Journal of Research Initiatives

Volume 6
Issue 1 *Inclusive and Multicultural Education* Article 2

June 2022

Does the mathematics self-concept explain the gender-gap in advanced mathematics achievement among US secondary school students?

Asitha Kodippili
Fayetteville State University

Deepthika C. Senaratne
Fayetteville State University

Does the mathematics self-concept explain the gender-gap in advanced mathematics achievement among US secondary school students?

About the Author(s)

Asitha Kodippili is an Associate Professor in the Dept. of Mathematics & Computer Science at Fayetteville State University, USA.

Deepthika Senaratne is an Associate Professor in the Dept. of Mathematics & Computer Science at Fayetteville State University, USA.

Keywords

TIMSS, USA, self-concept, achievement, advanced-mathematics.

Does the Mathematics Self-Concept Explain the Gender-Gap In Advanced Mathematics Achievement Among Us Secondary School Students?

Asitha Kodippili, Fayetteville State University
Deepthika C. Senaratne, Fayetteville State University

Abstract

This study examines the role of self-concept regarding mathematical ability in explaining the gender gap in advanced mathematics performance of US high school students. The study is based on data generated from the Third International Mathematics and Science Study (TIMSS 1995 – 2015), a large-scale project which investigated the relationship between self-concept in mathematics and mathematical achievement. In the US, secondary school males in advanced mathematics classes consistently show a statistically significant higher mathematics self-concept than females. Male students also consistently have significantly higher mathematical achievement scores than females. However, by controlling for the mathematics self-concept, we found that this gender gap in achievement decreased by one third. These results indicate that self-concept in mathematics is an essential variable accounting for gender differences in high school students' achievement levels in advanced mathematics.

Introduction

Based on TIMSS 2007-2011-2015 (Mullis et al., 2016), trends in mathematics achievement by gender revealed no statistically significant gender gap in performance in mathematics of 8th-grade students in the U.S. However, there is a *statistically significant* difference in average ***advanced mathematics*** achievement in U.S. 12th grade students in favor of the male. Among all the countries participating in the study, the U.S. had the most significant gender gap on advanced mathematical achievement assessments, with males significantly outperforming females. This was not because there were so many males in the classes and so few females in them, as participation in advanced mathematics in the U.S. is 51% males and 49% females.

United States students had the highest difference in average advanced mathematics achievement in favor of males. In the U.S. (Mullis, Martin, Foy & Hooper, 2016), U.S. students had the highest difference in average advanced mathematics achievement in favor of males among all the participating countries. Another possible explanation for this variation in advanced mathematics performance is students' perception and evaluation of mathematics, i.e., their self-concept in mathematics. Recent research has documented the high self-concept's critical role in academic achievement (Byrne, 1984; Marsh & Yeung, 1997; Valentine, Dubois, & Cooper, 2004). Academic self-concept, a sub-domain of general self-concept, is defined as a student's self-perception of their academic ability formed with peers, teachers, and parents (Marsh, 1987; Liu & Wang, 2008). In addition, self-belief and motivational variables such as self-concept and interest influence students’ willingness to engage and actively participate in learning activities and are associated with favorable long-term results (Bandaru, 1997; Nagy, Trautwein, Baumert, Köller, & Garrett, 2006).

Many studies have investigated the relationship between self-concept and achievement in mathematics education (Wilkins, Zembylas, and Travers, 2002; Wilkins, 2004; Wang, 2007; Goldman and Penner, 2016). However, recent large-scale comparative studies suggest conflicting findings between self-concept and student achievement across nations. For example, using TIMSS data, Wilkins (2004) reported a positive relationship between self-concept and mathematics achievement in 16 different countries. However, Kifer’s analysis (2002) indicated that many of the highest-performing countries had some of the lowest overall beliefs in student self-ability.

Some studies took the approach of "self-as-doer" and chose a single item, "I like mathematics, or I usually do well in mathematics," as the self-concept construct (Wilkins 2004). The existing literature suggests two significant aspects of self-concept, the **self-as-doer** and the **self-as-object** (James 1890; Shavelson, Hubner, & Stanton, 1976; Marsh and Shavelson, 1985). The multidimensional self-concept construct is essential for reliable results, and according to Marsh (1990a, 1990b). Therefore, it is vital to use at least three domain-specific reliable indicators for latent constructs.

Three large-scale international comparative projects have gathered student responses to both aspects of the self-concept factor mentioned above to find out more about the relationship between academic self-concept in mathematics and achievement. The three projects were 1) *The Program for International Student Assessment* (PISA 2000-2015), the *Third International Mathematics and Science Study* (TIMSS 1995 – 2015), and the *TIMSS-Advanced* (1995 – 2015). For instance, aiming to capture the self-concept in mathematics for 12th-grade students pursuing advanced mathematics courses, the *TIMSS-Advanced* study gathered student responses to the following survey questions:

Get absorbed?

Sense of satisfaction?

Feel bored?

Like studying math?

Interesting to learn theory?

Dread math class?

Like learning new things?

Challenging mathematics?

Favorite subject?

Math jobs interesting?

Wish not have to study math?

Think in terms of math?

Unlike these three international studies, most research on self-concept and mathematics achievement is based on elementary and middle school level general mathematics achievement. Also, usually, the self-concept construct is based on one or a few self-as-doer domain-specific indicators. Therefore, this study constructs the latent variable "index of self-concept in mathematics" using student responses to **self-as-doer** (9 -questions) and **self-as-object** (3 – questions). Then examine the contribution of gender difference in self-concept in mathematics to the gender gap in achievement in advanced mathematics of 12th-grade students in the USA using the *TIMSS-Advanced*-2015 data set.

The research questions that guide this investigation are:

1. Is there a statistically significant relationship between gender and students' self-concept in mathematics?

2. Does mathematics self-concept explain the differences in advanced mathematics achievement?
3. Does the mathematics self-concept influence the magnitude of gender differences in advanced mathematics achievement in the U.S.?

Method

As previously noted, the data for this study is drawn from the *Third International Mathematics and Science* (TIMMS) advanced database. The database comprises student achievement results in advanced mathematics and physics and student, teacher, school, and curricular background questionnaire data for the ten countries. The data for this study is the 12th grade USA students. A total of 2954 (female = 1506, male = 1448) from a sample of 241 schools participated in the TIMSS-Advanced program in 2015. Participants ages ranged from 15 to 21 (mean = 18.10, sd = 0.40). This study is based on 2889 complete cases due to some missing data related to the study's variables.

TIMSS employs a two-stage stratified & cluster sample design, with a sample of schools drawn as a first stage and one or more classes of students selected from each of the sampled schools as a second stage. The mathematics assessment framework (Mullis, Martin, 2014) for TIMSS Advanced-Mathematics is organized around two dimensions; **content domains** algebra, calculus, and geometry, and **cognitive domains**: knowing, applying, and reasoning.

TIMSS assesses the ability of the whole student body based on a large number of assessment items. However, to keep the individual student burden to a minimum, it administered a limited number of assessment items to each student. As a result, given their background characteristics, student scores are transformed using Item response theory (IRT) into 5-plausible values to characterize student participation in assessment. Plausible values represent an individual's performance on the entire assessment might have been having it been observed. Our statistical analysis uses the student's advanced **mathematics achievement** (5-plausible values), appropriate sampling weights provided in the data set, the participants' responses to 12 survey questions, and gender. In addition, we use the 12-Items of interest in the survey to construct self-concept in mathematics; all of these items are Likert type with four points strongly agree (1) to strongly disagree (4). Table 1 represents the twelve items of interest and response results. Figure 3 in Appendix A shows the correlation matrix of those responses.

Description	***Strongly Agree***	***Agree***	***Dis-agree***	***Strongly Disagree***
Get absorbed (A)	958	1333	436	162
Sense of Satisfaction (B)	1985	741	116	47
Feel bored (C)	516	1195	914	264
Like studying math (D)	118	739	1135	834
Interesting to learn theory (E)	560	1062	743	524
Dread Math Class (F)	306	610	1027	946
Like learning new things (G)	788	1229	655	217
Challenging Mathematics (H)	1222	1088	425	154
Favorite Subject (I)	1154	831	483	421
Math jobs interesting (J)	914	878	632	465
Wish not have to study math	261	517	912	1199
Think in terms of math (L)	543	921	857	568

Table 1: Variables of the study and participants' response results

Self-Concept Construct

We used latent class analysis (LCA) (Lazarsfeld, 1950) to construct the mathematical self-concept. LCA is a statistical method to identify unobserved subpopulations of individuals based on their observed values on a set of categorical or nominal indicators in cross-sectional data. LCA uses maximum likelihood estimation to fit a hypothesized model in which membership in each number of latent classes is related to performance on the included indicators and produces fitted probabilities of class membership for individuals. We estimate the class membership probabilities (i.e., the probability for an individual's membership in a specific class) and the item response probabilities conditional upon class membership (i.e., the probability for an individual to provide a detailed response to a specific item given that she or he has been classified in a specific latent class). According to the item response probabilities, observations are grouped into classes.

Finding the optimal number of latent classes follows a stepwise process that combines the statistical model fitting indicators, Akaike information criterion (AIC), Bayesian information criterion (BIC), and model usefulness indicators such as interpretability of the classes. We used R-package *POLCA* (Drew et al., 2016) in latent class analysis. Based on the above model fitting indicators, we found 5-classes with class member shares (19.4%, 30.6%, 22.4%, 21.4%, and

6.2%) as the preferred model. Class membership share indicates the probability that a student belongs to a particular class. We labeled them as *very-high*, *high*, *average*, *low, and very-low math* self-concept classes, respectively.

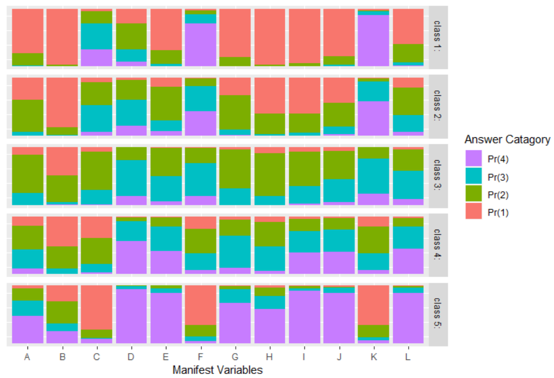

Figure 1: Class-specific probabilities of 4-answers for the five latent class model of the students' responses.

The height of the stack bars represents class-specific response probabilities. For example, class 1 has high probabilities of responding strongly agree on **self-as-doer** indicators A, B, E, G, H, I, J, and L and high probabilities of responding strongly disagree on **self-as-object** indicators F and K. On the other hand, class 5 has high probabilities of responding strongly agree on all **self-as-object** indicators C, F, and K. Class 2 has high probabilities of responding strongly agree or agree on all **self-as-doer** indicators and a high probability of strongly disagree or disagree in **self-as-object** indicators. Interestingly, the indicator "*Like Studying Math (D),*" which many researchers have used as the proxy for self-concept, has less than 25% strongly agree with responses probability even among the students in the very high self-concept group. This shows the importance of using multiple indicators of both self-as-doer and self-as-object to construct a latent variable (Marsh, 19901, 1990b).

Exploratory Data Analysis

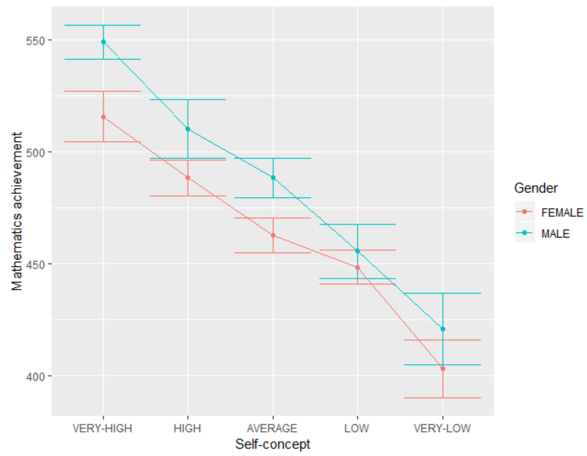

Figure 2: Relationship between performance and index of self-concept in mathematics

As shown in Figure 2 (mean and 1-std. plot), expressing a positive self-concept in mathematics is closely related to advanced mathematics performance. The result is similar for both males and females. In particular, at the high end of the self-concept index, the male achievement score is higher than the female. However, there are also some gender differences in mathematics self-concept. As shown in Table 2, a high percentage of males have an average to a very-high self-concept index value compared to females. The overall average and standard deviation of self-concept for males and females are 2.450 (0.054), 2.787 (0.064), respectively. The self-concept variable is reverse coded, very-high = 1, and very-low = 5.

Gender	Self-concept	# Students	%
Female	Very High	232	15.8
	High	437	29.7
	Average	307	20.8
	Low	384	26.0
	Very Low	113	7.7
Male	Very High	333	23.5
	High	449	31.7
	Average	339	23.9
	Low	236	16.7
	Very Low	59	4.2

Table 2: Gender and Self-concept distribution

Statistical Analysis

To address research questions two and three of the present study, we used the multilevel linear model (Goldstein, 1987; Raudenbush & Bryk, 2002) and the BIEFESURVEY package in R. Unconditional mean model (Assume no covariates for both student and school level)
The unconditional mean model facilitates examining variation in the outcome variable (mathematics achievement score) across level-2 units (schools).

Level 1 (student level): $y_{ij} = \beta_{0j} + e_{ij}$, $e_{ij} \sim N(0, \sigma^2)$

Level 2 (school level): $\beta_{0j} = \gamma_{00} + u_{0j}$, $u_{0j} \sim N(0, {\tau_{00}}^2)$

This gives the combine model: $y_{ij} = \gamma_{00} + u_{0j} + e_{ij}$

In the context of our analysis, we can redefine these variables as follows:

y_{ij} : achievement score of student i in school j

β_{0j} : mean achievement score for school j

γ_{00} : (Grand mean) or mean of the means of achievement score of each school

u_{0j} : random effect of the jth school on the intercept

e_{ij} : random error associated with student i in school j

σ^2 : known as the within-group variance

${\tau_{00}}^2$: known as a between-group variance.

The ratio of the between-group variation to the total variance $\frac{{\tau_0}^2}{\sigma^2 + {\tau_{00}}^2}$ is defined as the intra-class correlation (ICC or ρ).

Results

Research Question 1: Is there a relationship between gender and students' self-concept in mathematics?

We use the chi-squared test of association to answer research question one.

Self-concept	Female	Male
Very High	232 (288.1)	333 (276.9)
High	437 (451.7)	449 (434.3)
Average	307 (329.4)	339 (316.6)
Low	384 (316.1)	236 (303.9)
Very Low	113 (87.7)	59 (84.3)

Table 3: Chi-squared test of independence

There is an association between gender and students' self-concept in mathematics. While 23.5% of male students have a very-high self-concept in mathematics, only 15.8% of females have a very-high self-concept in mathematics. Also, 33.7% of the females exhibit low or very-low self-concept, but only 21.1% of males exhibit low or very-low self-concept in mathematics. The Chi-squared test of independence results of *the p*-value (< 0.0001) indicates that these variables are not independent of each other and that there is a statistically significant relationship between gender and self-concept in mathematics.

Research Question 2: Does mathematics self-concept explain the differences in advanced mathematics achievement?

To answer research question two, we first ran the null model and then added the self-concept variable to the student level of the null model.

	Null Model			*Model 1*		
Fixed effects	*Coefficient*	*Std. Error*	*P.value*	*Coefficient*	*Std. Error*	*P.value*
Intercept: γ_{00}	*489.6*	*5.34*	*<0.01*	*489.6*	*5.7*	*<0.01*
Self-concept (γ_{10})				*-27.9*	*2.7*	*<0.01**
Random effect	*variance*					
Intercept (u_{0j}): $\tau_{00}{}^2$	*4911*	*781*		*5012*	*853*	*<0.01*
Level 1 (e_{ij}): σ^2	*5496*	*155*		*4416*	*120*	*<0.01*

Table 4: Results from Hierarchical Linear Modeling

Unconditional mean model results implied that the population of student achievement scores y_{ij} has an estimated mean of 487.8 and a standard deviation of $\sqrt{5496 + 4911}$ = 102. The school population means β_{0j} has an estimated mean of 394.4 and a standard deviation of $\sqrt{4911}$ = 70. The interclass correlation of 0.47 is a statistically significant p-value (< 0.05). This significantly large interclass correlation justifies the use of multilevel modeling in our statistical analysis. Also, a significant value of ρ means that there are many differences between schools, so the school a student belongs to has a significant effect on student achievement scores.

The result shown in model 1 (Table 4) indicates a statistically significant association between self-concept and advanced mathematics achievement ($\gamma_{10} = -28.3$). The self-concept variable is centered on mean and reversed coded.

Research Question 3: Does the mathematic self-concept influence the magnitude of gender difference in advanced mathematics achievement in the U.S.?

To answer the last research question, we first ran a model with gender and then added self-concept and an interaction term gender X Self-concept to the model. Unfortunately, the interaction term self-concept X gender is not statistically significant (Table 5). However, in the interaction term self-concept & gender, the model shows a decrease in gender effect from 30.7 to 21.4, about a 30% decrease in gender-gap.

	Model 1		*Model 2*			
Fixed effects	*Coefficient*	*Std. Error*	*Coefficient*	*Std. Error*	*Coefficient*	*Std. Error*
Intercept: γ_{00}	*473.9*	*5.29*	*477.9*	*5.44*	*478.2*	
Gender: γ_{10} *(female = 0)*	*30.7*	*5.81*	*21.3*	*4.41*	*21.4*	
Self-concept			*-24.5*	*3.09*	*-26.6*	
Self-concept X Gender			*-4.5*	*3.95*		
Random effect	*variance*					
Intercept (u_{0j} *):* ${\tau_{00}}^2$	*4904*	*803*	*4955*	*869*		
Level 1 (e_{ij})*:* σ^2	*5296*	*166*	*4326*	*128*		

Table 5: Hierarchical Linear Model Results

Conclusion

In this study, we investigated the relationship between gender and self-concept in mathematics among secondary school students pursuing advanced mathematics, self-concept in mathematics, performance in advanced mathematics, and the influence of self-concept on the gender gap in advanced mathematics achievement. The study began by constructing a self-concept variable from the student responses to the 12 survey questions using latent class analysis. The chi-squared independent test indicated an association between gender and self-concept in mathematics. The exploratory analysis showed that the higher the self-concept level, the higher the achievement. The result was the same for both male and female students and supported the Marsh and Yeung (1997) results of similar research. At the high end of the self-concept category, male students' mathematics achievement is significantly higher than that of girls.

Finally, we examined the predictability of self-concept in mathematics achievement using multilevel linear model analysis. The analysis was conducted to determine whether self-concept is a significant predictor of mathematics achievement and whether the interaction of gender and self-concept affects mathematics achievement. The results show that self-concept is a significant predictor of mathematics achievement. The interaction of gender and self-concept is not statistically significant. However, controlling for self-concept, gender had a decreasing effect on mathematics achievement. Male-female self-concept differences explain about a third of the gender gap in advanced mathematics performance.

References

Goldman, A.D., & Penner, A. M (2016). Exploring international gender differences in mathematics self-concept. *International Journal of Adolescence and Youth, 21(4)*, 403-418.

Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York: Freeman.

Byrne, B. (1984). The general/academic self-concept nomological network: A review of construct validation research. *Review of Educational Research, 54*(3), 427-456.

Drew A. Linzer, Jeffrey B. Lewis (2011). POLCA: An R Package for Polytomous Variable Latent Class Analysis. *Journal of Statistical Software, 42(10)*, 1-29. http://www.jstatsoft.org/v42/i10/.

Goldstein, H. (1987). *Multilevel models in educational and social research*. London: Griffin.

James, W. (1890). *Principles of psychology* (Vol. 1). New York: Holt.

Lazarsfeld, P. F. (1950). *The logical and mathematical foundation of latent structure analysis. In S. A. Stouffer, et al. (Eds), Measurement and Prediction (pp. 361–412)*. Princeton, NJ: Princeton University Press.

Liu, W. C., & Wang, C. K. J. (2005). Academic self-concept: a cross-sectional study of grade and gender differences in a Singapore secondary school. *Asia Pacific Education Review, 6(1)*, 20-27.

Marsh, H. W. (1987). The big-fish-little-pond effect on academic self-concept. *Journal of Educational Psychology, 79*, 280 –295.

Marsh, H.W. (1990a). Causal ordering of academic self-concept and academic achievement: a multi-wave, longitudinal panel analysis. *Journal of Educational Psychology*. *82*(4), 646-656.

Marsh, H. W. (1990b). A multidimensional, hierarchical self-concept: Theoretical and empirical justification. *Educational Psychology Review, 2*, 77-172.

Marsh, H. W., & Shavelson, R. (1985). Self-concept: its multifaceted, hierarchical structure. *Educational Psychologist, 20*, 107–125.

Marsh, H. W., & Yeung, A. S. (1997). Causal effects of academic self-concept on academic achievement: Structural equation models of longitudinal data. *Journal of Educational Psychology, 89*(1), 41-54.

Mullis, I.V.S. & Martin, M.O. (Eds.) (2014). *TIMMS Advanced 2015 Assessment Frameworks*. http://timssandpirls.bc.edu/timss2015-advanced/frameworks.html

Mullis, I. V. S., Martin, M. O., Foy, P., & Hooper, M. (2016). *TIMSS 2015 International Results in Mathematics*. Retrieved from Boston College, TIMSS & PIRLS International Study Center website: http://timssandpirls.bc.edu/timss2015/international-results/

Mullis, I. V. S., Martin, M. O., Foy, P., & Hooper, M. (2016). *TIMSS Advanced 2015 International Results in Advanced Mathematics and Physics*. http://timssandpirls.bc.edu/timss2015/international-results/advanced/

Nagy, G., Trautwein, U., Baumert, J., Köller, O., & Garrett, J. (2006). Gender and course selection in upper secondary education: Effects of academic self-concept and intrinsic value. *Educational Research and Evaluation, 12(4)*, 323–345.

Raudenbush, S. W., & Bryk, A. S. (2002). *Hierarchical linear models (2nd ed.)*. Thousand Oaks, CA: Sage

Shavelson, R. J., Hubner, J. J., & Stanton, G. C. (1976). Validation of construct interpretations r*eview of Educational Research, 46,* 407–441.

Valentine, J. C., Dubois, D. L., & Cooper, H. (2004). The relations between self-beliefs and academic achievement: A systematic review. *Educational Psychologist, 39*(2), 111-133.

Wang, J. (2007). A trend study of self-concept and mathematics achievement in a cross-cultural context. *Mathematics Education Research Journal, 19(3)*, 40-54.

Wilkins, J. L. M. (2004). Mathematics and science self-concept: An international investigation. *The Journal of Experimental Education, 72(4)*, 331-346.

Wilkins, J. L. M., Zembylas, M., & Travers, K. J. (2002). *Investigating correlates of mathematics and science literacy in the final year of secondary school. In D. F. Robitaille & A. E. Beaton (Eds.), Secondary analysis of the TIMSS results A synthesis of current research*. Boston, MA: Kluwer Academic Publishers.

Attachment

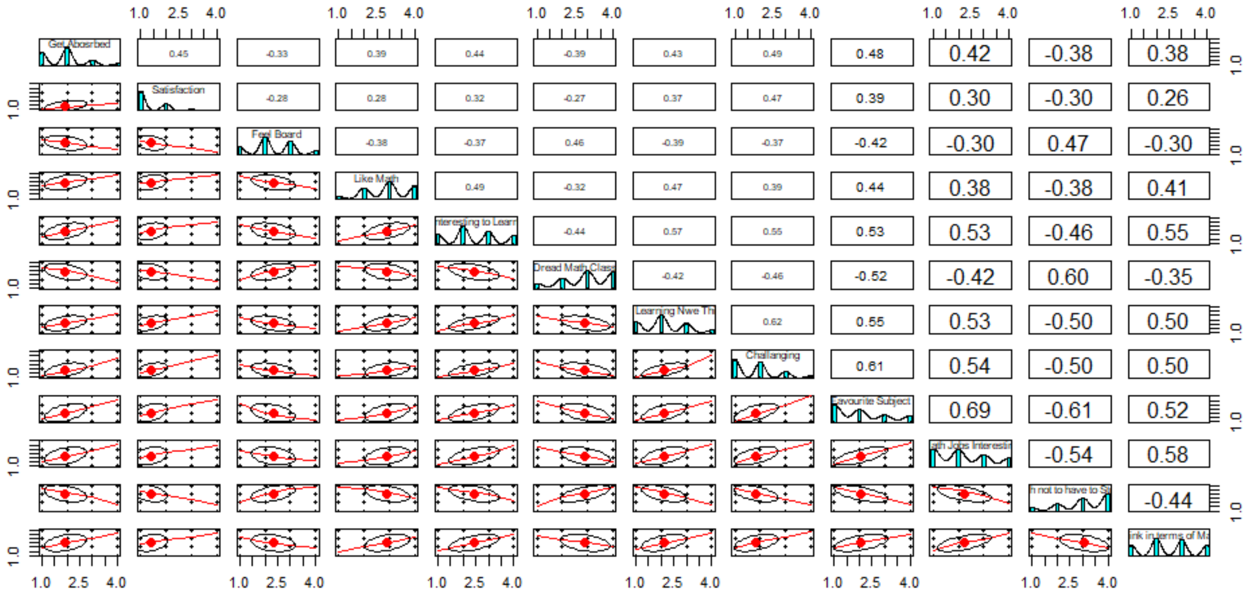

Figure 3: Correlation matrix of variables used for the self-concept construct.