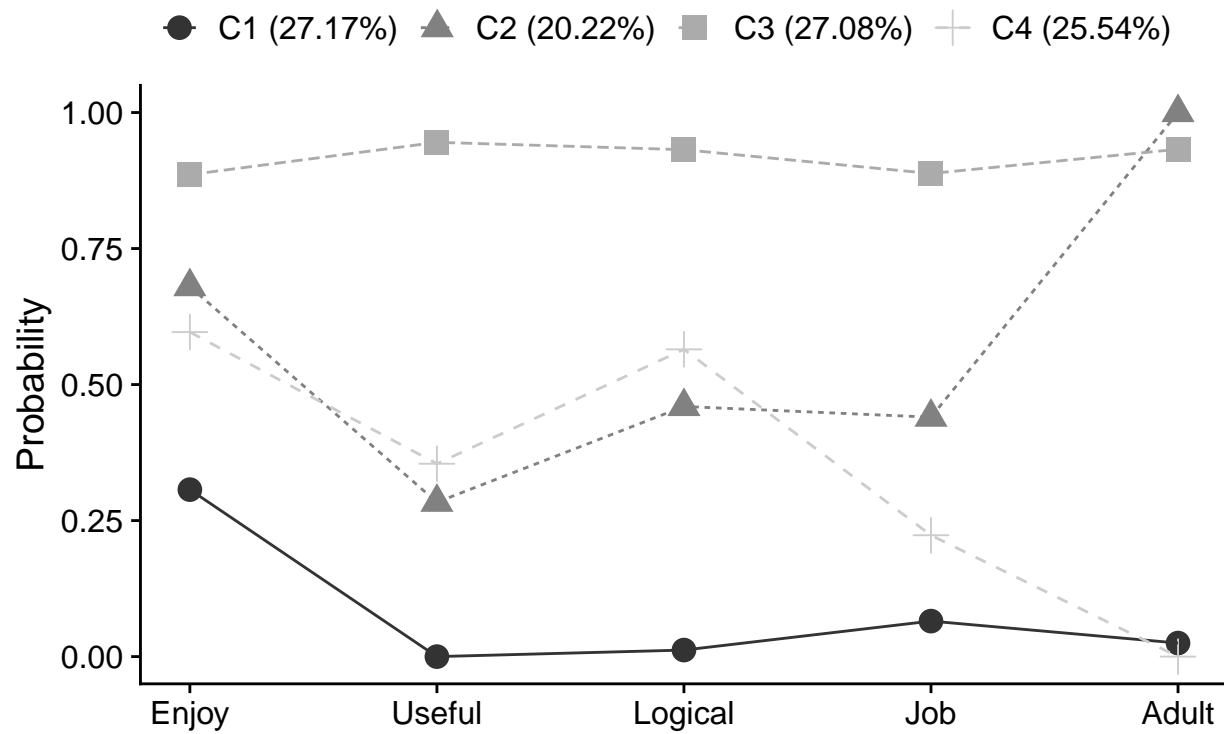
Plot time 1 LCA

```

plot_lca_function(
  model_name = model_t1_c4,
  item_num = 5,
  class_num = 4,
  item_labels = c("Enjoy", "Useful", "Logical", "Job", "Adult"),
  plot_title = "Time 1 LCA Posterior Probability Plot"
)

```


Time 1 LCA Posterior Probability Plot

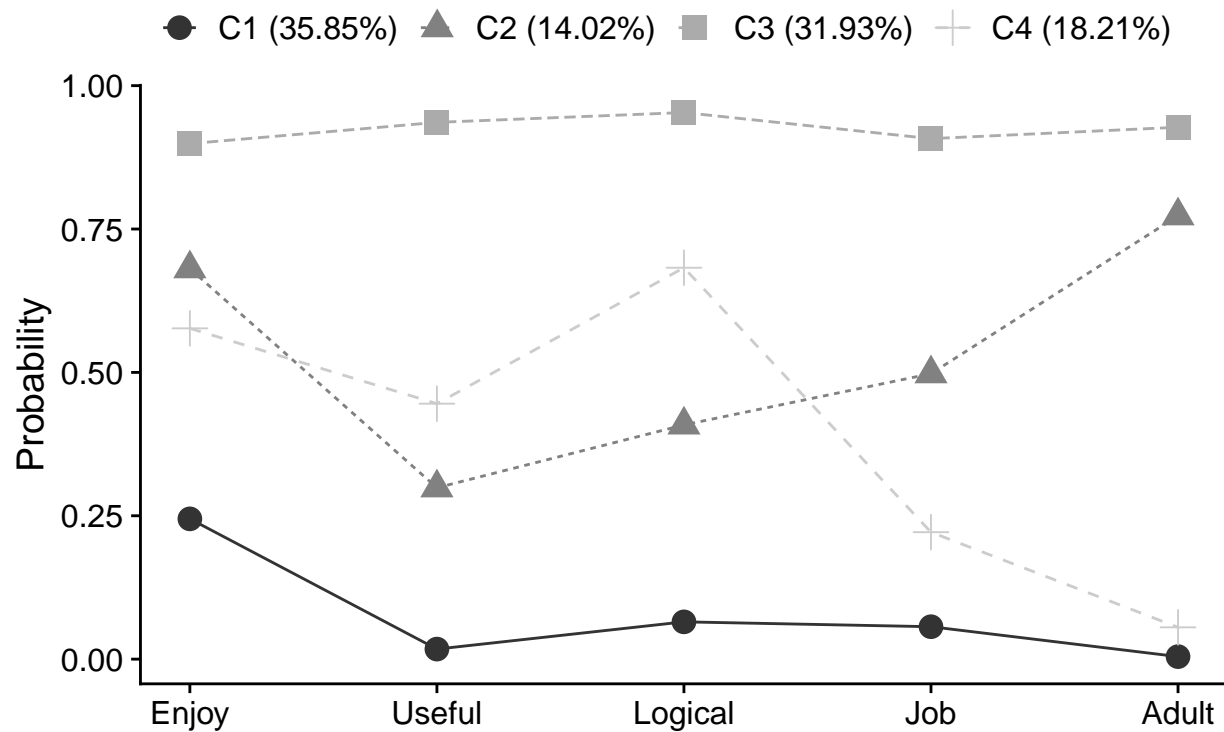


```
ggsave(here("figures", "T1_C4_LCA_plot.png"), dpi=300, height=5, width=7, units="in")
```

Plot time 2 LCA

```
plot_lca_function(  
  model_name = model_t2_c4,  
  item_num = 5,  
  class_num = 4,  
  item_labels = c("Enjoy", "Useful", "Logical", "Job", "Adult"),  
  plot_title = "Time 2 LCA Posterior Probability Plot"  
)
```

Time 2 LCA Posterior Probability Plot



```
ggsave(here("figures", "T2_C4_LCA_plot.png"), dpi=300, height=5, width=7, units="in")
```

Estimate Latent Transition Analysis

Estimate non-invariant estimated LTA model

```
lta_non_inv <- mplusObject(  
  
  TITLE =  
    "4-Class-Non-Invariant",  
  
  VARIABLE =  
    "usev = ab39m ab39t ab39u ab39w ab39x ! 7th grade indicators  
      ga33a ga33h ga33i ga33k ga33l; ! 10th grade indicators  
  
    categorical = ab39m-ab39x ga33a-ga33l;  
  
    classes = c1(4) c2(4);",
```

```

ANALYSIS =
  "estimator = mlr;
  type = mixture;
  starts = 500 100;
  processors=10;";

MODEL =
  "%overall%
  c2 on c1; !!! estimate all multinomial logistic regressions !!!

  !!! The above syntax can also be written as: !!!
      ! c2#1 on c1#1 c1#2 c1#3; !
      ! c2#2 on c1#1 c1#2 c1#3; !
      ! c2#3 on c1#1 c1#2 c1#3; !

  MODEL c1: !!! the following syntax will estimate item thresholds freely !!!
  %c1#1%
  [AB39M$1-AB39X$1];
  %c1#2%
  [AB39M$1-AB39X$1];
  %c1#3%
  [AB39M$1-AB39X$1];
  %c1#4%
  [AB39M$1-AB39X$1];

  MODEL c2:
  %c2#1%
  [GA33A$1-GA33L$1];
  %c2#2%
  [GA33A$1-GA33L$1];
  %c2#3%
  [GA33A$1-GA33L$1];
  %c2#4%
  [GA33A$1-GA33L$1];";

OUTPUT = "tech1 tech15 svalues;";

usevariables = colnames(lsay_data),
rdata = lsay_data)

lta_non_inv_fit <- mplusModeler(lta_non_inv,
  dataout=here("LTA_models", "lta.dat"),
  modelout=here("LTA_models", "4-class-non-invariant.inp"),
  check=TRUE, run = TRUE, hashfilename = FALSE)

```

Estimate invariant LTA model

```
lta_inv <- mplusObject(
```

```

TITLE =
  "4-Class-Invariant",

VARIABLE =
  "usev = ab39m ab39t ab39u ab39w ab39x ! 7th grade indicators
      ga33a ga33h ga33i ga33k ga33l; ! 10th grade indicators

  categorical = ab39m-ab39x ga33a-ga33l;

  classes = c1(4) c2(4);",

ANALYSIS =
  "estimator = mlr;
  type = mixture;
  starts = 500 100;
  processors=10;",

MODEL =
  "%overall%
  c2 on c1;

  MODEL c1:
  %c1#1%
  [AB39M$1-AB39X$1] (1-5);  !!! labels that are repeated will constrain parameters to equality !!!
  %c1#2%
  [AB39M$1-AB39X$1] (6-10);
  %c1#3%
  [AB39M$1-AB39X$1] (11-15);
  %c1#4%
  [AB39M$1-AB39X$1] (16-20);

  MODEL c2:
  %c2#1%
  [GA33A$1-GA33L$1] (1-5);
  %c2#2%
  [GA33A$1-GA33L$1] (6-10);
  %c2#3%
  [GA33A$1-GA33L$1] (11-15);
  %c2#4%
  [GA33A$1-GA33L$1] (16-20);",

SAVEDATA =
  "file = LTA_Inv_CPROBS.dat;
  save = cprob;
  missflag = 9999;",

OUTPUT = "tech1 tech15 svalues;",

usevariables = colnames(lsay_data),
rdata = lsay_data)

lta_inv_fit <- mplusModeler(lta_inv,
  dataout=here("LTA_models", "lta.dat"),

```

```
modelout=here("LTA_models", "4-class-invariant.inp"),
check=TRUE, run = TRUE, hashfilename = FALSE)
```

Conduct Satorra-Bentler χ^2 difference testing

- non-invariant (comparison): This model has **more** parameters.
- invariant (nested): This model has **less** parameters.

```
# *0 = null or nested model & *1 = comparison or parent model

lta_models <- readModels(here("LTA_models"), quiet = TRUE)

T0 <- lta_models[["X4.class.invariant.out"]][["summaries"]][["ChiSqCategoricalLRT_Value"]]
T1 <- lta_models[["X4.class.non.invariant.out"]][["summaries"]][["ChiSqCategoricalLRT_Value"]]
c0 <- lta_models[["X4.class.invariant.out"]][["summaries"]][["LLCorrectionFactor"]]
c1 <- lta_models[["X4.class.non.invariant.out"]][["summaries"]][["LLCorrectionFactor"]]
d0 <- lta_models[["X4.class.invariant.out"]][["summaries"]][["ChiSqCategoricalLRT_DF"]]
d1 <- lta_models[["X4.class.non.invariant.out"]][["summaries"]][["ChiSqCategoricalLRT_DF"]]
df <- abs(d0-d1)

# Satorra-Bentler scaled Difference test equations
cd <- (((d0*c0)-(d1*c1))/(d0-d1))
t <- (((T0*c0)-(T1*c1))/(cd))

t      # Satorra-Bentler chi-square value
df      # difference test degrees of freedom

# Significance test
(p_diff <- pchisq(t, df, lower.tail=FALSE))
```

RESULT: The Satorra-Bentler scaled χ^2 difference test comparing the invariant and non-invariant LTA models was, $T(19) = 20.05, p = .39$.

Alternate, less verbose way to run LTA with the `createMixtures` function.

```
data <- lsay_data %>% select(5:14) # select only the indicator variables

createMixtures(
  classes = 4,
  filename_stem = "sci_attitude",
  model_overall = "c2 ON c1;",
  model_class_specific = c(
    "[ab39m$1] (a{C}); [ab39t$1] (b{C}); [ab39u$1] (c{C}); [ab39w$1] (d{C}); [ab39x$1] (e{C});",
    "[ga33a$1] (a{C}); [ga33h$1] (b{C}); [ga33i$1] (c{C}); [ga33k$1] (d{C}); [ga33l$1] (e{C});",
    rdata = data,
    ANALYSIS = "PROCESSORS IS 10; STARTS = 500 100; PARAMETERIZATION = PROBABILITY;",
    VARIABLE = "CATEGORICAL = ab39m-ab39x ga33a-ga33l;")

runModels(filefilter = "sci_attitude")
```

```
results <- readModels(filefilter = "sci_attitude")
```

Read invariance model and extract parameters (intercepts and multinomial regression coefficients)

```
lta_inv1 <- readModels(here("LTA_models", "4-Class-Invariant.out" ), quiet = TRUE)

par <- as_tibble(lta_inv1[["parameters"]][["unstandardized"]]) %>%
  select(1:3) %>%
  filter(grepl('ON|Means', paramHeader)) %>%
  mutate(est = as.numeric(est))
```

Manual method to calculate transition probabilities:

Although possible to extract transition probabilities directly from the output the following code illustrates how the parameters are used to calculate each transition. This is useful for conducting advanced LTA model specifications such as making specific constraints within or between transition matrices.

```
# Name each parameter individually to make the subsequent calculations more readable
a1 <- unlist(par[13,3]); a2 <- unlist(par[14,3]); a3 <- unlist(par[15,3]); b11 <- unlist(par[1,3]);
b21 <- unlist(par[4,3]); b31 <- unlist(par[7,3]); b12 <- unlist(par[2,3]); b22 <- unlist(par[5,3]);
b32 <- unlist(par[8,3]); b13 <- unlist(par[3,3]); b23 <- unlist(par[6,3]); b33 <- unlist(par[9,3])

# Calculate transition probabilities from the logit parameters
t11 <- exp(a1+b11)/(exp(a1+b11)+exp(a2+b21)+exp(a3+b31)+exp(0))
t12 <- exp(a2+b21)/(exp(a1+b11)+exp(a2+b21)+exp(a3+b31)+exp(0))
t13 <- exp(a3+b31)/(exp(a1+b11)+exp(a2+b21)+exp(a3+b31)+exp(0))
t14 <- 1 - (t11 + t12 + t13)

t21 <- exp(a1+b12)/(exp(a1+b12)+exp(a2+b22)+exp(a3+b32)+exp(0))
t22 <- exp(a2+b22)/(exp(a1+b12)+exp(a2+b22)+exp(a3+b32)+exp(0))
t23 <- exp(a3+b32)/(exp(a1+b12)+exp(a2+b22)+exp(a3+b32)+exp(0))
t24 <- 1 - (t21 + t22 + t23)

t31 <- exp(a1+b13)/(exp(a1+b13)+exp(a2+b23)+exp(a3+b33)+exp(0))
t32 <- exp(a2+b23)/(exp(a1+b13)+exp(a2+b23)+exp(a3+b33)+exp(0))
t33 <- exp(a3+b33)/(exp(a1+b13)+exp(a2+b23)+exp(a3+b33)+exp(0))
t34 <- 1 - (t31 + t32 + t33)

t41 <- exp(a1)/(exp(a1)+exp(a2)+exp(a3)+exp(0))
t42 <- exp(a2)/(exp(a1)+exp(a2)+exp(a3)+exp(0))
t43 <- exp(a3)/(exp(a1)+exp(a2)+exp(a3)+exp(0))
t44 <- 1 - (t41 + t42 + t43)
```

Create transition table

```
t_matrix <- tibble(
  "Time1" = c("C1=1", "C1=2", "C1=3", "C1=4"),
  "C2=1" = c(t11, t21, t31, t41),
  "C2=2" = c(t12, t22, t32, t42),
  "C2=3" = c(t13, t23, t33, t43),
  "C2=4" = c(t14, t24, t34, t44))
```

```
t_matrix %>%
  gt(rowname_col = "Time1") %>%
  tab_stubhead(label = "7th grade") %>%
  tab_header(
    title = md("**Student transitions from 7th grade (rows) to 10th grade (columns)**"),
    subtitle = md("&nbsp;") %>%
  fmt_number(2:5, decimals = 2) %>%
  tab_spanner(label = "10th grade", columns = 2:5)
```

Student transitions from 7th grade (rows) to 10th grade (columns)

7th grade	10th grade			
	C2=1	C2=2	C2=3	C2=4
C1=1	0.27	0.27	0.32	0.15
C1=2	0.09	0.56	0.19	0.16
C1=3	0.15	0.21	0.52	0.12
C1=4	0.08	0.35	0.27	0.30

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