Examining educational technology and achievement through latent variable modeling

Elena C. Papanastasiou,
Intercollege, Cyprus

Efi Paparistodemou
Ministry of Education, Cyprus

Contact information:
Elena C. Papanastasiou,
7, Mourouzi st. #402
Nicosia 1055
Cyprus

papanast@msu.edu

Abstract

The relationship between technology use and achievement has not always been straightforward. A series of studies that have examined the TIMSS 1995 and 1999 databases have shown that there are some inverse relationships between computer use and achievement. These studies have found that students who use computers most frequently under specific situations tend to have lower achievement in mathematics[1]. Similar results have also been found in other studies (e.g. based n ETS data) as well[2]. The effects of technology on achievement however, are likely to be transformed with the increase in the use of computers within the student's homes and their classrooms. Moreover in a current study on the effects of calculator technology on student achievement, Collins and Mittag (2005) show that the inferential calculator did not appear to give students any clear advantage or disadvantage in their performance on examinations[3]. Therefore, the purpose of this study is to examine the current interrelationships that exist between technology use and mathematics achievement with the TIMSS 2003 dataset. These relationships will be examined from the perspective of the students after controlling for their educational background. The sample of this study includes grade 8 students from the USA, Cyprus, the Russian Federation, and South Africa. The analyses for this study will be performed with the use of structural equation modeling.

Introduction

The use of computers in the teaching and learning of mathematics appear to be increasing exponentially year by year. Numerous studies have been undertaken in the last decades in connection to various areas of mathematics such as algebra[4], geometry[5] and probability and statistics[6]. The common aspect of all of these studies is their attempt to effectively use computer environments in order to improve student's understanding of mathematics. However, this is not a simple task since the relationship between computer use and school related variables such as student achievement is constantly transformed by the ever increasing presence of computers in everyday life, and by our increasing reliance on computer technologies. As a result, educators need to constantly adapt their practices to conform to the educational needs of the students.

The purpose of this study is to propose and test a model concerning the current relationship between technology use and mathematics achievement with the TIMSS 2003 dataset. This model will be examined in four countries; those of the USA, Cyprus, the Russian Federation, and South Africa. The present study will try to enhance the current understanding of how the technology-achievement relationship has evolved in the current years in which the number of computers at home and school settings has increased, and in which technology has become an integral part of our daily lives.

Educational technology and mathematics

The key feature of a computer-based environment is that it presents a formal, computable representation of mathematical objects and relationships. Papert's (1991) early work has been very influential in the development of computer environments labeled as 'microworlds'[7]. According to Papert, learners interact with the microworld and build their own computer-based models. These models reflect the learners' thinking about the mathematical objects and relationships as they work on particular activities.

Noss and Hoyles define a computer environment as a flexible, interactive, expressive medium for working with mathematical objects and operations[8]. Computer-based environments provide access to formal mathematical knowledge through the nature of the 'intermediate' screen objects with which students interact in order to construct and manipulate new objects and relationships. Moreover, these environments allow the learner to explore simultaneously the structure of the accessible objects, their relations and the representations that makes them accessible. It can be said that the microworld 'evolves' as the learner's knowledge grows.

According to Lajoie, Jacobs and Lavigne (1995), computer-based learning environments support the 'learning by doing' philosophy[9]. For example, in a computational modeling approach to statistics, a modeling language and various sets of associated tools are made available to learners, allowing them to pursue personally meaningful investigations. Learning by doing involves building up mental structures so that ideas may get linked into a mental network that will allow some ideas to assimilate readily while others to be radically transformed by the assimilating structure. If a concept, which is taught, is well assimilated to the teacher's internal structure, but the structures of the learners are sufficiently different from the teacher's, then what is taught will be radically transformed and there will not be an effective link with the student's mental network[10]. Arguing along similar lines, Harel and Papert (1990) describe 'instructional software' in which

> 'The communication between the software producers and their medium is dynamic. It requires constant goal-defining and redefining, planning and replanning, representing, building and rebuilding, blending, reorganizing, evaluating, modifying, and reflecting in similar senses.' (p. 46)[11].

In other words, instructional technology should be used as computer-based environments in order to help students construct ideas. Children who are educated in a computer-based environment have the opportunity to express their own representations and also to re-construct and re-design the computer environment without losing its main kernel. This ownership helps to give meaning to the task and enables children to feel that they own the ideas developed during their interaction with the task.

Calculator use and mathematics

Calculators can be considered as one of the oldest modern technological devices that are still being used in mathematics classes. The advent of calculator technology has influenced the teaching of mathematics in a profound way[12] . In the case of graphic calculators, previous studies concluded that it is possible to improve students' understanding of variables by giving them environments in which they could manipulate examples, predict, test and gain experiences on which higher-level abstractions could be built[13]. The value of using a graphic calculator was seen to be that it intrinsically uses variables in its operations and that the multi-line display allows the user to see, reflect upon and react with several sequential inputs/outputs.

Research on younger students (11-12 year-olds) has also shown the promising results of the use of calculators. According to Cedillo (1997), children's performance on given algebraic tasks using graphic calculators helped them gain awareness of the generality of algebraic expressions[14]. The results of the same study found that calculators even helped children to proceed to some understanding of inverse functions and algebraic equivalence. Elliott, Hudson and O'Reilly (2000) have also investigated the use of graphical calculators to explore their effects on students' visualization skills in the context of graphing functions. They found that the students' perceptions have been influenced in a positive way towards the validity of visual methods in mathematics[15].

There is no doubt that technology (either in the form of computers, or in the form of calculators) holds potential for improving the students' educational experiences, as well as for improving people's everyday lives. However, educational technology has to be used by students and educators appropriately, since it is the type of technology use that is associated with higher academic performance[16]. With the use of technology, educators need to shift the focus from instruction to the idea of construction. This is especially important since some prior studies have found inverse relationships between school computer use and achievement[17]. What remains to be seen is how these relationships have evolved in the USA, Cyprus, South Africa and the Russian Federation, based on the data from the TIMSS 2003 dataset.

Methods

The TIMSS 2003 is the third cycle of a continuing series of international mathematics and science assessments conducted every four years. TIMSS assesses achievement in about 50 countries around the world, and collects a rich array of information about the educational contexts for learning mathematics and science. This is done by asking students, their teachers and school principals to provide information through questionnaires, about the curriculum, the schools, the classrooms and the instruction. The aim of TIMSS is "to improve the teaching and learning of mathematics and science by providing data about students in relation to different types of curricula, instructional practices, and school environments" (Mullis, Martin, Gonzales and Chrostowski 2004 13)[18].

The mathematics assessment framework on which the assessments were created was based on two dimensions; a cognitive and a content dimension. The cognitive dimension was defined as the set of behaviors that the students were expected to perform while engaging in the mathematics content. The cognitive dimensions were those of knowing facts and procedures, using concepts, solving routine problems and reasoning. The content dimension defined the specific mathematics subjects that were covered in the assessment. These included the content domains of numbers, algebra, measurement, geometry and data.

TIMSS used Item Response Theory (IRT) to summarize the achievement results with a mean of 500 and a standard deviation of 100. The IRT method of scaling has allowed the performance of students across countries to be summarized on a common metric although not all students had taken the same items on the mathematics test. IRT has also enabled the provision of accurate measures of trends from previous assessments. A family of 2-parameter and 3-parameter models were used for the dichotomously scored multiple choice items, while a generalized partial credit model was used for the construct-response items [19].

The sample of students used in the current paper will include population 2 of TIMSS which includes eighth-grade students. These students tended to be between the ages of 14 and 15 years olds.

Country characteristics

To be able to comprehend the results of the study, it is also important to provide some background information on the countries whose students will be compared. As presented in Table 1, Cyprus was included as a representative of a small, average income country, with the large majority of the students having computers at their homes (82%). However, the performance of Cyprus on TIMSS (459) was below the international average (467). South Africa and the Russian Federation are similar in that they are low income countries, with only about one third of their students owning computers. However, the Russian Federation obtained an average score of 508 on the TIMSS mathematics test which was above the international average, while South Africa only scored 264 on the mathematics test. South Africa was the country with the lowest achievement in mathematics on TIMSS. Finally, the USA is an example of a high income country, with almost all of the students in the sample students owning computers (93%). The performance of the USA on TIMSS was above average, with a mean of 504.

The sample size for Cyprus was 4002 students, with 48.6% of the students being female. The sample size for the Russian Federation was 4667 with exactly 50% of the sample being female. The sample size of South Africa was 8840, with 50.6% females, while the USA with a sample size of 8912 had 51.9% females in their sample.

[Insert Table 1 about here]

Structural equation modeling

Structural equation modeling (SEM) is a statistical technique that can be used in theory development because it enables researchers to both propose and test theories about the interrelationships among variables in multivariate settings (Heck, Larsen and Marcoulides, 1990). The use of such models is especially helpful since it allows simultaneous examination of multiple relationships without the concern of inflated alpha estimates. Some additional advantages of SEM include the reduction of measurement error by including multiple indicators per latent variable, the ability to acknowledge and model error terms, as well as the ability to concurrently test overall models rather than individual coefficients.

For the purpose of this study, the data were analyzed with the use of the structural equation modeling software AMOS 5.0.1 [20]. The estimation procedure that was used for the estimation of the model in this study was the Maximum Likelihood estimation procedure (ML).

Hypothesized model

As a first step for this analysis, a model was originally developed to attempt to explain the data. The conceptual model of this study (see Figure 1) and the relationships between the various latent variables shown in this model are based on the review of the literature. The outcome of the study is the student's mathematics score, as measured by the TIMSS. Based on the model, there are two latent technology-related variables, and one technology-related observed variable that are hypothesized to predict the student's mathematics score. More specifically, the first latent variable is that of computer use. This latent variable is comprised of three items measuring the frequency with which several activities took place with the use of a computer. These were the items of 'I look up ideas and information for mathematics', 'I write reports for school', and 'I process and analyze data'.

The second latent variable that was hypothesized to influence the student's mathematics score was that of computer-related extracurricular activities. This latent variable was comprised of two questions, those of 'I play computer games (outside of school)', and 'I use the internet (outside of school).

The third technology related variable was the observed variable of using calculators. This was a single question that asked the students the frequency with which they used calculators in their mathematics classes. This variable was purposely excluded from the latent variable of 'computer use' so that calculator use could be examined independently of computer use.

The last latent variable that was included in this model was that of the student's 'educational background'. This variable was comprised of three items; those of the education of the father, the education of the mother, as well as the number of books in the student's home. Although this variable is not directly related to technology, it was purposely included in the model to control for such variation in the student's background. The student's socioeconomic status (SES) has universally been known to affect the student's achievement in school. However, for the purpose of this study the educational background which is one of the indicators included in estimating the SES was considered as more interesting than SES itself.

[Insert Figure 1 about here]

Since latent variables are ones that are created through SEM, they also have to be defined by a scale. This is done by fixing the path from a latent variable to one of its observed variables to the value of 1.0 [21]. Thus, in order to set the scale for the latent variable of 'computer use', the path from this variable to the question, "I look up ideas and information for mathematics" was set to a value of 1. The variable that set the scale for the latent variable of 'extracurricular activities' was that of 'playing computer games'. Finally, the variable that set the scale for the latent variable of educational background was that of 'father's education'.

All observed variables are represented in the structural model with rectangles, while all unobserved and latent variables are represented with circles. The smaller circles that have direct paths to the latent variables are called "disturbances", which represent the variation of each variable that cannot be explained by the model. Finally, the arrows that are labeled with names such as em1 and ede, which have direct paths to the endogenous observed variables represent the errors in the measurement of each of those observed variables. These error terms are very important to be included in the model since no assumptions are made that the variables used in this study are perfectly reliable.

Results

The first step in examining the results of the analyses include the examination of the fit criteria, to determine whether the hypothesized model fit each country's data. Six fit indices were taken into consideration, as well as the percentage of variance (R^2) of mathematics achievement. With the exception of the chi square (χ^2) and the χ^2/df, the rest of the indices fit the data quite well for all countries. More specifically, the chi-square statistic was significant in all countries indicating that the data were significantly different from the model. This result was expected however since this statistic and its significance are influenced by large sample sizes. The χ^2/df which is influenced by large samples to a lesser extent, only indicated a good fit for the Russian Federation since its value of χ^2/df=2.13 was less than 2.5.

The Root Mean Square Error of Approximation (RMSEA) had a good fit for all countries, since according to Hu and Bentler[22] its values were equal or less than 0.06. The Normed Fit Index (NFI), the Comparative Fit Index (CFI), as well as the Tucker-Lewis Index (TLI) are all indices in which values between 0.90 and 0.94 indicate a good fit, while indices equal or higher than 0.95 indicate a very good fit. In the case of Cyprus, the NFI and the CFI indicated a good fit, while the TLI equaled 0.89. In the case of the Russian Federation, all three indices indicated a very good fit since they were all higher than 0.95 (NFI=0.99, CFI=0.96, TLI=0.99). In South Africa the TLI did not support the fit of the model (TLI=0.81), although the NFI and the CFI both equaled 0.90 indicating a good fit. Finally, in the USA the NFI and the CFI indicated a very good fit (NFI=0.95, CFI=0.96), while the TLI=0.92 indicated a good fit. Overall, in all four countries the majority of the fit indices supported the fit of the model (when one ignores the χ^2 which is greatly influenced by the sample size).

The percentage of variance of mathematics education explained ($R^2_{\text{math score}}$) ranged from 25% to 50%. The least amount of variance explained was in the case of the Russian Federation (25%), while in South Africa 50% of the variance of the dependent variable was explained. These percentages are quite significant, indicating that the model overall does a good job in explaining a medium to large portion of the variance of the students mathematics scores on TIMSS.

[Insert Table 2 about here]

Since the fit of the model in all four countries has been established, the parameter estimates can then be examined and interpreted. The standardized parameter estimates of the model in the four countries are presented in Figures 2-5 below. These parameters indicate the contribution of each of the latent and observed variables to the overall model. More specifically, they represent the amount by which each endogenous (dependent) variable would change for every standardized unit of change of an exogenous (independent) variable. In addition, the numbers located on the top right side of each endogenous variable reflect the proportion of the variance of that variable that is explained by the model (R^2).

[Insert Figures 2-5 about here]

The standardized regression weights for all four countries are presented in Table 3. The path coefficients from the three latent variables (computer use, extracurricular activities and educational background) to their corresponding observed variables are all adequate, across countries. This indicates that the observed variables are representative of the latent domains they are supposed to measure. These results are presented at the bottom of Table 3.

The most interesting aspects of the path coefficients however, are the paths that directly lead to the student's mathematics score. Table 3, as well as Figures 2-5 demonstrate that the factor that has the greatest effect on the mathematics scores is that of the student's educational background. The highest effect of educational background was found in the USA (β=0.65), which was followed by Cyprus (β=0.61). The lowest effect of educational background was found in the Russian Federation, although its effect was still very high (β=0.53).

Computer use did not have an effect on the student's math scores in Cyprus or the Russian federation, although it had a slightly negative effect in South Africa (β=-0.19) and the USA (β=-0.13). Similar results were found with the students technology-related extracurricular activities. In all four countries, students who spent more time on computer-related extracurricular activities tended to have lower mathematics scores on TIMSS. The largest effect was found in South Africa (β=-0.25). Finally, calculator use in mathematics was associated with lower mathematics scores in Cyprus (β=-0.15), and with higher scores in the USA (β=0.10). Overall however, one can see that technology use in all countries was associated with lower mathematics scores across countries. The only exception was the case of the USA in which calculator use was associated with higher levels of mathematics.

Relationships between the three latent variables were also found in this study. Across all countries, students who used the computer frequently for school work were more likely to also use the computer for extracurricular activities. The strongest path existed in the Russian Federation (β=0.54), while the path for the USA was very weak (β=0.09). Another result of the study was that students from more educated backgrounds were more likely to be involved in technology-related extracurricular activities. A final result of the study was that students from more educated backgrounds were more likely to use computers for their school work. The strongest relationship was found in the Russian Federation (β=0.38). The only exception was found in South Africa where students from more educated backgrounds tended to use the computer less for school work (β=-0.20).

[Insert Table 3 about here]

Discussion

The overall results of the study are not especially encouraging in regards to the overall relationship between technology use and achievement. After controlling for the effects of educational background, the paths between technology use and achievement tend to be small and negative. This is consistent for all countries, with the exception of one path in the USA model which will be discussed further on. Although these paths do not imply-cause effect relationships, they should be looked into more closely.

More specifically, the results of this study fall along two lines. First educational background appears to have a much larger effect on mathematics achievement than any of the technology related variables. This is not surprising since educational background has always been shown to affect student's school performance on many subjects, as well as their patterns of computer use [23]. Such results though always tend to come as a blow to educational systems which appear incapable of surpassing the effects of SES and educational background. Despite the many years of research by numerous researchers around the world, the effects of education on students still tend to be small. Based on this result, children of better educated parents and stronger educational backgrounds are advantaged in school, while children of less educated backgrounds are disadvantaged. This is quite disappointing and it makes one wonder how this problem in the field of education can be solved.

The newest trend and hope for education has been that of technology. Technology holds immense potential for improving student performance as well as in improving people's everyday lives. However, in order to be effective, educational technology has to be used appropriately. Most likely, the potential of technology in education has not been reached yet. According to the second set of results of this study, the students who use technology (for school work or for leisure) to a smaller extent, tend to have higher mathematics achievement on TIMSS than the students who use such technologies more frequently. Although this effect is small, it does exist. Similar results have also been found in prior studies of TIMSS[24], PISA[25], and other datasets[26].

The inverse relationship between technology use and achievement might come in contrast to other studies that tend to praise the use of technology and showcase its positive results [27] . One should keep in mind though, that, although technology might work exceptionally well when it is used by trained educators, it might not work as well in other occasions where teachers do not adopt didactical ideas for the use of technology. Sutherland and Balacheff (1999) raise the issue of didactical complexity that can occur in computational environments for the learning of mathematics[28]. They argue that computer-based environments can provide access to mathematical worlds as long as the teacher is aware of the types of constructive interactions that take place between the student and the computer environment. When higher order constructive interactions do not take place, there is no guarantee that the students will be able to benefit from the computer related activities or computer microworlds.

The interpretation of the negative results of the current study can be explained as follows; On the one hand, it is not surprising that frequent use of technology-related extracurricular activities is associated with lower levels of mathematics achievement. Spending large amounts of time in using the internet and in playing computer games means that those students end up spending less time studying, which therefore leads to lower achievement. This result should not come as a surprise to anyone. On the other hand however, the surprising result is that the students who used the computer frequently to analyze data, to write reports and to look up information also had lower results than the students who performed those activities less frequently. A possible interpretation of this finding is that the specific activities that are performed are not advantageous for the student's learning. It is possible that such activities might help increase the student's technological literacy, and other related skills. They are not necessarily advantageous for the learning of mathematics however. This is in accord with Wenlinsky (1998) who found that the thinking skills that were associated with various activities are the ones that would influence whether the students would benefit from technology use or not. So according to the same author, computer activities that required the use of higher order thinking skills were more beneficial for the students who used them. The results of this study come to reinforce the importance of the proper use of technology. Technology alone does not automatically improve mathematical learning. In particular, the use of computer environments should take into account a deeper consideration of the ways in which learners structure their own learning. If this consideration takes place, learners are able to draw upon and reconstruct the material in ways that they consider appropriate in order to construct meaning for the mathematical subject areas that they are being taught[29].

The use of calculators in mathematics did not have any practically significant effect in the Russian Federation and in South Africa. However, although the use of calculators was negatively associated with mathematics achievement in Cyprus, it was positively associated with achievement in the USA. In the case of the educational system in Cyprus, calculators are believed to impede the student's learning in mathematics. Therefore, there is no specific policy on the use of calculators in middle school, although their use is not encouraged in the subject area of mathematics. In addition, there is no unit of mathematics that focuses on teaching students how to use calculators Therefore calculators tend to be used 'covertly' by students who are weak in mathematics.

In the USA however, there have been decades of research that focused on calculator use. The National Council of Teachers of Mathematics (NCTM) in the USA have even urged the use of calculators to reduce the use of drill and practice activities and encourage the focus on problems that foster the development of underlying mathematical concepts[30]. This research and efforts that have specifically focused on the proper use of calculators in mathematics must have finally paid off. As a result, the use of calculators is taught in mathematics, their use is permitted in specific units, and their use is currently associated with positive results on TIMSS.

In the ever-changing world of technology, education needs to adapt its practices to respond to society's needs. With the constant increase in the percentage of homes that own computers, and with the decrease in the age in which children start using computers, educational practices need to be adapted as well. This includes the way in which computers are used, as well as the computer-related content that needs to be taught. However, as was the case with calculators in the USA, research into the subject of educational technology needs to continue in order to enable it to reach its full potential.

Table 1. Background characteristics of country samples

	Cyprus	**Russian Federation**	**South Africa**	**USA**
Sample size	4002	4667	8840	8912
% Females	48.6%	50%	50.6	51.9
Population	0.8	144.1	45.3	288.4
Gross National Income per Capita ($)	12,320	2,130	2,500	35,400
Average student age	13.8	14.2	15.1	14.2
% of students that have computers	82 (0.6)	30 (2.0)	37 (1.3)	93 (0.4)
Average scale score	459 (1.7)	508 (3.7)	264 (5.5)	504 (3.3)

Table 2. Fit Indices across countries

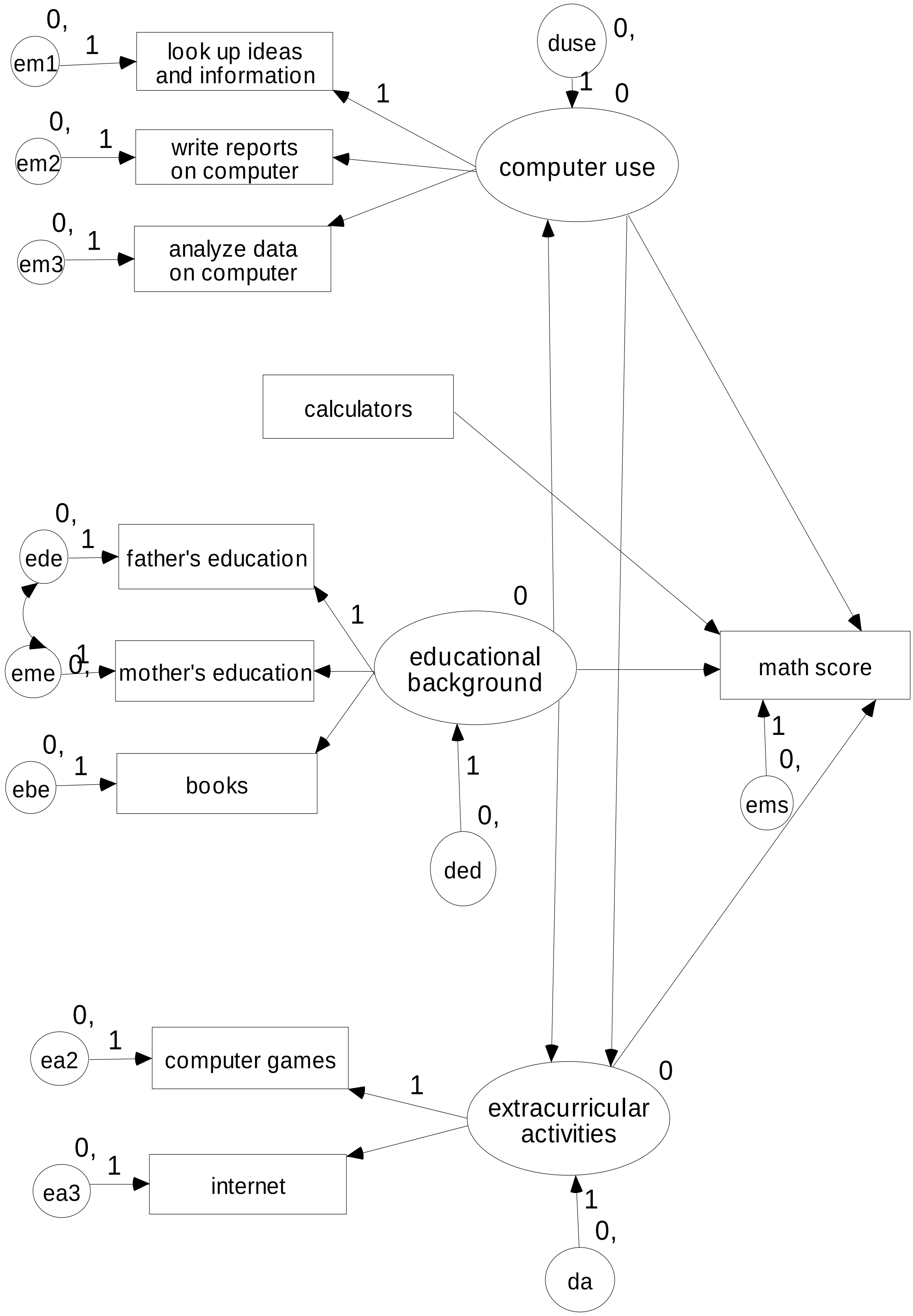
	Cyprus	**Russian Federation**	**South Africa**	**USA**
χ^2	338.87 (p=0.00)	61.84 (p=0.00)	839.92 (p=0.00)	553.63 (p=0.00)
χ^2/df	11.69	2.13**	28.96	19.09
NFI	0.94 *	0.99**	0.90*	0.95**
CFI	0.94 *	0.96**	0.90*	0.96**
TLI	0.89*	0.99**	0.81	0.92*
RMSEA	0.05**	0.02**	0.06**	0.05**
R^2 (math score)	38%	25%	50%	43%

* good fit

**very good fit

Table 3. Standardized regression weights by country

			Standardized regression weights			
			Cyprus	Russian Federation	South Africa	USA
Computer use	→	Math score	-.086	-.065	-.189	-.133
Extracurricular activities	→	Math score	-.074	-.132	-.248	-.100
Educational background	→	Math score	.614	.533	.605	.654
Use calculators	→	Math score	-.152	-.089	-.026	.105
Educational background	→	Computer use	.156	.377	-.195	.200
Educational background	→	Extracurricular activities	.162	.144	.144	.051
Computer use	→	Extracurricular activities	.156	.542	.262	.093
Computer use	→	Look up ideas and information	.553	.612	.624	.600
Computer use	→	Write reports	.717	.736	.609	.595
Computer use	→	Process and analyze data	.695	.684	.602	.814
Extracurricular activities	→	Use internet	.990	.689	.808	.771
Extracurricular activities	→	Play computer games	.482	.614	.382	.554
Educational background	→	Mother's education	.503	.577	.543	.494
Educational background	→	Father's education	.467	.544	.517	.558
Educational background	→	Books at home	.498	.604	.396	.624


0,
em1
1
look up ideas and information
0,
em2
1
write reports on computer
0,
em3
1
analyze data on computer
duse
0,
1
0
1
computer use
calculators
0,
ede
1
father's education
eme
1
0,
mother's education
0,
ebe
1
books
1
0
educational background
1
0,
ded
math score
1
0,
ems
0,
ea2
1
computer games
0,
ea3
1
internet
1
0
extracurricular activities
1
0,
da

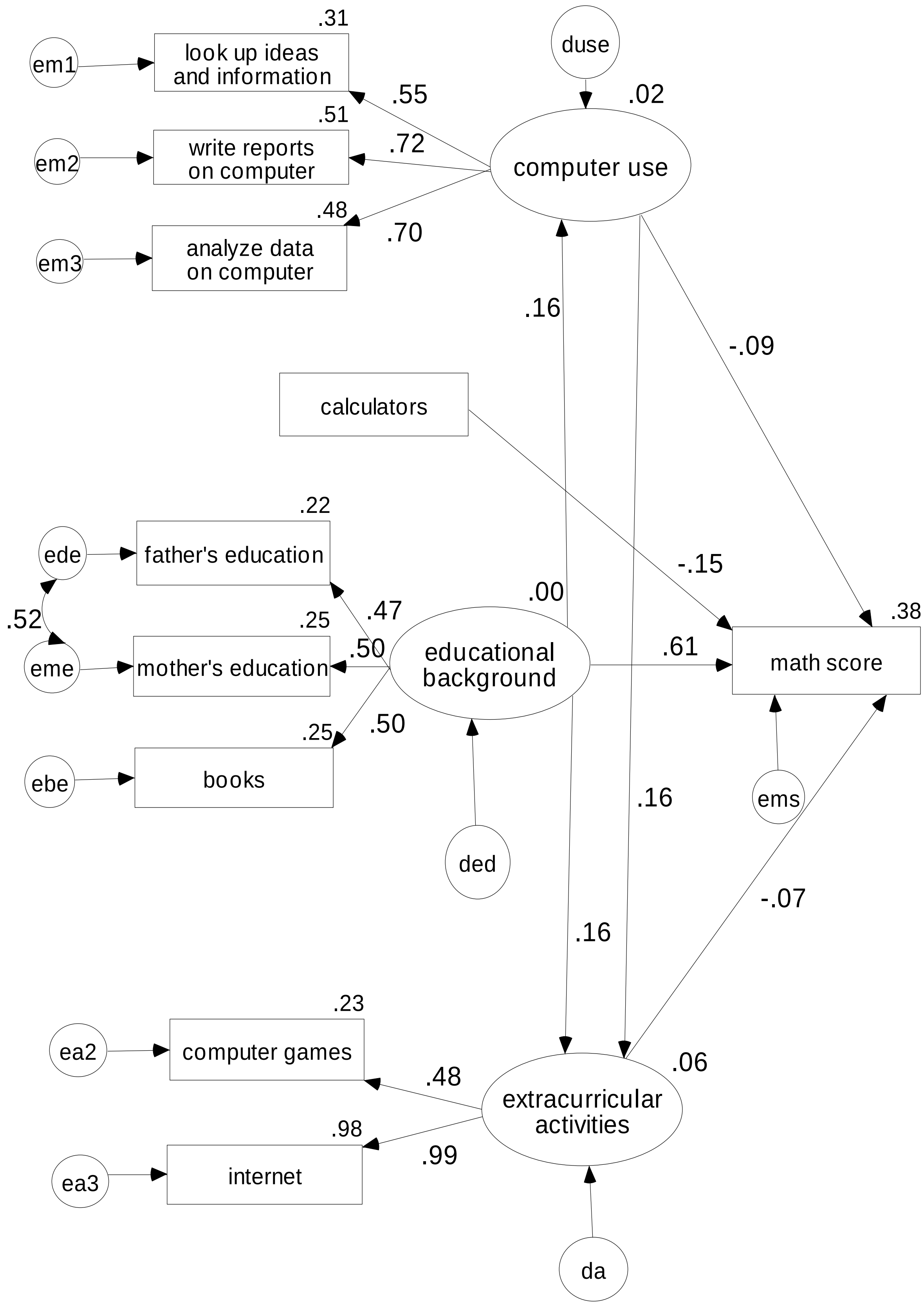


Figure 2. Cyprus model results

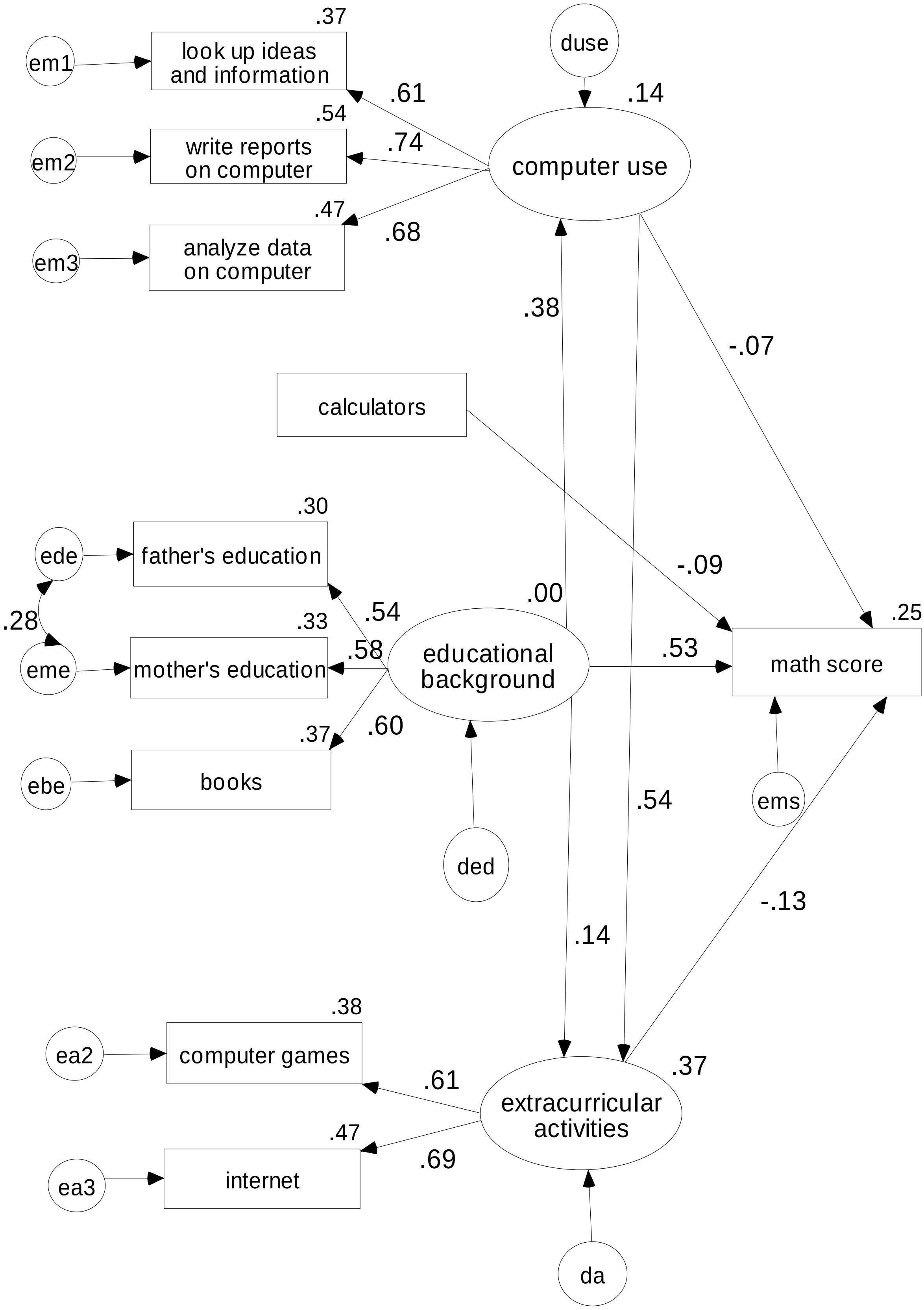


Figure 3. Russian Federation model results

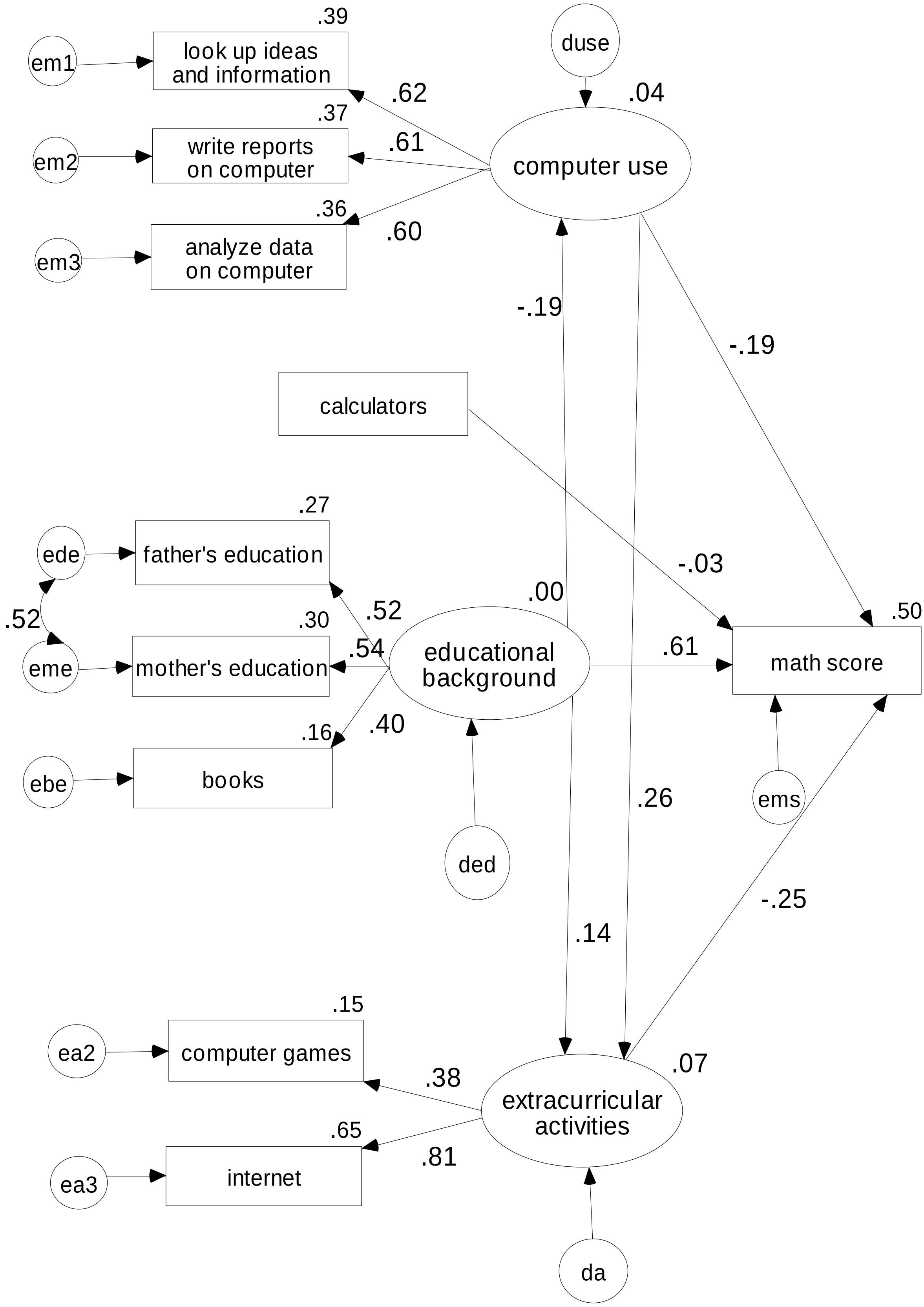


Figure 4. South African model results

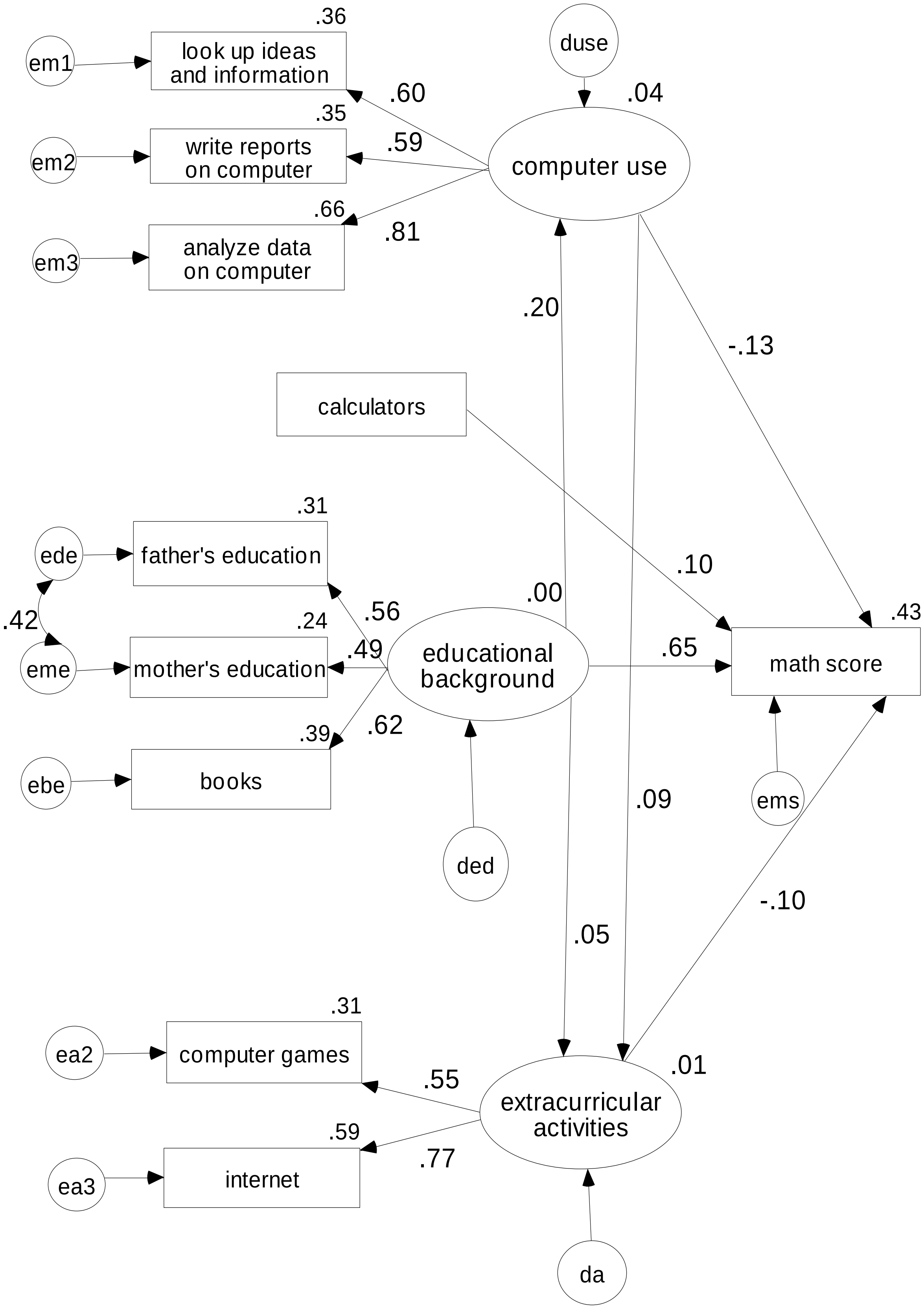


Figure 5. USA model results

Bibliography

[1] Elena C. Papanastasiou "Factors that differentiate mathematics students in Cyprus, Hong Kong, and the USA," *Educational Research and Evaluation* 8 (2002): 129-146. ; Elena C. Papanastasiou, Michalinos Zembylas and Charalambos Vrasidas, "Reexamining patterns of negative computer-use and achievement relationships. Where and why do they exist?," in *Proceedings of the IRC-2004. TIMSS. Volume* 1: edited by Constantinos Papanastasiou (University Press, 2004), pp. 127-138.

[2] Harold Wenglinsky, *Does it compute? The relationship between educational technology and student achievement in mathematics,* (Princeton, NJ: ETS Policy Information Center-Research Division, 1998).

[3] Linda Brant Collins, and Kathleen Mittag Cage "Effect of calculator technology on student achievement in an introductory statistics course," *Statistics Education Research Journal,* 4(2005): 7-15.

[4] Jere Confrey, "Six approaches to functions using multi-representational software," *Proceedings of the 18th Conference of the International Group for the Psychology of Mathematics Education, 2(1994):* 217-224.; Avalos Cedillo, "Algebra as language in use: a study with 11-12-year-olds using graphic calculators," *Proceedings of the 21st Conference of the International Group for the Psychology of Mathematics Education, 2*(1997)*,* 137-144.

[5] Richard Noss, and Celia Hoyles, Windows on Mathematical Meanings: Learning Cultures and Computers (Dordrecht: Kluwer, 1996); Federica Olivero, "Conjecturing in open geometric situations using dynamic geometry: an exploratory classroom experiment," *Research in Mathematics Education, 3* (2001): 229-246.

[6] David Pratt and Richard Noss, "The Co-ordination of Meanings for Randomness," *Proceedings of the Twenty Second Annual Conference of the International Group for the Psychology of Mathematics Education,* 4 (*1998*): 17-24.; Efi Paparistodemou, and Richard Noss, "Designing for Local and Global Meanings of Randomness' continuum," *Proceedings of the Twentieth Eighth Annual Conference of the International Group for the Psychology of Mathematics Education Vol.* (2004), *p*p. 497-504.

[7] Seymour Papert, "Situating Constructionism," in *Constructionism,* edited by Idit Harel and Seymour Papert (New Jersey: ABLEX,1991), pp. 1-11.

[8] Richard Noss, and Celia Hoyles, *Windows on Mathematical Meanings: Learning Cultures and Computers* (Dordrecht: Kluwer, 1996).

[9] Susanne Lajoie, Victoria R.Jacobs, and Nancy Lavigne, "Empowering Children in Use of Statistics," *Journal of Mathematical Behavior, 14* (1995): 401-425.

[10] Uri Wilensky, "What is normal anyway? Therapy for epistemological anxiety," *Educational Studies in Mathematics, 33,* (1997): 171-202.

[11] Idit Harel, and Seymour Papert, 1990. "Software Design as a Learning Environment," in *Constructionist Learning,* 1990, edited by Harel, Idit (Massachusetts: MIT Media LaboratoryP, pp. 19-50.

[12] Penelope H. Dunham, and Thomas P. Dick, "Research on graphing calculators," *Mathematics Teacher, 87* (1994): 440-445.

[13] Alan Graham, and Michael Thomas, "Tapping into algebraic variable through the graphic calculator," *Proceedings of the 21st Conference of the International Group for the Psychology of Mathematics Education, 3*(1997): 9-16.

[14] Avalos Cedillo, "Algebra as language in use: a study with 11-12-year-olds using graphic calculators," *Proceedings of the 21st Conference of the International Group for the Psychology of Mathematics Education, 2*(1997)*,* 137-144.

[15] Sally Elliott, Brian Hudson, and Declan O'Reilly, "Visualization and the influence of technology in A-level mathematics: a classroom investigation," *Research in Mathematics Education, 2* (2000): 151-168.

[16] John Schacter, "The impact of education technology on student achievement. What the most current research has to say" (www.mff.org/publications/publications.taf?page=161[October 2006]). ; Rupert Wegerif, "The role of educational software as a support for teaching and learning conversations," *Computers and education,* 43 (2004): 179-191.

[17] Elena C. Papanastasiou, Michalinos Zembylas, and Charalambos Vrasidas, "An examination of the PISA database to explore the relationship between computer use and science achievement," *Educational Research and Evaluation, 11*(2005): 529-543. ; Jason Ravits, John Mergendoller, and Wayne Rush, "*What's school got to do with it? Cautionary tales about correlations between computer use and academic achievement"* (paper presented at the annual meeting of the American Educational Research Association, New Orleans, LA, April 2002). ; Harold Wenglinsky, *Does it compute? The relationship between educational technology and student achievement in mathematics,* (Princeton, NJ: ETS Policy Information Center-Research Division, 1998).

[18] Ina V. S., Mullis, Michael O. Martin, Teresa A., Smith, Robert A. Garden, Kelvin D. Gregory, Eugenio J Gonzalez, Steven J. Chrostowski, and Kathleen M. O'Connor, *TIMSS Assessment frameworks and specifications 2003 (2nd ed.)* (Chestnut Hill, MA: TIMSS and PIRLS International Study Center, Lynch School of Education, Boston College, 2003).

[19] Ina V. S., Mullis, Michael O Martin, Eugenio J. Gonzalez, and Steven J. Chrostowski, *TIMSS 2003 international mathematics report Findings from IEA's Trends in International Mathematics and Science Study at the Fourth and Eighth grades (*Chestnut Hill, MA: TIMSS and PIRLS International Study Center, Lynch School of Education, Boston College, 2004).

[20] James L. Arbuckle, 2003. *Amos 5.0* [Computer software]. Chicago: SPSS.

[21] Barbara M. Byrne, *Structural equation modeling with AMOS: Basic concepts, applications and programming* (Mahwah, NJ: Lawrence Erlbaum Associates Publishers, 2001).

[22] Li-tze Hu, and Peter M. Bentler, "Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives," *Structural equation modeling, 6* (1999): 1-55.

[23] Matthew DeBell and Chris Chapman, "*Computer and internet use by students in 2003"* NCES 2006-065.(Washington D.C: U.S. Department of Education, National Center for Educational Statistics, 2006).

[24] Elena C. Papanastasiou "Factors that differentiate mathematics students in Cyprus, Hong Kong, and the USA," *Educational Research and Evaluation* 8 (2002): 129-146. ; Elena C. Papanastasiou, Michalinos Zembylas and Charalambos Vrasidas, "Reexamining patterns of negative computer-use and achievement relationships. Where and why do they exist?," in *Proceedings of the IRC-2004. TIMSS. Volume* 1: edited by Constantinos Papanastasiou (University Press, 2004), pp. 127-138.

[25] Elena C. Papanastasiou, Michalinos Zembylas, and Charalambos Vrasidas, "An examination of the PISA database to explore the relationship between computer use and science achievement," *Educational Research and Evaluation, 11*(2005): 529-543.

[26] Harold Wenglinsky, *Does it compute? The relationship between educational technology and student achievement in mathematics,* (Princeton, NJ: ETS Policy Information Center-Research Division, 1998).

[27] Robert James, and Charles Lamb, "Integrating science, mathematics, and technology in middle school technology-rich environments: A study of implementation and change," *School Science and Mathematics, 100 (*2000): 27-36. ; Jay Sivin-Kachala, *Report on the effectiveness of technology in schools, 1990-1997* (Washington, DC: Software Publisher's Association, 1998).; Lani Van Dusen and Blaine R. Worthren, "The impact of integrated learning system implementation on student outcomes: Implications for research and evaluation," *International journal of educational research, 21* (1994):13-24.

[28] Rosamund Sutherland and Nicolas Balacheff, "Didactical complexity of computational environments for the learning of mathematics," *International Journal of Computers for Mathematical Learning, 4* (1999): 1-26.

[29] Richard Noss, and Celia Hoyles, *Windows on Mathematical Meanings: Learning Cultures and Computers* (Dordrecht: Kluwer, 1996).

[30] National Council of Teachers of Mathematics (NCTM), *Curriculum and evaluation standards for school's mathematics* (Reston, VA, 1989).