Models Describing Secondary-School Students' Opinions and Attitudes Toward Mathematics

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Abstract In this research, we create some new models which additionally explain some aspects of students' motivation to learn mathematics and consequently give information about students' opinions about the mathematics taught in school. We observed a correlation between classroom experiences and mathematics contents with students' perception of general contents of mathematics. The research was conducted on the sample of 552 17-19-year-old Slovenian general upper secondary school (Gimnazija) students from the grades 3 and 4. The results show that students find general mathematics contents slightly more fascinating, attractive and exciting than boring, unattractive or unexciting, but this result correlates negatively with contents taught in school and the teaching of these contents. Our research unveils that mathematics cannot be treated as a uniform construct, but it instead consists of three more or less connected components.

Keywords: CFA, EFA, mathematics contents, mathematics teaching, SEM analysis.

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Introduction

One of the recently unearthed problems worldwide is students' lack of interest in electing STEM (Science, Technology, Engineering, Mathematics) subjects, where an election is an option; students choose enrolment into such studies at the higher educational levels (Osborne et al., 2003). In search of explanation of these trends, many expose elementary and secondary school experiences as a potential source for lack of interest, both at the content and instructional levels. It is hypothesized that students' opinions and attitudes toward STEM school subjects are a combination of students' relationship with the contents taught in that subject and the related classroom experiences, together with their satisfaction with the teacher (Šorgo et al., 2018). On the other hand, some studies have shown that students' attitudes towards secondary school science are not stable and are becoming progressively more negative over time (Abrahams, 2009; Whitley et al., 2012). Some of the recent research has shown that the quality of student-teacher relationships may play a crucial role in the upper-elementary school (Wang & Eccles, 2012; Zee et al., 2013). Teaching of mathematics is tightly connected with students' emotions (Hannula, 2006), motivation (Pajares & Graham, 1999), their attitude toward the subject (Kibrislioglu, 2015), and their self-confidence in relation to mathematics (Henderson & Rodrigues, 2008).

In our study, we used an adaptation of the STEM Semantics Scale (Tyler-Wood et al., 2010). The adaptation was first used by Šorgo et al. (2018) in a study about predictive power of school experiences with STEM subjects in choosing a career as a researcher or educator. Recently, in research about students' interest in school biology connected to the career aspirations the mention adaptation was also performed (Šorgo & Špernjak, 2020). The constructed theoretical models were created in the wake of the models from Pekrun et al. (2011).

The aim of our study was to explore connections between attitudes toward general content of mathematics, content taught at elementary and secondary schools, and related teaching practices, by application of the models proposed by Pekrun and co-workers (2011) in the framework of emotions.

We focused on the following research questions:

- Are theoretical models used by Pekrun et al. (2011) valid for our study?
- Do theoretically predicted factors form new combined factors?
- Is it possible to upgrade some of these models by reducing the number of items?
- How are factors (constructs) correlated in the models?

Based on the research questions, we formed next hypotheses:

- H1: Opinions of mathematics is a single construct.
- H2: Students' attitudes toward mathematics are formed from 5 different non-correlated constructs (general interest in mathematics, elementary school contents, secondary school contents, teaching of mathematics in elementary school, and teaching of mathematics in secondary school).
- H3: Contents in elementary school influence students' opinions about mathematics.
- H4: Teaching in secondary school has a great impact on students' opinions about mathematics.

Methods

Instrument

The questionnaire was based on a seven-point semantic scale with bipolar adjectives (Gardner, 1995). As proposed in the STEM Semantics Scale, we offered the following adjective pairs: *fascinating–boring* (F–B), *interesting–mundane* (I–M), *important–unimportant* (I–U), *attractive–unattractive* (A–U) and *exciting–unexciting* (E–U). Internal consistency and unidimensionality of each scale have already been observed by Šorgo et al. (2018). The five leading questions in the questionnaire were the following:

- I find mathematical contents (statistics, algebra, geometry, algorithms and programming, mathematical finance, optimization methods, mathematical modelling): (Q21),
- I find mathematical contents from elementary school: (Q22),
- I find mathematical contents from secondary school: (Q23),
- I find teaching mathematics from elementary school: (Q24),
- I find teaching mathematics from secondary school: (Q25).

Sample

The research was conducted on the sample of 552 secondary school students. All of the students considered in the study were in the third (59.4 %) or fourth grade (40.6 %) of the 4-year general upper secondary school, "Gimnazija", programme. Mostly, the participants were between 17 and 19 years old. The sample covered around 10 % of the complete number of Slovenian "Gimnazija" students from these two generations. More information about the Slovenian school system, the structure of the "Gimnazija" programme, and a detailed description of the sample and sampling can be found in Šorgo et al. (2018).

Statistical analyses and procedures

We used the models suggested by Pekrun et al. (2011). The first model is based on the prediction that the latent construct MATHEMATICS is unidimensional. Furthermore, the second model predicts correlation between five different latent variables MATG (general mathematics contents), MATES (elementary school mathematics contents), MATSS (secondary school mathematics contents, MATTES (teaching in elementary school) and MATTSS (teaching in secondary school) were observed. The third model additionally describes the second one and is based on the prediction that a single second-ordered construct MATHEMATICS follows from aforementioned five different constructs. To investigate the constructs' validity, we chose a two-step approach. In the first phase, we conducted an exploratory analysis (EFA) with the application of standard procedures for such types of analyses (principal component analysis with direct oblimin rotation in SPSS 24) to explore unidimensionality and reliability of the theoretically proposed factors (Field, 2013). Confirmatory factor analysis (CFA) (Schmitt, 2011) was the next step, and was carried out by AMOS 25. Due to a poor fit of the initially proposed models', procedures for their improvement were performed.

Research results

Descriptive results

Frequencies and descriptive statistics on the opinions about basic mathematics contents, mathematics contents taught in elementary and secondary school and the opinions on teaching in elementary and secondary school were considered. Table 1 shows that each construct has appropriate reliability (alpha values in the table). Skewness of observed variables (indicators) does not exceed a value of 0.8 (0.18–0.79) and the standard error of skewness is 0.14. Because of the large sample and the fact that all upper-mentioned values fall below the suggested thresholds, we might not need to be extremely concerned with the non-normal contribution when we perform SEM analysis (Lei & Lomax, 2005). Students find general mathematics contents more fascinating than boring (M = 3.60), more attractive than unattractive (M = 3.73) and more exciting than unexciting (M = 3.82). On the other hand, the majority of the means of students' opinions about school contents and teaching in elementary or secondary school are more negative than positive (see Table 1).

Table 1: Descriptive results regarding students' opinions about school contents and teaching in elementary and secondary school on a 7-point scale (N = 552)

Item		Mean	Median	Mode	Std. Deviation	Skewness
General interest in mathematics Alpha = 0.95;						
Q21a	F–B	3.60	3.00	3	1.82	0.37
Q21b	I–M	3.37	3.00	3	1.84	0.44
Q21c	I–U	3.02	3.00	1	1.85	0.68
Q21d	A–U	3.73	4.00	4	1.88	0.27
Q21e	E–U	3.82	4.00	4	1.93	0.22
Contents from elementary school Alpha = 0.95;						
Q22a	F–B	3.35	3.00	3	1.75	0.48
Q22b	I–M	3.25	3.00	2	1.80	0.51
Q22c	I–U	2.78	2.00	1	1.72	0.79
Q22d	A–U	3.42	3.00	3	1.76	0.42
Q22e	E–U	3.59	3.00	4	1.83	0.35
Contents from secondary school Alpha = 0.95;						
Q23a	F–B	3.60	3.00	2	1.80	0.37
Q23b	I–M	3.38	3.00	2	1.81	0.42
Q23c	I–U	3.21	3.00	1	1.91	0.57
Q23d	A–U	3.71	4.00	4	1.81	0.23
Q23e	E–U	3.86	4.00	3	1.84	0.18
Teaching in elementary school Alpha = 0.96;						
Q24a	F–B	3.43	3.00	3	1.76	0.42
Q24b	I–M	3.26	3.00	3	1.80	0.53
Q24c	I–U	2.95	3.00	1	1.74	0.69
Teaching in elementary school Alpha = 0.96;						
Q24d	A–U	3.44	3.00	3	1.76	0.34
Q24e	E–U	3.56	3.00	3	1.79	0.31
Teaching in secondary school Alpha = 0.96;						
Q25a	F–B	3.44	3.00	3	1.80	0.47
Q25b	I–M	3.26	3.00	1	1.88	0.56
Q25c	I–U	3.07	3.00	1	1.89	0.70
Q25d	A–U	3.56	3.00	4	1.89	0.36
Q25e	E–U	3.69	4.00	4	1.89	0.29

Note. a = *fascinating–boring* (F–B); b = *interesting – mundane* (I–M); c = *important–unimportant* (I–U); d = *attractive–unattractive* (A–U) and e = *exciting–unexciting* (E–U).

CFA of the theoretical models

Based on Pekrun et al. (2011), we first designed three different theoretical models. Model 1 assumes that every observed variable is a predictor of a single first-order variable MATHEMATICS (see Figure 1).

We can see from the model that the factor loadings for importance of contents in elementary school (0.57), importance of teaching secondary school mathematics (0.55) and also for other descriptors of students' opinions on teaching mathematics in elementary school are outstandingly low.
Model 2 was produced on five different constructs, MATG, MATES, MATSS, MATTES, and MATTSS (see Figure 2).

The model offers correlations between all created constructs. We can observe that there are still strong correlations between constructs MATES and MATTES (0.82), between constructs MATSS and MATTSS (0.86) and between constructs MATG and MATSS (0.86).

In the theoretical Model 3, a second-order latent variable MATHEMATICS was established from first-order constructs MATG, MATES, MATSS, MATTES, and MATTSS. This model shows that those latent variables (with the exception of MATES and MATTES, which have the smallest factor loadings, 0.68 and 0.59, respectively) explain the students' opinions about learning mathematics (see Figure 3).

We performed SEM analyses to explore the model fits. The construct validity of Models 1, 2 and 3 was checked by observing RMSEA (root mean square of error approximation; 0.24, 0.12, 0.13), GFI (goodness of fit index; 0.31, 0.69, 0.67), AGFI (adjusted goodness of fit; 0.18, 0.62, 0.61), CFI (comparative fit index; 0.55, 0.90, 0.88), Chisq (Chi-square; 8892.28, 2211.60, 2594.63), and *df* (degrees of freedom; 275, 265, 270), respectively. However, all three of the observed models do not fit perfectly, which can be assume from Yuan et al. (2016).

Through inspection of the models, we concluded that Model 2 showed the best fit, so we tried to improve it (see Figure 4)

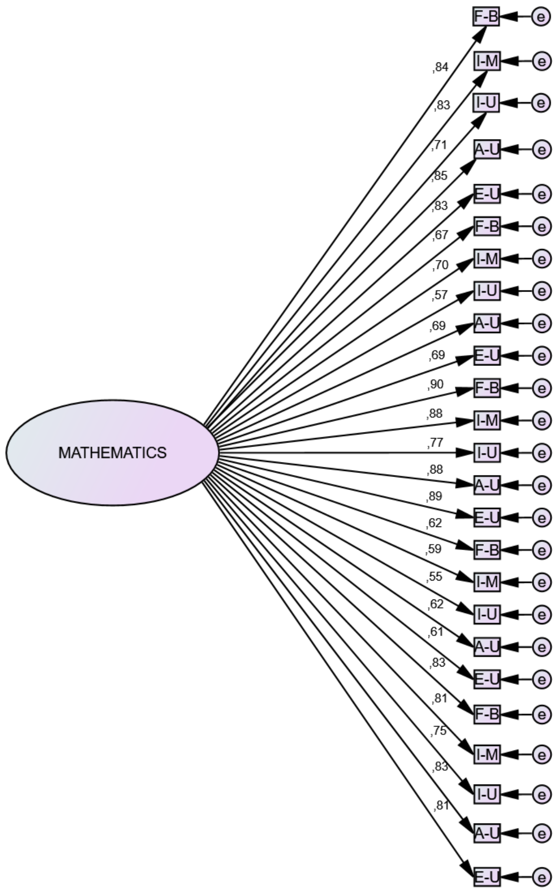

Figure 1: CFA diagram of Model 1

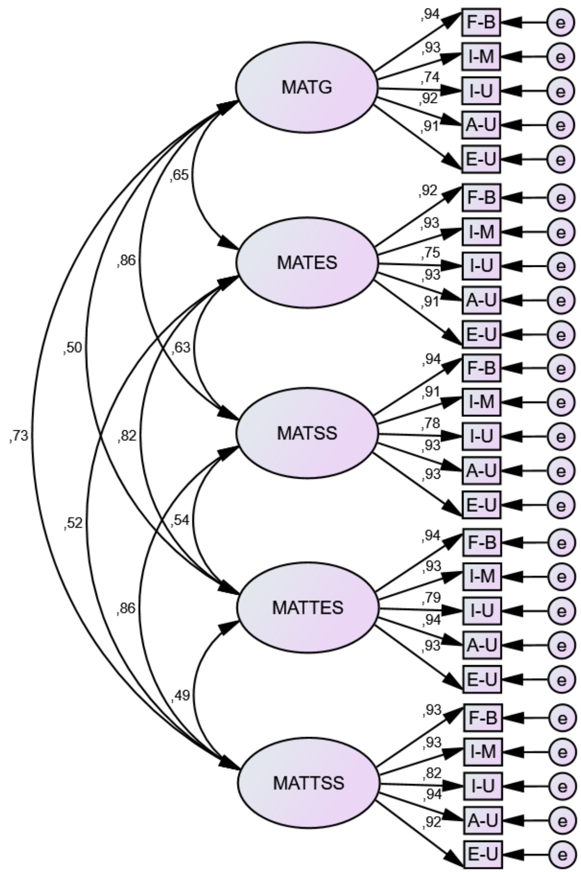

Figure 2: CFA diagram of Model 2

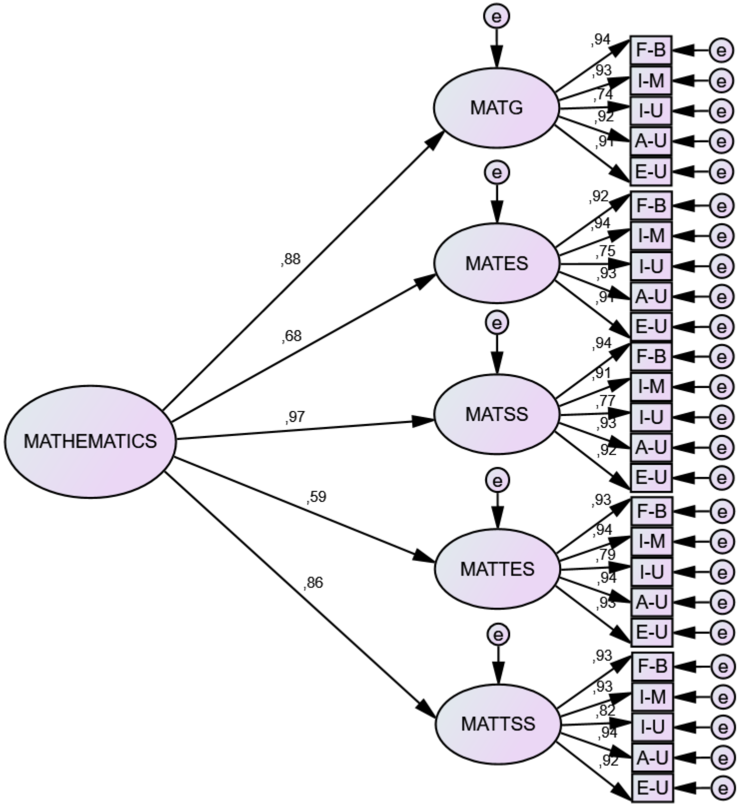

Figure 3: CFA diagram of Model 3

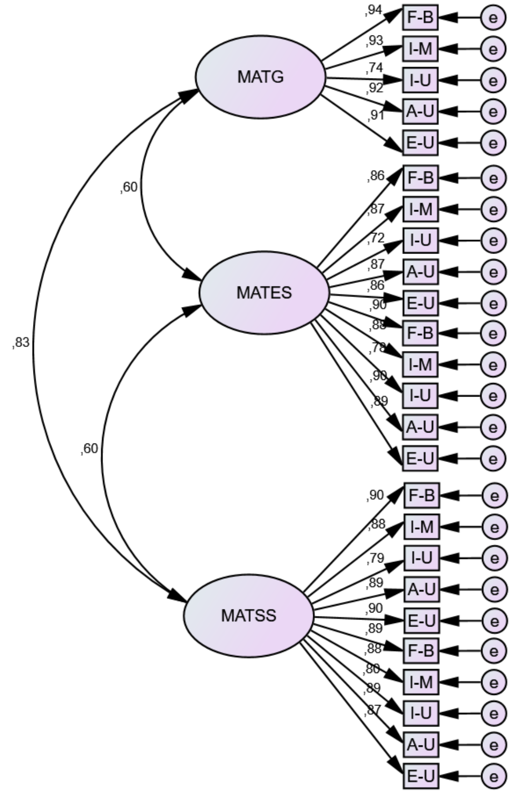

Figure 4: CFA diagram of Model 4

Principal component analysis (PCA) of the questionnaire

By performing exploratory factor analysis, more precisely, principal component analysis with direct oblimin rotation based on the eigenvalue >1 criterion, four components were identified. Sampling adequacy was checked with the Kaiser-Meyer-Olkin measure (KMO, 0.96) and sphericity (with Bartlett's test of sphericity) by $\chi^2 = 19257.31$, $df = 300$, $p < .001$.

The first factor gathered students' opinions about the secondary school mathematics (Q23a–Q23e and Q25a–Q25e). The second component represented students' opinions about the elementary school mathematics (Q22a–Q22e and Q24a–Q24e). The third component represented students' opinions on the general mathematics interest. The last, fourth factor, was formed from students' opinions about the importance of mathematics (Q21c, Q22c and Q24c).
After the application of parallel analysis (Hayton et al., 2004), only the first three factors were retained.

The explained variance of the matrix was 83.80 % when these four factors were considered, and 79.67 % when only three factors were considered. These differences are too minor to be considered as important, however; the percent is still satisfactorily high.

From the component correlation matrix in the Table 2, one can see that the third component (i.e. general mathematics interest) negatively correlates with all of the other factors, which is counter-intuitive and was regarded as quite surprising.

Table 2: Component Correlation Matrix

Component	1	2	3	4
1	1,00			
2	.43	1.00		
3	-.52	-.38	1.00	
4	.24	.22	-.15	1.00

Three-construct Model 4 based on PCA analysis

Based on the aforementioned exploratory factor analysis of our questionnaire, we created a new three-construct model with the suggested latent variables MATES, MATSS, and MATG. We tested the model and got the following fit indices:

- GFI = 0.52,
- AGFI = 0.421,
- CFI = 0.79,
- RMSEA = 0.16,
- Chisq = 4275,60,
- *df* = 272.

Poor fit indices suggested some further improvement of the model was in order. Additionally, Figure 4 shows, that the correlations between MATG and MATSS are still high, so further research was necessary.

Improved Model 4

Due to the facts from Section 3.4. and results from the PCA we modified the Model 4 to create a model with better fit indices and a smaller correlation among the factors (see Figure 5). We get the following fit indices:

- GFI = 0.91,
- AGFI = 0.86,
- CFI = 0.97,
- RMSEA = 0.082,
- Chisq = 398,23,
- *df* = 84.

From Yuan et al. (2016) one can observe that the improved Model 4 has a good fit. The adaptation of the model revealed that removing mathematics contents taught in elementary school from construct MATES and teaching of mathematics from construct, MATSS stabilizes our model.

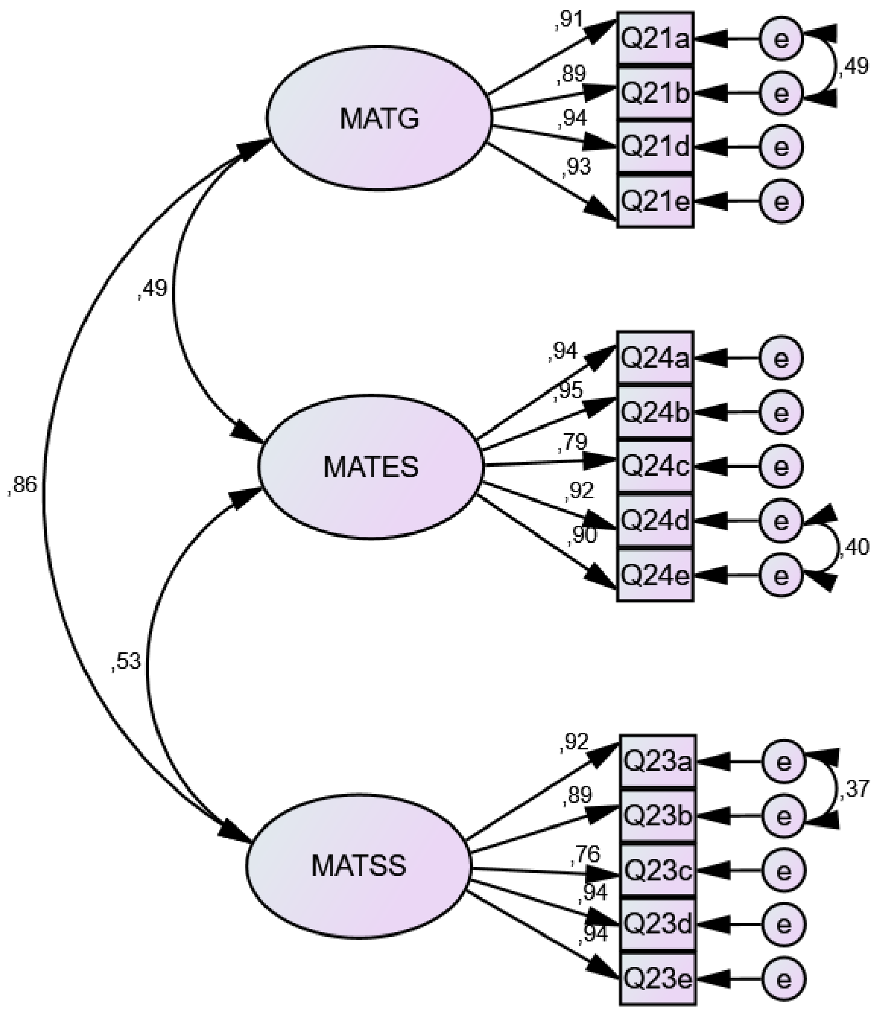

Figure 5: Improved Model 4

Importance of mathematics as a single construct

With a purpose of continuing our model research, we again studied descriptives from Table 1. The importance of mathematics stands out from the other answers (the mode of Q21c–Q25c is 1 and the mean is the lowest among all the answers). On the other hand, if we recall the results from the PCA in section 3.3., one can observe that the factor 4 was constructed from the answers Q21c, Q22c and Q24c, therefore we could use it as the independent construct. Table 3 additionally shows that in every correlation matrix answers Q21c–Q25c reach the smallest value of correlation coefficient. That is the reason for starting the exploratory factor analysis.

Table 3: Correlation matrices for each question from Q21–Q25

Correlation matrix for Q21					
	Q21a	Q21b	Q21c	Q21d	Q21e
Q21a	1.000				
Q21b	.905	1.000			
Q21c	*.682*	*.696*	1.000		
Q21d	.854	.836	*.707*	1.000	
Q21e	.852	.831	*.662*	.877	1.000
Correlation matrix for Q22					
	Q22a	Q22b	Q22c	Q22d	Q22e
Q22a	1.000				
Q22b	.878	1.000			
Q22c	.683	.728	1.000		
Q22d	.844	.867	.711	1.000	
Q22e	.836	.835	.630	.876	1.000
Correlation matrix for Q23					
	Q23a	Q23b	Q23c	Q23d	Q23e
Q23a	1.000				
Q23b	.886	1.000			
Q23c	.717	.710	1.000		
Q23d	.859	.836	.708	1.000	
Q23e	.861	.820	.704	.893	1.000
Correlation matrix for Q24					
	Q24a	Q24b	Q24c	Q24d	Q24e
Q24a	1.000				
Q24b	.896	1.000			
Q24c	*.742*	*.760*	1.000		
Q24d	.856	.869	*.738*	1.000	
Q24e	.860	.848	.703	.896	1.000
Correlation matrix for Q25					
	Q25a	Q25b	Q25c	Q25d	Q25e
Q25a	1.000				
Correlation matrix for Q25					
Q25b	.885	1.000			
Q25c	*.763*	*.777*	1.000		
Q25d	.859	.872	*.758*	1.000	
Q25e	.835	.845	*.729*	.891	1.000

We removed the answers from the primary constructs and checked if they correlate (see Table 4). As the results were satisfactory (only Q22c and Q24c for primary school slightly stand out), we formed new construct, named IMPORTANCE_OF_MATHEMATICS. The Cronbach's alpha of this new construct was 75.9 % -it passed the 70 % threshold value.

Table 4: Correlation matrix for Q21c–Q25c

	Q21c	Q22c	Q23c	Q24c	Q25c
Q21c	1.000				
Q22c	.526	1.000			
Q23c	.741	.464	1.000		
Q24c	.433	.746	.422	1.000	
Q25c	.669	.458	.807	.464	1.000

Four-construct Model 6

By application of the error terms and observing the standardized residual covariances, we obtained the four-construct Model 6 (see Figure 6). Analogously to the analysis in section 3.3., the sampling adequacy of new constructs was checked with the Kaiser-Meyer-Olkin (KMO) measure (0.801) and sphericity (with Bartlett's test of sphericity), c^2 = 1623.833, *df* = 6, $p < .001$.

We obtained the improved four-construct model with the suggested latent variables MATES, MATSS, MATG and IMPORTANCE_OF_MATHEMATICS.
We performed SEM analyses to explore the model fits. The construct validity of Model 6 was checked by observing RMSEA (0.11), GFI (0.87), AGFI (0.8), CFI (0.95), Chisq (685.53), and *df* (92).

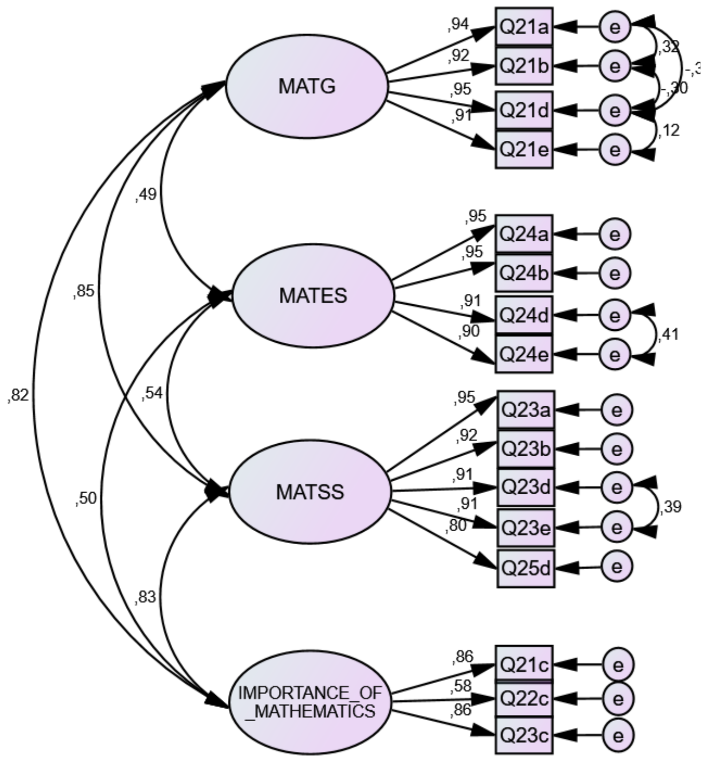

Figure 6: EFA diagram of Model 6

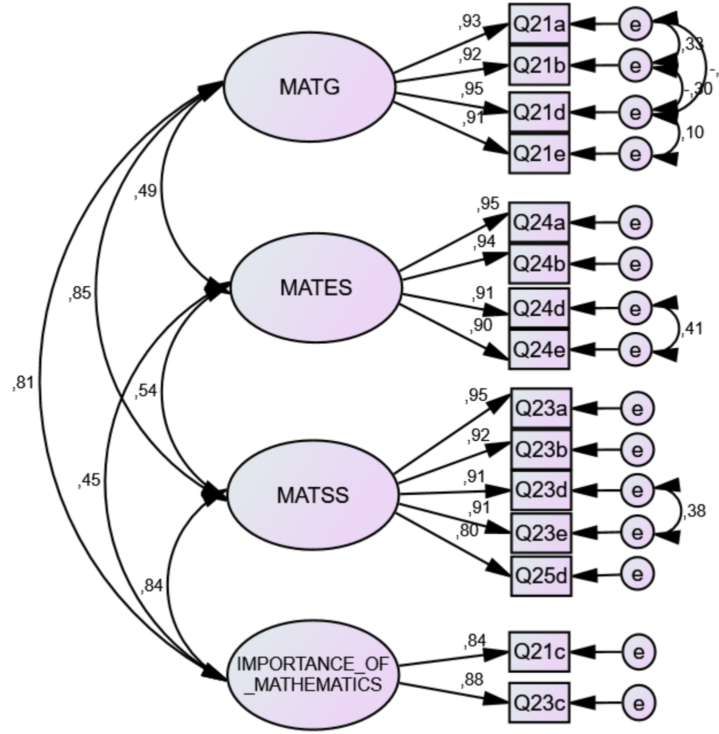

Figure 7: EFA diagram of Improved Model 6

Improved Model 6

Due to the reflection in section 3.5., the construct IMPORTANCE_OF_MATHEMATICS could be updated such that we exclude answers about the importance of contents from primary school mathematics (Q22c), which gave the smallest correlation indices (see Table 8). An exploratory factor analysis diagram of the improved Model 6 is depicted in Figure 7.

The explained variance of the matrix was 82.00 % when the new factor and factors MATG, MATES, and MATSS were used.

The following are model fits, which show that the improved Model 6 has a better fit than the afore-constructed Model 6:

- RMSEA = 0.10,
- GFI = 0.89,
- AGFI = 0.84,
- CFI = 0.96,
- Chisq = 482.81,
- *df* = 78.

Discussion and Conclusion

From the descriptives, one can observe that students' opinion about general mathematics contents is more positive than negative. On the other hand, students' opinions on the contents and teaching in elementary or secondary school are exactly the opposite. From the high correlation between theoretical constructs MATSS and MATTSS and between MATES and MATTES, we found out that these latent variables might be parts of a single construct. Therefore, we might define another model that gives us more accurate information about defining the second-latent variable MATHEMATICS. Moreover, there are still some options for further polishing of the Model 4. From the PCA results and the pattern matrix we could create one more latent variable, named "THE IMPORTANCE OF MATHEMATICS". This could be the option for further analysis.

The results from the PCA together with the descriptive statistics seem fairly interesting. The most remarkable result of the PCA is the negative correlation between students' opinions about general mathematics contents and their opinions about the contents taught in school together with the teaching. Apparently, students perceive mathematics as something more or less valuable; however, they want that it presented in school in a more attractive, important, interesting, fascinating and exciting fashion.

The improved Model 4 revealed that the contents of primary school mathematics do not influence students' perceptions about primary school mathematics, and in contrast, the teaching of mathematics in secondary school does not influence students' opinions about the secondary school mathematics. Due to the lack of the information, we could not understand these two findings and therefore we left those questions open for further study of the subject. Model 6 showed that students' opinions about mathematics could be more thoroughly observed by additional observation of their perception of the importance of mathematics as a single construct. The improved Model 6 additionally showed that we do not consider the importance of contents and teaching of elementary school mathematics when dealing with students' opinions about the importance of mathematics.

Our research unveiled that mathematics could not be treated as a uniform construct. We do not have a full explanation of the relative unimportance and unattractiveness of school mathematics. We also believe that there are such respectable mathematics teachers who insert lots of efforts to make their lessons exciting and make a great impression on students, and give them a positive attitude toward mathematics. But the results show that there is room for improvement of our secondary school teaching in such a way that the students would better recognize our efforts. Results also hint at the mathematics contents in elementary school not being attractive and important enough for students, so this again calls for further study. By changing our teaching approaches in secondary school mathematics and choosing more attractive contents in elementary school mathematics, those two indicators would play a more important role in shaping students' perceptions of mathematics.

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