PSC205A Assignment 07: Longitudinal Multivariate

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Read in data

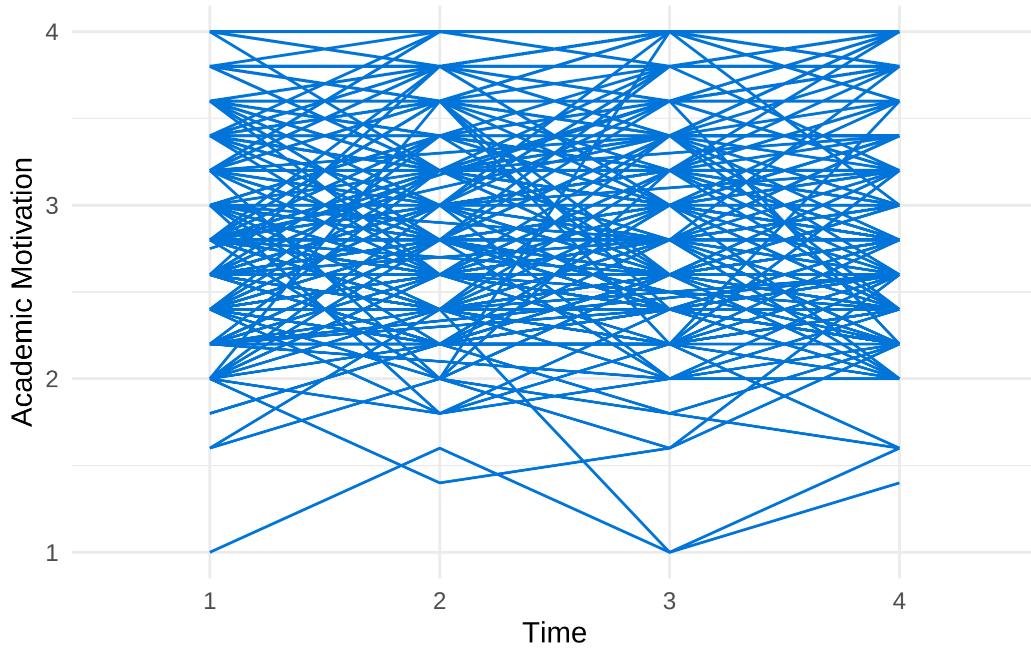
```
library(lavaan)
library(ggplot2)
```

```
mhs <- read.csv("mhs.csv", na.strings = ".")
```

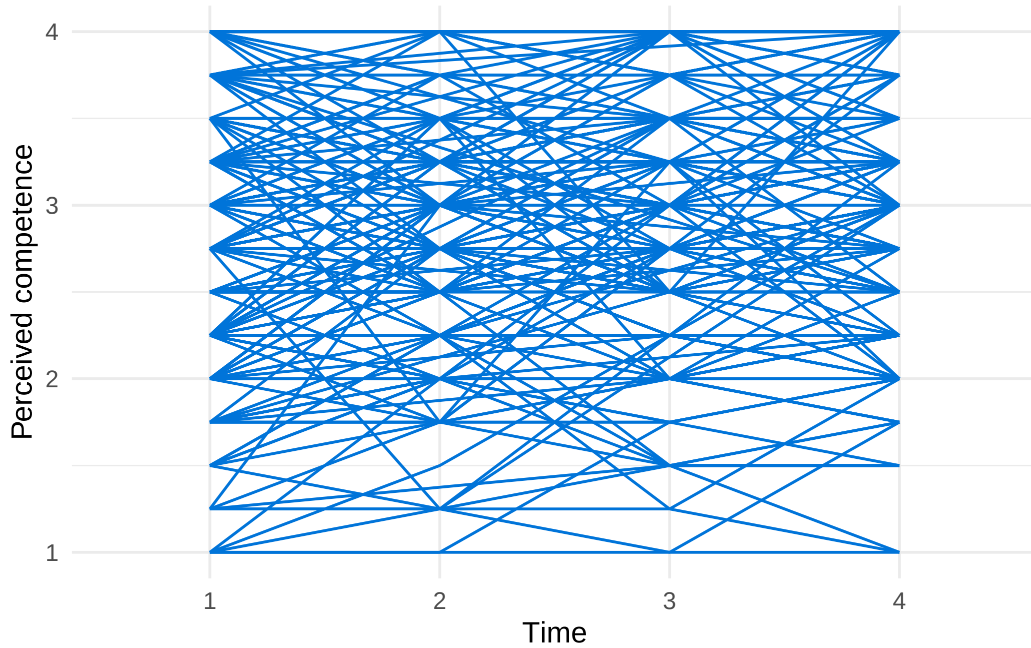
1. Individual trajectories plot

These plots show us that we should not expect an accentuated change over time in academic motivation and perceived competence. It is possible that the results show these variables remain stable over the four time points.

```
mot_data <- mhs |>
  dplyr::select(id, mot1:mot4) |>
  tidyr::pivot_longer(cols = c(mot1:mot4),
                      names_to = "timepoint",
                      names_prefix = "mot",
                      names_transform = as.factor,
                      values_to = "motivation") |>
  dplyr::filter(!is.na(motivation))

ggplot(mot_data, aes(x = timepoint, y = motivation, group = id)) +
  #geom_point()+
  geom_line(color = "#0074D9")+
  theme_minimal()+
  labs(x = "Time", y = "Academic Motivation")
```




```
pc_data <- mhs |>
  dplyr::select(id, pc1:pc4) |>
  tidyr::pivot_longer(cols = c(pc1:pc4),
                      names_to = "timepoint",
                      names_prefix = "pc",
                      names_transform = as.factor,
                      values_to = "competence") |>
  dplyr::filter(!is.na(competence))

ggplot(pc_data, aes(x = timepoint, y = competence, group = id)) +
  #geom_point()+
  geom_line(color = "#0074D9")+
  theme_minimal()+
  labs(x = "Time", y = "Perceived competence")
```



2. Latent Growth model

Both models show a small positive slope, suggesting a slight positive growth of academic motivation and perceived competence over time. Additionally, for both models, the covariance between slope and intercept is non-significantly different from zero, meaning that initial values on the target variable do not influence the expected growth over time.

```
mod_mot <- "i =~ 1*mot1 + 1*mot2 + 1*mot3 + 1*mot4
            s =~ 0*mot1 + 1*mot2 + 2*mot3 + 3*mot4"

fit_mot <- growth(mod_mot, missing="fiml", data=mhs)
```

```
Warning in lav_data_full(data = data, group = group, cluster = cluster, : lavaan WARNING: so
  160 162
```

```
summary(fit_mot, standardized=TRUE)
```

```
lavaan 0.6.16 ended normally after 43 iterations
```

```
  Estimator                                         ML
  Optimization method                           NLMINB
  Number of model parameters                         9

                                                  Used       Total
  Number of observations                           261         263
  Number of missing patterns                        14

Model Test User Model:

  Test statistic                                 4.980
  Degrees of freedom                                 5
  P-value (Chi-square)                           0.418

Parameter Estimates:

  Standard errors                             Standard
  Information                                 Observed
  Observed information based on                Hessian

Latent Variables:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  i =~
    mot1              1.000                               0.453    0.823
    mot2              1.000                               0.453    0.790
    mot3              1.000                               0.453    0.765
    mot4              1.000                               0.453    0.735
  s =~
    mot1              0.000                               0.000    0.000
    mot2              1.000                               0.098    0.171
    mot3              2.000                               0.196    0.331
    mot4              3.000                               0.295    0.477

Covariances:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  i ~~
    s                 0.005    0.008    0.559    0.576    0.104    0.104

Intercepts:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
   .mot1              0.000                               0.000    0.000
   .mot2              0.000                               0.000    0.000
   .mot3              0.000                               0.000    0.000
```

```
   .mot4             0.000                                  0.000    0.000
    i                2.836    0.034   83.492    0.000    6.254    6.254
    s                0.043    0.011    3.838    0.000    0.440    0.440

Variances:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
   .mot1              0.098    0.020    4.939    0.000    0.098    0.323
   .mot2              0.105    0.014    7.667    0.000    0.105    0.318
   .mot3              0.089    0.013    7.005    0.000    0.089    0.253
   .mot4              0.061    0.018    3.370    0.001    0.061    0.160
    i                 0.206    0.029    7.109    0.000    1.000    1.000
    s                 0.010    0.004    2.318    0.020    1.000    1.000
```

```r
mod_pc <- "i =~ 1*pc1 + 1*pc2 + 1*pc3 + 1*pc4
           s =~ 0*pc1 + 1*pc2 + 2*pc3 + 3*pc4"

fit_pc <- growth(mod_pc, missing="fiml",data=mhs)
```

```
Warning in lav_data_full(data = data, group = group, cluster = cluster, : lavaan WARNING: so
  160 162
```

```r
summary(fit_pc , standardized=TRUE)
```

```
lavaan 0.6.16 ended normally after 46 iterations

  Estimator                                         ML
  Optimization method                           NLMINB
  Number of model parameters                         9

                                                  Used       Total
  Number of observations                           261         263
  Number of missing patterns                        14

Model Test User Model:

  Test statistic                                15.293
  Degrees of freedom                                 5
  P-value (Chi-square)                           0.009

Parameter Estimates:
```

```
  Standard errors                             Standard
  Information                                 Observed
  Observed information based on                Hessian

Latent Variables:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  i =~
    pc1               1.000                               0.660    0.876
    pc2               1.000                               0.660    0.904
    pc3               1.000                               0.660    0.951
    pc4               1.000                               0.660    0.932
  s =~
    pc1               0.000                               0.000    0.000
    pc2               1.000                               0.097    0.133
    pc3               2.000                               0.194    0.279
    pc4               3.000                               0.291    0.410

Covariances:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  i ~~
    s                -0.018    0.012   -1.538    0.124   -0.279   -0.279

Intercepts:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
   .pc1               0.000                               0.000    0.000
   .pc2               0.000                               0.000    0.000
   .pc3               0.000                               0.000    0.000
   .pc4               0.000                               0.000    0.000
    i                 2.767    0.046   59.858    0.000    4.192    4.192
    s                 0.066    0.012    5.343    0.000    0.680    0.680

Variances:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
   .pc1               0.132    0.024    5.498    0.000    0.132    0.233
   .pc2               0.123    0.017    7.320    0.000    0.123    0.232
   .pc3               0.080    0.013    6.209    0.000    0.080    0.166
   .pc4               0.088    0.020    4.487    0.000    0.088    0.175
    i                 0.436    0.051    8.552    0.000    1.000    1.000
    s                 0.009    0.005    2.049    0.041    1.000    1.000
```

3. Group differences

Testing for differences in trajectories of perceived competence between males and females, it was found that males (`female = 0`) start at higher values in T1 than females (`female = 1`) but have a less steep slope of latent growth compared to the target group. That indicates that although males start with higher perceived competence, the change over time is more accentuated for females. For both groups, the covariance between intercept and slope is non-significantly different from zero, following the group trend of non-association between rate of change and initial values of perceived competence.

```r
fit_pc_inv <- growth(mod_pc, group = "female", data=mhs)
```

```
Warning in lav_data_full(data = data, group = group, cluster = cluster, : lavaan WARNING: gr
```

```r
summary(fit_pc_inv)
```

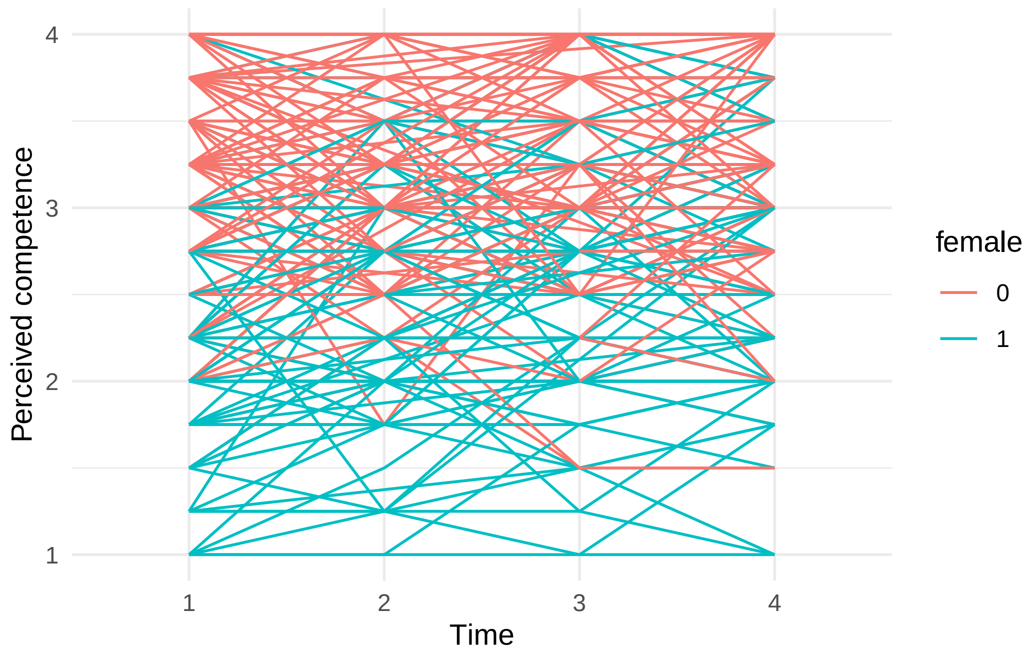
```
lavaan 0.6.16 ended normally after 67 iterations

  Estimator                                         ML
  Optimization method                           NLMINB
  Number of model parameters                        18

  Number of observations per group:               Used       Total
    1                                               68         106
    0                                               85         147

Model Test User Model:

  Test statistic                                17.332
  Degrees of freedom                                10
  P-value (Chi-square)                           0.067
  Test statistic for each group:
    1                                            1.650
    0                                           15.682

Parameter Estimates:

  Standard errors                             Standard
  Information                                 Expected
  Information saturated (h1) model          Structured
```

```
Group 1 [1]:

Latent Variables:
                   Estimate  Std.Err  z-value  P(>|z|)
  i =~
    pc1               1.000
    pc2               1.000
    pc3               1.000
    pc4               1.000
  s =~
    pc1               0.000
    pc2               1.000
    pc3               2.000
    pc4               3.000

Covariances:
                   Estimate  Std.Err  z-value  P(>|z|)
  i ~~
    s                -0.000    0.013   -0.016    0.987

Intercepts:
                   Estimate  Std.Err  z-value  P(>|z|)
   .pc1               0.000
   .pc2               0.000
   .pc3               0.000
   .pc4               0.000
    i                 2.459    0.081   30.407    0.000
    s                 0.083    0.017    4.834    0.000

Variances:
                   Estimate  Std.Err  z-value  P(>|z|)
   .pc1               0.116    0.033    3.513    0.000
   .pc2               0.089    0.020    4.529    0.000
   .pc3               0.078    0.018    4.292    0.000
   .pc4               0.026    0.021    1.233    0.218
    i                 0.375    0.077    4.849    0.000
    s                 0.008    0.005    1.447    0.148


Group 2 [0]:
```

```
Latent Variables:
                   Estimate  Std.Err  z-value  P(>|z|)
  i =~
    pc1               1.000
    pc2               1.000
    pc3               1.000
    pc4               1.000
  s =~
    pc1               0.000
    pc2               1.000
    pc3               2.000
    pc4               3.000

Covariances:
                   Estimate  Std.Err  z-value  P(>|z|)
  i ~~
    s                -0.004    0.013   -0.309    0.757

Intercepts:
                   Estimate  Std.Err  z-value  P(>|z|)
   .pc1               0.000
   .pc2               0.000
   .pc3               0.000
   .pc4               0.000
    i                 3.108    0.063   49.471    0.000
    s                 0.055    0.017    3.296    0.001

Variances:
                   Estimate  Std.Err  z-value  P(>|z|)
   .pc1               0.116    0.031    3.737    0.000
   .pc2               0.131    0.025    5.340    0.000
   .pc3               0.061    0.015    4.033    0.000
   .pc4               0.114    0.027    4.282    0.000
    i                 0.253    0.054    4.681    0.000
    s                 0.001    0.005    0.183    0.855
```

```
pc_data_sex <- mhs |>
  dplyr::select(id, female, pc1:pc4) |>
  tidyr::pivot_longer(cols = c(pc1:pc4),
                      names_to = "timepoint",
                      names_prefix = "pc",
                      names_transform = as.factor,
```

```
                            values_to = "competence") |>
  dplyr::mutate(female = factor(female)) |>
  dplyr::filter(!is.na(competence), !is.na(female))

ggplot(pc_data_sex, aes(x = timepoint, y = competence, group = id, color=female)) +
  #geom_point()+
  geom_line()+
  theme_minimal()+
  labs(x = "Time", y = "Perceived competence")
```



4. Interrelations between perceived competence and motivation

The correlation between motivation and competence intercepts is large and positive, suggesting that participants with higher starting values on motivation also start with higher values on perceived competence and vice-versa. Similar to the individual model analyses, none of the intercepts were significantly associated with the slopes, indicating no relation between starting values and change. However, as with the intercepts, the slopes' correlations of the two latent growths are significant, and positive, meaning that participants who change on one variable tend to change in the other in the same direction.

```r
mod_complete <-
" mot_i =~ 1*mot1 + 1*mot2 + 1*mot3 + 1*mot4
  mot_s =~ 0*mot1 + 1*mot2 + 2*mot3 + 3*mot4

  pc_i =~ 1*pc1 + 1*pc2 + 1*pc3 + 1*pc4
  pc_s =~ 0*pc1 + 1*pc2 + 2*pc3 + 3*pc4
"

fit_complete <- growth(mod_complete,missing="fiml", data=mhs)
```

```
Warning in lav_data_full(data = data, group = group, cluster = cluster, : lavaan WARNING: so
  160 162
```

```r
summary(fit_complete, standardized=TRUE)
```

```
lavaan 0.6.16 ended normally after 87 iterations

  Estimator                                         ML
  Optimization method                           NLMINB
  Number of model parameters                        22

                                                  Used       Total
  Number of observations                           261         263
  Number of missing patterns                        18

Model Test User Model:

  Test statistic                                43.624
  Degrees of freedom                                22
  P-value (Chi-square)                           0.004

Parameter Estimates:

  Standard errors                             Standard
  Information                                 Observed
  Observed information based on                Hessian

Latent Variables:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  mot_i =~
```

```
    mot1              1.000                                     0.460    0.836
    mot2              1.000                                     0.460    0.793
    mot3              1.000                                     0.460    0.771
    mot4              1.000                                     0.460    0.743
  mot_s =~
    mot1              0.000                                     0.000    0.000
    mot2              1.000                                     0.104    0.180
    mot3              2.000                                     0.208    0.349
    mot4              3.000                                     0.312    0.505
  pc_i =~
    pc1               1.000                                     0.663    0.878
    pc2               1.000                                     0.663    0.908
    pc3               1.000                                     0.663    0.941
    pc4               1.000                                     0.663    0.936
  pc_s =~
    pc1               0.000                                     0.000    0.000
    pc2               1.000                                     0.102    0.140
    pc3               2.000                                     0.205    0.291
    pc4               3.000                                     0.307    0.434

Covariances:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  mot_i ~~
    mot_s             0.003    0.008    0.373    0.709    0.064    0.064
    pc_i              0.200    0.028    7.077    0.000    0.656    0.656
    pc_s             -0.002    0.007   -0.371    0.711   -0.053   -0.053
  mot_s ~~
    pc_i              0.010    0.008    1.179    0.238    0.141    0.141
    pc_s              0.003    0.002    1.217    0.224    0.241    0.241
  pc_i ~~
    pc_s             -0.018    0.011   -1.609    0.108   -0.266   -0.266

Intercepts:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
   .mot1              0.000                                     0.000    0.000
   .mot2              0.000                                     0.000    0.000
   .mot3              0.000                                     0.000    0.000
   .mot4              0.000                                     0.000    0.000
   .pc1               0.000                                     0.000    0.000
   .pc2               0.000                                     0.000    0.000
   .pc3               0.000                                     0.000    0.000
   .pc4               0.000                                     0.000    0.000
    mot_i             2.838    0.034   83.412    0.000    6.171    6.171
```

```
    mot_s             0.043    0.011    3.843    0.000    0.413    0.413
    pc_i              2.764    0.046   59.764    0.000    4.172    4.172
    pc_s              0.064    0.012    5.233    0.000    0.627    0.627

Variances:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
   .mot1              0.091    0.019    4.839    0.000    0.091    0.301
   .mot2              0.108    0.014    7.923    0.000    0.108    0.321
   .mot3              0.089    0.012    7.310    0.000    0.089    0.249
   .mot4              0.056    0.017    3.317    0.001    0.056    0.145
   .pc1               0.131    0.023    5.644    0.000    0.131    0.230
   .pc2               0.120    0.016    7.298    0.000    0.120    0.224
   .pc3               0.087    0.013    6.838    0.000    0.087    0.175
   .pc4               0.076    0.019    4.121    0.000    0.076    0.152
    mot_i             0.211    0.029    7.263    0.000    1.000    1.000
    mot_s             0.011    0.004    2.690    0.007    1.000    1.000
    pc_i              0.439    0.051    8.644    0.000    1.000    1.000
    pc_s              0.010    0.004    2.337    0.019    1.000    1.000
```

5. Perceived competence growth curve analysis

```
mod_pc_latent <- "

 PC_1 =~ pc1_1 + pc2_1 + pc3_1 + pc4_1
 PC_2 =~ pc1_2 + pc2_2 + pc3_2 + pc4_2
 PC_3 =~ pc1_3 + pc2_3 + pc3_3 + pc4_3
 PC_4 =~ pc1_4 + pc2_4 + pc3_4 + pc4_4

 PCi =~ 1*PC_1 + 1*PC_2 + 1*PC_3 + 1*PC_4
 PCs =~ 0*PC_1 + 1*PC_2 + 2*PC_3 + 3*PC_4

"
```

Group invariance

Given the non-significant difference in the chi squared tests across the more restricted models, it is possible to assume that males and females are invariant in perceived competence across all levels of measurement invariance, except for the residuals.

```
fit.configural = sem(mod_pc_latent,data=mhs, group="female", missing="fiml", group.equal=c
fit.loadings   = sem(mod_pc_latent,data=mhs, group="female", missing="fiml", group.equal=c
fit.intercepts = sem(mod_pc_latent,data=mhs, group="female", missing="fiml", group.equal=c
fit.varcov     = sem(mod_pc_latent,data=mhs, group="female", missing="fiml", group.equal=c
fit.regress    = sem(mod_pc_latent,data=mhs, group="female", missing="fiml", group.equal=c
fit.invariant  = sem(mod_pc_latent,data=mhs, group="female",
                     group.equal=c("loadings","intercepts", "lv.variances","lv.covariances

anova(fit.configural, fit.loadings, fit.intercepts, fit.varcov, fit.regress, fit.invariant
  knitr::kable(caption = "Multiple group invariance test.", digits=3)
```

Table 1: Multiple group invariance test.

	Df	AIC	BIC	Chisq	Chisq diff	RMSEA	Df diff	Pr(>Chisq)
fit.configural	202	6564.273	6923.869	441.993	NA	NA	NA	NA
fit.loadings	214	6545.497	6862.788	447.217	5.224	0.000	12	0.950
fit.intercepts	224	6531.768	6813.804	453.489	6.271	0.000	10	0.792
fit.varcov	231	6524.699	6782.058	460.420	6.931	0.000	7	0.436
fit.regress	231	6524.699	6782.058	460.420	0.000	0.000	0	NA
fit.invariant	247	4384.317	4555.542	532.668	72.248	0.167	16	0.000

Growth curve

Similar to the results found in `Q2`, the correlation between intercept and slope is negative but non-significant. The growth curve slope of this model was positive, just as found in the analysis using composite scores. However, the statistical significance was not computed because the model failed to converge. We can suppose that this model also shows a positive growth of perceived competence over time.

```
fit_growth <- growth(mod_pc_latent,  missing="fiml", data=mhs)
summary(fit_growth, standardized=TRUE, fit.measures=TRUE)
```

```
lavaan 0.6.16 ended normally after 62 iterations

  Estimator                                         ML
  Optimization method                           NLMINB
  Number of model parameters                        41

                                                  Used       Total
  Number of observations                           261         263
```

```
  Number of missing patterns                        16

Model Test User Model:

  Test statistic                                 278.215
  Degrees of freedom                                 111
  P-value (Chi-square)                             0.000

Model Test Baseline Model:

  Test statistic                                2240.393
  Degrees of freedom                                 120
  P-value                                          0.000

User Model versus Baseline Model:

  Comparative Fit Index (CFI)                      0.921
  Tucker-Lewis Index (TLI)                         0.915

  Robust Comparative Fit Index (CFI)                  NA
  Robust Tucker-Lewis Index (TLI)                     NA

Loglikelihood and Information Criteria:

  Loglikelihood user model (H0)                -3320.338
  Loglikelihood unrestricted model (H1)        -3181.230

  Akaike (AIC)                                  6722.675
  Bayesian (BIC)                                6868.820
  Sample-size adjusted Bayesian (SABIC)         6738.833

Root Mean Square Error of Approximation:

  RMSEA                                            0.076
  90 Percent confidence interval - lower           0.065
  90 Percent confidence interval - upper           0.087
  P-value H_0: RMSEA <= 0.050                      0.000
  P-value H_0: RMSEA >= 0.080                      0.285

  Robust RMSEA                                        NA
  90 Percent confidence interval - lower              NA
  90 Percent confidence interval - upper              NA
  P-value H_0: Robust RMSEA <= 0.050                  NA
```

```
  P-value H_0: Robust RMSEA >= 0.080                NA

Standardized Root Mean Square Residual:

  SRMR                                           0.088

Parameter Estimates:

  Standard errors                             Standard
  Information                                 Observed
  Observed information based on                Hessian

Latent Variables:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  PC_1 =~
    pc1_1             1.000                               0.696    0.725
    pc2_1             0.972    0.020   49.752    0.000    0.676    0.760
    pc3_1             0.930    0.019   47.974    0.000    0.647    0.736
    pc4_1             0.978    0.022   45.169    0.000    0.680    0.695
  PC_2 =~
    pc1_2             1.000                               0.679    0.786
    pc2_2             0.983    0.018   54.136    0.000    0.668    0.764
    pc3_2             0.979    0.017   57.268    0.000    0.664    0.797
    pc4_2             0.989    0.020   50.356    0.000    0.672    0.724
  PC_3 =~
    pc1_3             1.000                               0.652    0.826
    pc2_3             0.973    0.016   61.017    0.000    0.635    0.749
    pc3_3             0.973    0.014   67.379    0.000    0.635    0.801
    pc4_3             0.997    0.017   59.037    0.000    0.650    0.733
  PC_4 =~
    pc1_4             1.000                               0.670    0.856
    pc2_4             0.969    0.015   66.808    0.000    0.649    0.777
    pc3_4             0.929    0.015   60.098    0.000    0.623    0.725
    pc4_4             0.978    0.016   61.529    0.000    0.656    0.737
  PCi =~
    PC_1              1.000                               0.951    0.951
    PC_2              1.000                               0.974    0.974
    PC_3              1.000                               1.014    1.014
    PC_4              1.000                               0.987    0.987
  PCs =~
    PC_1              0.000                               0.000    0.000
    PC_2              1.000                               0.140    0.140
    PC_3              2.000                               0.291    0.291
```

```
    PC_4              3.000                               0.425    0.425

Covariances:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  PCi ~~
    PCs              -0.015    0.012   -1.253    0.210   -0.242   -0.242

Intercepts:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
   .pc1_1             0.000                               0.000    0.000
   .pc2_1             0.000                               0.000    0.000
   .pc3_1             0.000                               0.000    0.000
   .pc4_1             0.000                               0.000    0.000
   .pc1_2             0.000                               0.000    0.000
   .pc2_2             0.000                               0.000    0.000
   .pc3_2             0.000                               0.000    0.000
   .pc4_2             0.000                               0.000    0.000
   .pc1_3             0.000                               0.000    0.000
   .pc2_3             0.000                               0.000    0.000
   .pc3_3             0.000                               0.000    0.000
   .pc4_3             0.000                               0.000    0.000
   .pc1_4             0.000                               0.000    0.000
   .pc2_4             0.000                               0.000    0.000
   .pc3_4             0.000                               0.000    0.000
   .pc4_4             0.000                               0.000    0.000
   .PC_1              1.093 31412.608    0.000    1.000    1.570    1.570
   .PC_2              0.635 29527.481    0.000    1.000    0.934    0.934
   .PC_3              0.221 24972.703    0.000    1.000    0.339    0.339
   .PC_4             -0.194 15557.734   -0.000    1.000   -0.289   -0.289
    PCi               1.754 31412.608    0.000    1.000    2.652    2.652
    PCs               0.495       NA                      5.218    5.218

Variances:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
   .pc1_1             0.437    0.048    9.042    0.000    0.437    0.475
   .pc2_1             0.334    0.039    8.594    0.000    0.334    0.422
   .pc3_1             0.355    0.040    8.965    0.000    0.355    0.459
   .pc4_1             0.496    0.053    9.409    0.000    0.496    0.517
   .pc1_2             0.285    0.034    8.405    0.000    0.285    0.382
   .pc2_2             0.318    0.037    8.584    0.000    0.318    0.416
   .pc3_2             0.253    0.031    8.261    0.000    0.253    0.365
   .pc4_2             0.409    0.046    8.853    0.000    0.409    0.476
   .pc1_3             0.198    0.024    8.208    0.000    0.198    0.318
```

```
.pc2_3              0.315     0.035     9.101     0.000     0.315     0.439
.pc3_3              0.225     0.026     8.720     0.000     0.225     0.359
.pc4_3              0.364     0.039     9.236     0.000     0.364     0.462
.pc1_4              0.164     0.023     7.285     0.000     0.164     0.268
.pc2_4              0.277     0.032     8.719     0.000     0.277     0.396
.pc3_4              0.349     0.038     9.175     0.000     0.349     0.474
.pc4_4              0.361     0.040     9.099     0.000     0.361     0.457
.PC_1               0.047     0.027     1.711     0.087     0.096     0.096
.PC_2               0.045     0.018     2.515     0.012     0.097     0.097
.PC_3               0.013     0.014     0.923     0.356     0.030     0.030
.PC_4               0.021     0.021     1.043     0.297     0.048     0.048
 PCi                0.438     0.053     8.203     0.000     1.000     1.000
 PCs                0.009     0.005     1.915     0.055     1.000     1.000
```

6. Extra

Modeling motivation and competence as latent variables and examining their change yielded results similar to what was found by examining the growth change using composite scores. That is, there is a positive correlation between motivation and competence intercepts but no significant correlation between intercepts and slopes. The slopes of the two latent growths are correlated significantly and positively, just as the results using composite scores. Overall, that means that using composites or modeling the latent factors gives comparable results with little loss of information.

```
mod_complete_latent <- "

 MOT_1 =~ mot1_1 + mot2_1 + mot3_1 + mot4_1
 MOT_2 =~ mot1_2 + mot2_2 + mot3_2 + mot4_2
 MOT_3 =~ mot1_3 + mot2_3 + mot3_3 + mot4_3
 MOT_4 =~ mot1_4 + mot2_4 + mot3_4 + mot4_4

 MOTi =~ 1*MOT_1 + 1*MOT_2 + 1*MOT_3 + 1*MOT_4
 MOTs =~ 0*MOT_1 + 1*MOT_2 + 2*MOT_3 + 3*MOT_4

 PC_1 =~ pc1_1 + pc2_1 + pc3_1 + pc4_1
 PC_2 =~ pc1_2 + pc2_2 + pc3_2 + pc4_2
 PC_3 =~ pc1_3 + pc2_3 + pc3_3 + pc4_3
 PC_4 =~ pc1_4 + pc2_4 + pc3_4 + pc4_4

 PCi =~ 1*PC_1 + 1*PC_2 + 1*PC_3 + 1*PC_4
 PCs =~ 0*PC_1 + 1*PC_2 + 2*PC_3 + 3*PC_4
```

```
"
```

```
fit_growth_complete <- growth(mod_complete_latent,  missing="fiml", data=mhs)
summary(fit_growth_complete, standardized=TRUE, fit.measures=TRUE)
```

```
lavaan 0.6.16 ended normally after 106 iterations

  Estimator                                         ML
  Optimization method                           NLMINB
  Number of model parameters                        86

                                                  Used       Total
  Number of observations                           261         263
  Number of missing patterns                        21

Model Test User Model:

  Test statistic                              1117.411
  Degrees of freedom                               474
  P-value (Chi-square)                           0.000

Model Test Baseline Model:

  Test statistic                              3880.742
  Degrees of freedom                               496
  P-value                                        0.000

User Model versus Baseline Model:

  Comparative Fit Index (CFI)                    0.810
  Tucker-Lewis Index (TLI)                       0.801

  Robust Comparative Fit Index (CFI)                NA
  Robust Tucker-Lewis Index (TLI)                   NA

Loglikelihood and Information Criteria:

  Loglikelihood user model (H0)              -7131.999
  Loglikelihood unrestricted model (H1)      -6573.293

  Akaike (AIC)                               14435.997
```

```
  Bayesian (BIC)                             14742.546
  Sample-size adjusted Bayesian (SABIC)      14469.890

Root Mean Square Error of Approximation:

  RMSEA                                          0.072
  90 Percent confidence interval - lower         0.067
  90 Percent confidence interval - upper         0.078
  P-value H_0: RMSEA <= 0.050                    0.000
  P-value H_0: RMSEA >= 0.080                    0.009

  Robust RMSEA                                      NA
  90 Percent confidence interval - lower            NA
  90 Percent confidence interval - upper            NA
  P-value H_0: Robust RMSEA <= 0.050                NA
  P-value H_0: Robust RMSEA >= 0.080                NA

Standardized Root Mean Square Residual:

  SRMR                                           0.095

Parameter Estimates:

  Standard errors                             Standard
  Information                                 Observed
  Observed information based on                Hessian

Latent Variables:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  MOT_1 =~
    mot1_1            1.000                               0.466    0.632
    mot2_1            0.646    0.019   33.438    0.000    0.301    0.328
    mot3_1            0.919    0.019   49.674    0.000    0.428    0.504
    mot4_1            0.862    0.019   46.497    0.000    0.401    0.468
  MOT_2 =~
    mot1_2            1.000                               0.493    0.570
    mot2_2            0.753    0.021   36.075    0.000    0.371    0.428
    mot3_2            0.980    0.022   44.501    0.000    0.483    0.556
    mot4_2            0.911    0.021   43.382    0.000    0.449    0.538
  MOT_3 =~
    mot1_3            1.000                               0.506    0.662
    mot2_3            0.709    0.019   37.163    0.000    0.359    0.393
    mot3_3            0.945    0.018   52.679    0.000    0.478    0.568
```

mot4_3	0.874	0.017	50.570	0.000	0.442	0.544
MOT_4 =~						
mot1_4	1.000				0.553	0.651
mot2_4	0.714	0.019	37.661	0.000	0.395	0.436
mot3_4	0.912	0.019	48.454	0.000	0.504	0.572
mot4_4	0.875	0.018	48.146	0.000	0.484	0.568
MOTi =~						
MOT_1	1.000				0.980	0.980
MOT_2	1.000				0.927	0.927
MOT_3	1.000				0.903	0.903
MOT_4	1.000				0.826	0.826
MOTs =~						
MOT_1	0.000				0.000	0.000
MOT_2	1.000				0.176	0.176
MOT_3	2.000				0.343	0.343
MOT_4	3.000				0.470	0.470
PC_1 =~						
pc1_1	1.000				0.697	0.725
pc2_1	0.973	0.019	49.925	0.000	0.678	0.765
pc3_1	0.930	0.019	47.793	0.000	0.649	0.735
pc4_1	0.978	0.022	45.075	0.000	0.682	0.695
PC_2 =~						
pc1_2	1.000				0.679	0.789
pc2_2	0.984	0.018	54.408	0.000	0.668	0.765
pc3_2	0.979	0.017	57.291	0.000	0.665	0.795
pc4_2	0.989	0.020	50.457	0.000	0.672	0.723
PC_3 =~						
pc1_3	1.000				0.664	0.833
pc2_3	0.971	0.016	61.549	0.000	0.645	0.756
pc3_3	0.971	0.014	67.613	0.000	0.645	0.804
pc4_3	0.995	0.017	59.011	0.000	0.661	0.736
PC_4 =~						
pc1_4	1.000				0.670	0.853
pc2_4	0.970	0.015	66.627	0.000	0.650	0.778
pc3_4	0.930	0.015	60.113	0.000	0.623	0.728
pc4_4	0.979	0.016	61.277	0.000	0.656	0.737
PCi =~						
PC_1	1.000				0.953	0.953
PC_2	1.000				0.979	0.979
PC_3	1.000				1.001	1.001
PC_4	1.000				0.993	0.993
PCs =~						
PC_1	0.000				0.000	0.000

```
    PC_2              1.000                               0.150    0.150
    PC_3              2.000                               0.306    0.306
    PC_4              3.000                               0.456    0.456

Covariances:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  MOTi ~~
    MOTs              0.011    0.012    0.940    0.347    0.279    0.279
    PCi               0.225    0.032    7.124    0.000    0.741    0.741
    PCs              -0.005    0.008   -0.601    0.548   -0.098   -0.098
  MOTs ~~
    PCi               0.006    0.010    0.552    0.581    0.096    0.096
    PCs               0.004    0.003    1.475    0.140    0.432    0.432
  PCi ~~
    PCs              -0.016    0.012   -1.346    0.178   -0.234   -0.234

Intercepts:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
   .mot1_1            0.000                               0.000    0.000
   .mot2_1            0.000                               0.000    0.000
   .mot3_1            0.000                               0.000    0.000
   .mot4_1            0.000                               0.000    0.000
   .mot1_2            0.000                               0.000    0.000
   .mot2_2            0.000                               0.000    0.000
   .mot3_2            0.000                               0.000    0.000
   .mot4_2            0.000                               0.000    0.000
   .mot1_3            0.000                               0.000    0.000
   .mot2_3            0.000                               0.000    0.000
   .mot3_3            0.000                               0.000    0.000
   .mot4_3            0.000                               0.000    0.000
   .mot1_4            0.000                               0.000    0.000
   .mot2_4            0.000                               0.000    0.000
   .mot3_4            0.000                               0.000    0.000
   .mot4_4            0.000                               0.000    0.000
   .pc1_1             0.000                               0.000    0.000
   .pc2_1             0.000                               0.000    0.000
   .pc3_1             0.000                               0.000    0.000
   .pc4_1             0.000                               0.000    0.000
   .pc1_2             0.000                               0.000    0.000
   .pc2_2             0.000                               0.000    0.000
   .pc3_2             0.000                               0.000    0.000
   .pc4_2             0.000                               0.000    0.000
   .pc1_3             0.000                               0.000    0.000
```

```
    .pc2_3            0.000                                        0.000    0.000
    .pc3_3            0.000                                        0.000    0.000
    .pc4_3            0.000                                        0.000    0.000
    .pc1_4            0.000                                        0.000    0.000
    .pc2_4            0.000                                        0.000    0.000
    .pc3_4            0.000                                        0.000    0.000
    .pc4_4            0.000                                        0.000    0.000
    .MOT_1            1.282       NA                               2.752    2.752
    .MOT_2            0.627       NA                               1.272    1.272
    .MOT_3            0.274       NA                               0.541    0.541
    .MOT_4           -0.214       NA                              -0.387   -0.387
     MOTi             1.968       NA                               4.310    4.310
     MOTs             0.532       NA                               6.138    6.138
    .PC_1             1.093       NA                               1.567    1.567
    .PC_2             0.630       NA                               0.927    0.927
    .PC_3             0.223       NA                               0.335    0.335
    .PC_4            -0.194       NA                              -0.289   -0.289
     PCi              1.752       NA                               2.634    2.634
     PCs              0.494       NA                               4.856    4.856

Variances:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
    .mot1_1           0.326    0.037    8.826    0.000    0.326    0.600
    .mot2_1           0.752    0.073   10.240    0.000    0.752    0.893
    .mot3_1           0.538    0.059    9.098    0.000    0.538    0.746
    .mot4_1           0.574    0.060    9.591    0.000    0.574    0.781
    .mot1_2           0.505    0.055    9.197    0.000    0.505    0.676
    .mot2_2           0.612    0.063    9.660    0.000    0.612    0.816
    .mot3_2           0.522    0.060    8.697    0.000    0.522    0.691
    .mot4_2           0.494    0.054    9.166    0.000    0.494    0.710
    .mot1_3           0.328    0.036    9.006    0.000    0.328    0.562
    .mot2_3           0.703    0.070   10.005    0.000    0.703    0.845
    .mot3_3           0.481    0.053    9.136    0.000    0.481    0.678
    .mot4_3           0.465    0.048    9.587    0.000    0.465    0.704
    .mot1_4           0.417    0.046    9.098    0.000    0.417    0.577
    .mot2_4           0.666    0.068    9.808    0.000    0.666    0.810
    .mot3_4           0.522    0.057    9.144    0.000    0.522    0.672
    .mot4_4           0.491    0.052    9.475    0.000    0.491    0.677
    .pc1_1            0.440    0.049    9.064    0.000    0.440    0.475
    .pc2_1            0.326    0.038    8.580    0.000    0.326    0.415
    .pc3_1            0.358    0.040    8.999    0.000    0.358    0.460
    .pc4_1            0.498    0.053    9.431    0.000    0.498    0.517
    .pc1_2            0.279    0.033    8.430    0.000    0.279    0.377
```

.pc2_2	0.317	0.037	8.624	0.000	0.317	0.415
.pc3_2	0.258	0.031	8.332	0.000	0.258	0.368
.pc4_2	0.412	0.046	8.891	0.000	0.412	0.477
.pc1_3	0.195	0.024	8.187	0.000	0.195	0.306
.pc2_3	0.311	0.034	9.090	0.000	0.311	0.428
.pc3_3	0.228	0.026	8.725	0.000	0.228	0.353
.pc4_3	0.369	0.040	9.246	0.000	0.369	0.458
.pc1_4	0.169	0.023	7.477	0.000	0.169	0.273
.pc2_4	0.275	0.031	8.802	0.000	0.275	0.394
.pc3_4	0.345	0.037	9.223	0.000	0.345	0.470
.pc4_4	0.361	0.039	9.165	0.000	0.361	0.456
.MOT_1	0.008	0.031	0.277	0.782	0.039	0.039
.MOT_2	0.005	0.022	0.208	0.835	0.019	0.019
.MOT_3	-0.027	0.018	-1.465	0.143	-0.105	-0.105
.MOT_4	-0.036	0.028	-1.319	0.187	-0.119	-0.119
MOTi	0.208	0.037	5.653	0.000	1.000	1.000
MOTs	0.008	0.006	1.286	0.198	1.000	1.000
.PC_1	0.044	0.026	1.697	0.090	0.091	0.091
.PC_2	0.041	0.017	2.365	0.018	0.088	0.088
.PC_3	0.021	0.014	1.536	0.124	0.048	0.048
.PC_4	0.008	0.020	0.423	0.672	0.018	0.018
PCi	0.442	0.053	8.315	0.000	1.000	1.000
PCs	0.010	0.005	2.252	0.024	1.000	1.000