Research Study 2022.003.Generalized-TRL-Scale

Study Completed November 26, 2023

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# Introduction

This R Notebook is for analyzing the content validity, inter-rater reliability, and intra-rater reliability of the Generalized Technology Readiness Level (GTRL) scale developed by Dr. Malcolm S. Townes.

# Project Setup

## Enable R Notebook Integration

The following code chunk enables the R Notebook to integrate seamlessly with the project organization format. This is normally included in the R Notebook to simplify file calls and enable file portability but it has been causing an error. Per Dr. Chris Prener, formerly a professor at Saint Louis University, the error is generated because the here::here() function has not been tested with certain combinations of functions. To work around this problem, the here() function is embedded when necessary where a file path is specified.

knitr::opts\_knit$set(root.dir = here::here())

## Load Dependencies

The following code chunk loads package dependencies required to perform the necessary tasks. Basic tasks include importing, reading, wrangling, and cleaning data; selecting a subset of the data; checking for unique observations, and analyzing missing data.

library(tidyverse) # loads the basic R packages  
#library(DescTools) # tools for descriptive statistics  
#library(expss) # tables  
library(here) # enables file portability  
library(irr) # various statistics for inter-rater reliability  
library(ICC) # estimation of Intraclass Correlation Coefficient  
library(readr) # functions for reading data  
library(dplyr) # functions for data wrangling  
library(janitor) # functions for data cleaning  
library(lme4) # linear mixed-effects models using 'Eigen' and S4  
library(naniar) # functions for analyzing missing data  
#library(memisc) # management of survey data and presentation of analysis results  
#library(methods) # functions in methods  
#library (modeest)# estimators of the mode of univariate data or univariate distributions  
#library(openxlsx) # read, write, and format Microsoft Excel files  
library(psych) # procedures for psychological, psychometric, and personality research  
library(psychometric) #applied psychometric theory  
library(readxl) # read Microsoft Excel files  
#library(XML) # tools for generating and parsing XML files  
#library(xml2) # tools for parsing XML files

# Analysis

## Import Data

The following code chunk imports the raw data used for the analysis.

# Content Validity Data  
dataCV <- read\_excel("Data/DataRaw/2022.003.GeneralizedTRL\_Validity\_NumericValues\_2023-10-31\_15.19.xlsx", sheet="Sheet0", col\_names = TRUE)  
  
# Reliability Data Time 1  
dataT1 <- read\_excel("Data/DataRaw/2022.003.GeneralizedTRL\_Phase-01\_NumericResponses\_2023-07-19\_08.48.xlsx", sheet="Sheet1", col\_names = TRUE)  
  
# Reliability Data Time 2  
dataT2 <- read\_excel("Data/DataRaw/2022.003.GeneralizedTRL\_Phase-02\_NumericResponses\_2023-10-14\_15.11.xlsx", sheet="Sheet1", col\_names = TRUE)

## Wrangle Data

### Data for Content Validity

The following code chunk selects and cleans the data that will be used for calculating the measures of content validity.

# Select data and create variables  
dataCV %>%  
 dplyr::select(., -c(1:22)) %>%  
 .[-c(1),] %>%  
 t(.) %>%  
 head(., -6) %>%  
 as.data.frame(.) %>%  
 rename("Rater1" = "V1", "Rater2" = "V2") %>%  
 mutate(Ne1 = if\_else(as.numeric(.$Rater1) == 3.0, 1, 0)) %>%  
 mutate(Ne2 = if\_else(as.numeric(.$Rater2) == 3.0, 1, 0)) %>%  
 mutate(Ne = Ne1 + Ne2) %>%  
 mutate(CVR = CVratio(2, as.numeric(Ne))) -> dataCV.clean  
  
# Subset item clarity data  
dataCV.clean %>%  
 .[c(1:10),] -> dataCV.item.clarity  
  
# subset item usefulness data  
dataCV.clean %>%  
 .[c(71:80),] -> dataCV.item.useful

### Data for Reliability

The following code chunk selects the specific data that will be used for calculating the various measures of inter-rater reliability.

# Time 1 Data  
dataT1 %>%  
 .[-c(1:2,13:23),] %>%  
 dplyr::select (-RowContent) %>%  
 mutate\_if (is.character, ~replace\_na(.,"")) %>%  
 mutate\_all (., as.numeric) -> dataT1.ICC   
  
dataT1.four <- dplyr::select(dataT1.ICC, -Rater05)  
  
# Time 2 Data  
dataT2 %>%  
 .[-c(1),] %>%  
 dplyr::select (-RowContent) %>%  
 mutate\_all (., as.numeric) -> dataT2.ICC  
  
dataT2.four <- dataT2.ICC

## Analysis of Content Validity Data

### Calculate Content Validity Index

The following code chunk calculates the content validity ratios for each item in the instrument.

# Calculate CVI for Unmodified Instrument  
CVI.clarity = sum(dataCV.item.clarity$CVR)/nrow(dataCV.item.clarity)  
CVI.useful = sum(dataCV.item.useful$CVR)/nrow(dataCV.item.useful)

## Analysis of Time 1 Reliability Data

### Calculate Alternative Measures of Inter-rater Reliability for Time 1 Reliability Data

The following code chunk calculates the intraclass correlation coefficient using various methods and Krippendorff’s alpha reliability coefficient.

cat("ICC Calculation - Agreement: 5 Raters, 10 Technologies, 44 Ratings {'irr' package}", "\n", "\n")

## ICC Calculation - Agreement: 5 Raters, 10 Technologies, 44 Ratings {'irr' package}   
##

IRRICC1a.T1 <- icc(dataT1.ICC, model = "twoway", type = "agreement", unit = "single", r0=0, conf.level = 0.95)  
IRRICC1a.T1

## Single Score Intraclass Correlation  
##   
## Model: twoway   
## Type : agreement   
##   
## Subjects = 4   
## Raters = 5   
## ICC(A,1) = -0.2  
##   
## F-Test, H0: r0 = 0 ; H1: r0 > 0   
## F(3,4.62) = 0.262 , p = 0.85   
##   
## 95%-Confidence Interval for ICC Population Values:  
## -0.28 < ICC < 0.398

cat("ICC Calculation - Consistency: 5 Raters, 10 Technologies, 44 Ratings {'irr' package}", "\n", "\n")

## ICC Calculation - Consistency: 5 Raters, 10 Technologies, 44 Ratings {'irr' package}   
##

IRRICC1c.T1 <- icc(dataT1.ICC, model = "twoway", type = "consistency", unit = "single", r0=0, conf.level = 0.95)  
IRRICC1c.T1

## Single Score Intraclass Correlation  
##   
## Model: twoway   
## Type : consistency   
##   
## Subjects = 4   
## Raters = 5   
## ICC(C,1) = -0.173  
##   
## F-Test, H0: r0 = 0 ; H1: r0 > 0   
## F(3,12) = 0.262 , p = 0.851   
##   
## 95%-Confidence Interval for ICC Population Values:  
## -0.232 < ICC < 0.356

cat("\n", "ICC Calculation: 5 Raters, 10 Technologies, 44 Ratings {'psych' package}", "\n", "\n")

##   
## ICC Calculation: 5 Raters, 10 Technologies, 44 Ratings {'psych' package}   
##

IRRICC1b.T1 <- ICC(dataT1.ICC, missing=FALSE, alpha=0.05, lmer=TRUE)  
IRRICC1b.T1

## Call: ICC(x = dataT1.ICC, missing = FALSE, alpha = 0.05, lmer = TRUE)  
##   
## Intraclass correlation coefficients   
## type ICC F df1 df2 p lower bound upper bound  
## Single\_raters\_absolute ICC1 -0.0015 0.99 9 40 0.46 -0.14 0.33  
## Single\_random\_raters ICC2 0.0000 1.00 9 36 0.46 -0.13 0.33  
## Single\_fixed\_raters ICC3 0.0000 1.00 9 36 0.46 -0.14 0.34  
## Average\_raters\_absolute ICC1k -0.0077 0.99 9 40 0.46 -1.47 0.71  
## Average\_random\_raters ICC2k 0.0000 1.00 9 36 0.46 -1.46 0.71  
## Average\_fixed\_raters ICC3k 0.0000 1.00 9 36 0.46 -1.49 0.72  
##   
## Number of subjects = 10 Number of Judges = 5  
## See the help file for a discussion of the other 4 McGraw and Wong estimates,

cat("\n", "\n", "\n", "Krippendorff's Alpha Reliability Coefficient Calculation: 5 Raters, 10 Technologies, 44 Ratings {'irr' package}", "\n", "\n")

##   
##   
##   
## Krippendorff's Alpha Reliability Coefficient Calculation: 5 Raters, 10 Technologies, 44 Ratings {'irr' package}   
##

# Put data into the correct form for the 'kripp.alpha' function  
dataT1.ICC %>%  
 t(.) -> dataT1.Kripp  
  
# Calculate Krippendorff's alpha  
IRRkripp.T1 <- kripp.alpha(dataT1.Kripp, "ordinal")  
IRRkripp.T1

## Krippendorff's alpha  
##   
## Subjects = 10   
## Raters = 5   
## alpha = -0.0538

cat("\n", "\n", "\n", "ICC Calculation - Agreement: 4 Raters, 10 Technologies, 40 Ratings {'irr' package}", "\n", "\n")

##   
##   
##   
## ICC Calculation - Agreement: 4 Raters, 10 Technologies, 40 Ratings {'irr' package}   
##

IRRICC2a.T1 <- icc(dataT1.four, model = "twoway", type = "agreement", unit = "single", r0=0, conf.level = 0.95)  
IRRICC2a.T1

## Single Score Intraclass Correlation  
##   
## Model: twoway   
## Type : agreement   
##   
## Subjects = 10   
## Raters = 4   
## ICC(A,1) = -0.137  
##   
## F-Test, H0: r0 = 0 ; H1: r0 > 0   
## F(9,23.3) = 0.535 , p = 0.834   
##   
## 95%-Confidence Interval for ICC Population Values:  
## -0.262 < ICC < 0.195

cat("\n", "\n", "\n", "ICC Calculation - Consistency: 4 Raters, 10 Technologies, 40 Ratings {'irr' package}", "\n", "\n")

##   
##   
##   
## ICC Calculation - Consistency: 4 Raters, 10 Technologies, 40 Ratings {'irr' package}   
##

IRRICC2c.T1 <- icc(dataT1.four, model = "twoway", type = "consistency", unit = "single", r0=0, conf.level = 0.95)  
IRRICC2c.T1

## Single Score Intraclass Correlation  
##   
## Model: twoway   
## Type : consistency   
##   
## Subjects = 10   
## Raters = 4   
## ICC(C,1) = -0.132  
##   
## F-Test, H0: r0 = 0 ; H1: r0 > 0   
## F(9,27) = 0.535 , p = 0.836   
##   
## 95%-Confidence Interval for ICC Population Values:  
## -0.249 < ICC < 0.187

cat("\n", "ICC Calculation: 4 Raters, 10 Technologies, 40 Ratings {'psych' package}", "\n", "\n")

##   
## ICC Calculation: 4 Raters, 10 Technologies, 40 Ratings {'psych' package}   
##

IRRICC2b.T1 <- ICC(dataT1.four, missing=FALSE, alpha=0.05, lmer=TRUE)  
IRRICC2b.T1

## Call: ICC(x = dataT1.four, missing = FALSE, alpha = 0.05, lmer = TRUE)  
##   
## Intraclass correlation coefficients   
## type ICC F df1 df2 p lower bound upper bound  
## Single\_raters\_absolute ICC1 0 1 9 30 0.46 -0.18 0.39  
## Single\_random\_raters ICC2 0 1 9 27 0.46 -0.18 0.39  
## Single\_fixed\_raters ICC3 0 1 9 27 0.46 -0.18 0.39  
## Average\_raters\_absolute ICC1k 0 1 9 30 0.46 -1.57 0.72  
## Average\_random\_raters ICC2k 0 1 9 27 0.46 -1.63 0.72  
## Average\_fixed\_raters ICC3k 0 1 9 27 0.46 -1.63 0.72  
##   
## Number of subjects = 10 Number of Judges = 4  
## See the help file for a discussion of the other 4 McGraw and Wong estimates,

## Analysis of Time 2 Reliability Data

### Calculate Alternative Measures of Inter-rater Reliability for Time 2 Reliability Data

The following code chunk calculates the intraclass correlation coefficient using various methods and Krippendorff’s alpha reliability coefficient.

cat("ICC Calculation: 4 Raters, 10 Technologies, 40 Ratings {'irr' package", "\n", "\n")

## ICC Calculation: 4 Raters, 10 Technologies, 40 Ratings {'irr' package   
##

IRRICC1a.T2 <- icc(dataT2.ICC, model = "twoway", type = "agreement", unit = "single", r0=0, conf.level = 0.95)  
IRRICC1a.T2

## Single Score Intraclass Correlation  
##   
## Model: twoway   
## Type : agreement   
##   
## Subjects = 10   
## Raters = 4   
## ICC(A,1) = 0.208  
##   
## F-Test, H0: r0 = 0 ; H1: r0 > 0   
## F(9,29.3) = 2.06 , p = 0.0678   
##   
## 95%-Confidence Interval for ICC Population Values:  
## -0.053 < ICC < 0.612

cat("ICC Calculation - Consistency: 5 Raters, 10 Technologies, 44 Ratings {'irr' package}", "\n", "\n")

## ICC Calculation - Consistency: 5 Raters, 10 Technologies, 44 Ratings {'irr' package}   
##

IRRICC1c.T2 <- icc(dataT2.ICC, model = "twoway", type = "consistency", unit = "single", r0=0, conf.level = 0.95)  
IRRICC1c.T2

## Single Score Intraclass Correlation  
##   
## Model: twoway   
## Type : consistency   
##   
## Subjects = 10   
## Raters = 4   
## ICC(C,1) = 0.209  
##   
## F-Test, H0: r0 = 0 ; H1: r0 > 0   
## F(9,27) = 2.06 , p = 0.0712   
##   
## 95%-Confidence Interval for ICC Population Values:  
## -0.058 < ICC < 0.615

cat("\n", "ICC Calculation: 4 Raters, 10 Technologies, 40 Ratings {'psych' package}", "\n", "\n")

##   
## ICC Calculation: 4 Raters, 10 Technologies, 40 Ratings {'psych' package}   
##

IRRICC1b.T2 <- ICC(dataT2.ICC, missing=FALSE, alpha=0.05, lmer=TRUE)  
IRRICC1b.T2

## Call: ICC(x = dataT2.ICC, missing = FALSE, alpha = 0.05, lmer = TRUE)  
##   
## Intraclass correlation coefficients   
## type ICC F df1 df2 p lower bound upper bound  
## Single\_raters\_absolute ICC1 0.21 2.0 9 30 0.068 -0.054 0.61  
## Single\_random\_raters ICC2 0.21 2.1 9 27 0.071 -0.053 0.61  
## Single\_fixed\_raters ICC3 0.21 2.1 9 27 0.071 -0.058 0.61  
## Average\_raters\_absolute ICC1k 0.51 2.0 9 30 0.068 -0.258 0.86  
## Average\_random\_raters ICC2k 0.51 2.1 9 27 0.071 -0.255 0.86  
## Average\_fixed\_raters ICC3k 0.51 2.1 9 27 0.071 -0.278 0.86  
##   
## Number of subjects = 10 Number of Judges = 4  
## See the help file for a discussion of the other 4 McGraw and Wong estimates,

cat("\n", "\n", "\n", "Krippendorff's Alpha Reliability Coefficient Calculation: 4 Raters, 10 Technologies, 40 Ratings {'irr' package}", "\n", "\n")

##   
##   
##   
## Krippendorff's Alpha Reliability Coefficient Calculation: 4 Raters, 10 Technologies, 40 Ratings {'irr' package}   
##

# Put data into the correct form for the 'kripp.alpha' function  
dataT2.ICC %>%  
 t(.) -> dataT2.Kripp  
  
# Calculate Krippendorff's alpha  
IRRkripp.T2 <- kripp.alpha(dataT2.Kripp, "ordinal")  
IRRkripp.T2

## Krippendorff's alpha  
##   
## Subjects = 10   
## Raters = 4   
## alpha = 0.208

cat("\n", "\n", "\n", "ICC Calculation - Agreement: 4 Raters, 10 Technologies, 40 Ratings {irr' package}", "\n", "\n")

##   
##   
##   
## ICC Calculation - Agreement: 4 Raters, 10 Technologies, 40 Ratings {irr' package}   
##

IRRICC2a.T2 <- icc(dataT2.four, model = "twoway", type = "agreement", unit = "single", r0=0, conf.level = 0.95)  
IRRICC2a.T2

## Single Score Intraclass Correlation  
##   
## Model: twoway   
## Type : agreement   
##   
## Subjects = 10   
## Raters = 4   
## ICC(A,1) = 0.208  
##   
## F-Test, H0: r0 = 0 ; H1: r0 > 0   
## F(9,29.3) = 2.06 , p = 0.0678   
##   
## 95%-Confidence Interval for ICC Population Values:  
## -0.053 < ICC < 0.612

cat("\n", "\n", "\n", "ICC Calculation - Consistency: 4 Raters, 10 Technologies, 40 Ratings {irr' package}", "\n", "\n")

##   
##   
##   
## ICC Calculation - Consistency: 4 Raters, 10 Technologies, 40 Ratings {irr' package}   
##

IRRICC2c.T2 <- icc(dataT2.four, model = "twoway", type = "consistency", unit = "single", r0=0, conf.level = 0.95)  
IRRICC2c.T2

## Single Score Intraclass Correlation  
##   
## Model: twoway   
## Type : consistency   
##   
## Subjects = 10   
## Raters = 4   
## ICC(C,1) = 0.209  
##   
## F-Test, H0: r0 = 0 ; H1: r0 > 0   
## F(9,27) = 2.06 , p = 0.0712   
##   
## 95%-Confidence Interval for ICC Population Values:  
## -0.058 < ICC < 0.615

cat("\n", "ICC Calculation: 4 Raters, 10 Technologies, 40 Ratings {'psych' package}", "\n", "\n")

##   
## ICC Calculation: 4 Raters, 10 Technologies, 40 Ratings {'psych' package}   
##

IRRICC2b.T2 <- ICC(dataT2.four, missing=FALSE, alpha=0.05, lmer=TRUE)  
IRRICC2b.T2

## Call: ICC(x = dataT2.four, missing = FALSE, alpha = 0.05, lmer = TRUE)  
##   
## Intraclass correlation coefficients   
## type ICC F df1 df2 p lower bound upper bound  
## Single\_raters\_absolute ICC1 0.21 2.0 9 30 0.068 -0.054 0.61  
## Single\_random\_raters ICC2 0.21 2.1 9 27 0.071 -0.053 0.61  
## Single\_fixed\_raters ICC3 0.21 2.1 9 27 0.071 -0.058 0.61  
## Average\_raters\_absolute ICC1k 0.51 2.0 9 30 0.068 -0.258 0.86  
## Average\_random\_raters ICC2k 0.51 2.1 9 27 0.071 -0.255 0.86  
## Average\_fixed\_raters ICC3k 0.51 2.1 9 27 0.071 -0.278 0.86  
##   
## Number of subjects = 10 Number of Judges = 4  
## See the help file for a discussion of the other 4 McGraw and Wong estimates,

## Analysis of Intra-Rater Reliabiltiy

### Select Data

The following code chunk selects and prepares the specific data that will be used for calculating the various measures of intra-rater reliability.

# Extract Time 1 Data  
dataT1 %>%  
 .[-c(1:2,13:23),] %>%  
 rename ("Tech" = "RowContent") %>%  
 pivot\_longer(2:6, names\_to = "Rater", values\_to = "RatingT1") %>%  
 arrange (Rater, Tech) %>%  
 dplyr::select (., Rater, Tech, everything()) -> data.TRT1  
  
# Extract Time 2 Data  
dataT2 %>%  
 .[-c(1),] %>%  
 rename ("Tech" = "RowContent") %>%  
 pivot\_longer(2:5, names\_to = "Rater", values\_to = "RatingT2") %>%  
 arrange (Rater, Tech) %>%  
 dplyr::select (., Rater, Tech, everything()) -> data.TRT2  
  
# Merge Data  
data.TRT <- merge(data.TRT1, data.TRT2, by=c("Rater", "Tech"))  
  
# Isolate Ratings Data  
data.TRT %>%  
 dplyr::select (-c(1:2)) %>%  
 mutate\_all (., as.numeric) -> data.TRT.ratings

### Calculate Alternative Measures of Intra-rater Reliability

The following code chunk calculates the intraclass correlation coefficient using various methods.

cat("ICC Calculation: 4 Raters, 10 Technologies, 80 Ratings {'irr' package", "\n", "\n")

## ICC Calculation: 4 Raters, 10 Technologies, 80 Ratings {'irr' package   
##

TRT.ICC1a <- icc(data.TRT.ratings, model = "twoway", type = "agreement", unit = "single", r0=0, conf.level = 0.95)  
TRT.ICC1a

## Single Score Intraclass Correlation  
##   
## Model: twoway   
## Type : agreement   
##   
## Subjects = 40   
## Raters = 2   
## ICC(A,1) = 0.557  
##   
## F-Test, H0: r0 = 0 ; H1: r0 > 0   
## F(39,39) = 3.45 , p = 9.55e-05   
##   
## 95%-Confidence Interval for ICC Population Values:  
## 0.297 < ICC < 0.739

cat("ICC Calculation - Consistency: 4 Raters, 10 Technologies, 80 Ratings {'irr' package", "\n", "\n")

## ICC Calculation - Consistency: 4 Raters, 10 Technologies, 80 Ratings {'irr' package   
##

TRT.ICC1c <- icc(data.TRT.ratings, model = "twoway", type = "consistency", unit = "single", r0=0, conf.level = 0.95)  
TRT.ICC1c

## Single Score Intraclass Correlation  
##   
## Model: twoway   
## Type : consistency   
##   
## Subjects = 40   
## Raters = 2   
## ICC(C,1) = 0.551  
##   
## F-Test, H0: r0 = 0 ; H1: r0 > 0   
## F(39,39) = 3.45 , p = 9.56e-05   
##   
## 95%-Confidence Interval for ICC Population Values:  
## 0.292 < ICC < 0.734

cat("\n", "ICC Calculation: 4 Raters, 10 Technologies, 80 Ratings {'psych' package}", "\n", "\n")

##   
## ICC Calculation: 4 Raters, 10 Technologies, 80 Ratings {'psych' package}   
##

TRT.ICC1b <- ICC(data.TRT.ratings, missing=FALSE, alpha=0.05, lmer=TRUE)  
TRT.ICC1b

## Call: ICC(x = data.TRT.ratings, missing = FALSE, alpha = 0.05, lmer = TRUE)  
##   
## Intraclass correlation coefficients   
## type ICC F df1 df2 p lower bound upper bound  
## Single\_raters\_absolute ICC1 0.56 3.5 39 40 6.2e-05 0.31 0.74  
## Single\_random\_raters ICC2 0.56 3.5 39 39 7.2e-05 0.31 0.74  
## Single\_fixed\_raters ICC3 0.56 3.5 39 39 7.2e-05 0.30 0.74  
## Average\_raters\_absolute ICC1k 0.72 3.5 39 40 6.2e-05 0.47 0.85  
## Average\_random\_raters ICC2k 0.72 3.5 39 39 7.2e-05 0.47 0.85  
## Average\_fixed\_raters ICC3k 0.72 3.5 39 39 7.2e-05 0.47 0.85  
##   
## Number of subjects = 40 Number of Judges = 2  
## See the help file for a discussion of the other 4 McGraw and Wong estimates,

cat("\n", "\n", "\n", "Krippendorff's Alpha Reliability Coefficient Calculation: 4 Raters, 10 Technologies, 80 Ratings {'irr' package}", "\n", "\n")

##   
##   
##   
## Krippendorff's Alpha Reliability Coefficient Calculation: 4 Raters, 10 Technologies, 80 Ratings {'irr' package}   
##

# Put data into the correct form for the 'kripp.alpha' function  
data.TRT.ratings %>%  
 t(.) -> data.intra.Kripp  
  
# Calculate Krippendorff's alpha  
IRR.Kripp.Intra <- kripp.alpha(data.intra.Kripp, "ordinal")  
IRR.Kripp.Intra

## Krippendorff's alpha  
##   
## Subjects = 40   
## Raters = 2   
## alpha = 0.531