

# **Comparing the relationship between using educational technology in mathematics and student achievement in South Africa and Germany**

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## **Abstract**

This study explored the relationship between educational technology and the mathematics achievement of South African and German students. Hierarchical Linear Models (HLM) showed that the availability of computers at school and using computers in the mathematics classroom in South Africa positively associated with the mathematics achievement of students. In Germany, the shared use of a computer/tablet with others at home and internet connection correlated positively with students' mathematics performances while students who owned mobile phones achieved lower mathematics results than their counterparts. Similarly, in both countries, students owning a computer/tablet, students using computers/tablets "every or almost every day" for schoolwork at home, school and other places achieved lower mathematics results than their counterparts.

## **Introduction**

Countries globally have been using various comparative studies to measure the effectiveness of their education systems. The International Association for the Evaluation of Educational Achievement (IEA) has been providing a platform for countries to compare the effectiveness of their education systems since 1985 (IEA, 2019). For instance, participants can measure and compare their learners' mathematics and science performance (Trends in Mathematics and Science Study [TIMSS]) and their reading skills (Progress in International Reading Literacy Study [PIRLS]) (IEA, 2019). More than 60 countries participate every four years in one or more of the comparative studies administered by the IEA (Mullis et al., 2016a). For instance, TIMSS provides insights into the curriculum implementation, school and home resources, background information of mathematics and science teachers, principals, learners and sometimes their parents (Mullis et al., 2016a). Participating countries can then use this background information to measure how it relates to learner performance in a country and across countries. For example, South Africa and Germany have been using TIMSS to measure their learners' mathematics and science performance against other participating countries since 1995. In the most recent assessment, TIMSS 2015, the mathematics achievement of South African learners was ranked second-last out of 48 participating countries (Mullis et al., 2016b). The average score of these learners was 376 out of a possible 1,000, and only 1% achieved above 625 points (Reddy et al., 2016). This means that only a few of these learners could successfully "apply understanding and knowledge in a variety of relatively complex situations and explain their reasoning" (Mullis et al., 2016b). What is of even greater concern is the context in which South Africa participated in the study. South Africa administered the TIMSS numeracy (TIMSS-N) assessment, which is an easier version of the fourth-grade assessment, to their Grade 5 learners to "allow more time for appropriate

interventions to be introduced into the schooling system” (Reddy et al., 2016, p. 3). Compared to South Africa, the Grade 4 learners from Germany achieved a higher average of 522, which was above the average of TIMSS (500) (Mullis et al., 2016b). Even though the learners’ mathematics average was above the international average, it was lower than the average (527 points) for countries from the European Union (EU) (Wendt et al., 2016). What’s more, only 5% of these learners achieved more than 625 points, indicating that only a few learners in Germany were ranked at the advance international benchmark level (Mullis et al., 2016b). The difference in the mathematics performance of these learners could be linked to various factors, such as the use of educational technology in mathematics.

The literature showed that some educational researchers used data from TIMSS to investigate how the use of educational technology influences the mathematics achievement of learners (Geesa et al., 2019; Sahin & Ozturk, 2018; Yavuz et al., 2019). Due to the clustered nature of TIMSS data, some researchers used Hierarchical Linear Modeling (HLM) to analyze the datasets (Wiberg, 2019). Researchers also used these datasets mostly to compare the mathematics performance between countries (Hu et al., 2018). However, limited studies have compared the integration of educational technology in mathematics education between South Africa and Germany. The latter was included because of the country’s performance around the center point (500) and because of the initiation of the DigitalPak#D project at the beginning of the year 2018, which aimed to equip 40,000 schools in Germany with new computers and software applications (Zech, 2018). This is important because similar projects, such as the Smart School project, were initiated in South Africa at the same time (Western Cape Education Department (WCED), 2019). Using data from TIMSS 2015, this study compares the relationship between using educational technology at school- and learner-level and the mathematics achievement of learners in South Africa and Germany. This study was guided by two research questions namely:

- What are the similarities and differences regarding the relationship between using educational technology at school-level and the South African and German learners’ mathematics performance?
- What are the similarities and differences regarding the relationship between using educational technology at learner-level and the South African and German learners’ mathematics performance?

## **Literature and theoretical framework**

### ***The relationships between using educational technology and mathematics achievement at school-level***

Research showed that the availability and use of educational technology at schools (Hu et al., 2018; Saal et al., 2019) and in mathematics classrooms (Bulut & Cutumisu, 2017; Eickelmann et al., 2017) influence learner achievement. However, the findings showed contrasting results between the use of educational technology and learner achievement in mathematics (see Table 1). For instance, Hu et al. (2018) found a positive relationship between the availability of ICT at school and learner performances in 44 countries that participated in PISA 2015. Likewise, Saal et al. (2019) found that South African learners who participated in TIMSS 2015 outperformed their counterparts in the case where the school had educational technology available that they could use. In contrast, Eickelmann et al. (2017) found a statistically negative relationship between the availability of computers and the mathematics achievement of German learners in PISA 2012. Similarly, Skryabin et al. (2015) found that computer usage at schools negatively influenced the achievement of the eight-graders in TIMSS 2011 and PISA 2012.

**Table 1.**

Significant positive and negative relationships for different uses of educational technology at school-level.

Different uses of educational technology	Significant positive relationships	Significant negative relationships
Availability educational technology at school	[(Hu et al., 2018); PISA 2015] [(Saal et al., 2019); TIMSS 2015; South Africa]	[(Eickelmann et al., 2017); PISA 2012. Incl. Germany] [(Skryabin et al., 2015); PISA 2012]
Availability/use of internet at school	[(Erdogdu & Erdogdu, 2015); PISA 2012; Turkey]	[(Eickelmann et al., 2017); PISA 2012]
Using computers during mathematics lessons	[(Saal et al., 2019); TIMSS 2015; South Africa] [(Visser et al., 2015; TIMSS 2011; South Africa)]	[(Eickelmann et al., 2017) PISA 2012. Incl. Germany, Netherlands] [(Bulut & Cutumisu, 2017); PISA 2012; Turkey]
Use computers “every, or almost every day” to look up ideas and information	(Falck et al., 2018) (Zhang & Wang, 2020)	
Use computers to practise skills and procedures		[(Kruger, 2018); TIMSS 2015; South Africa] [(Ayieko et al., 2017); TIMSS 2011; South Korea, Singapore, Chinese Taipei]

Focusing on the availability and use of the internet, Erdogdu and Erdogdu (2015) found that the availability of and accessibility to internet at school positively influenced the mathematics achievement of learners from Turkey in PISA 2012. However, Eickelmann et al. (2017) found that Australian learners in PISA 2012 performed worse when the internet connection was insufficient. The authors also found that when internet usage is promoted in German schools, learner achievement decreases. Concentrating on the availability and use of educational technology in the mathematics classroom, Saal et al. (2019), as well as Visser et al. (2015), found that South African learners, who participated in TIMSS 2015 and 2011 respectively, who were taught by mathematics teachers that used computers and software during mathematics lessons, outperformed their counterparts. Additionally, Saal et al. (2019) found that the relationship was significantly positive when learners shared or had their own computer available during mathematics lessons. On the other hand, Eickelmann et al. (2017) found that use of computers negatively correlated with learner achievement in Norway and Germany. Similarly, Bulut and Cutumisu (2017) found that the use of ICT in the mathematics classroom correlated negatively with the mathematics results of Finnish and Turkish learners participating in PISA 2012.

Contrasting relationships were also found between the different uses of educational technology and learner achievement. For instance, Falck et al. (2018) found that the mathematics achievement of learners who participated in TIMSS 2011 and who used computers “every, or almost every day” to look up ideas and information were higher than their counterparts, this result was also observed in the United States (Zhang & Wang, 2020). On the contrary, Ayieko et al. (2017), as well as Kruger (2018) cautioned against the frequent use of educational technology in mathematics instruction. This is because Ayieko et al. (2017) found that the mathematics reasoning scores of learners from Finland who participated in TIMSS 2011 decreased when they used computers “every, or almost every day” to practise skills and procedures. Kruger (2018) observed a similar relationship in South Africa using TIMSS 2015.

The former discussion indicates that there is an ongoing debate regarding the use of educational technology at the school-level. In particular, some researchers found that the use of educational technology has a positive influence on learner achievement, while others disagree. There is, thus, still more room for research focusing on the relationship between using educational technology and learner performances. The next section explains the different relationships between the use of educational technology in mathematics education at learner-level.

**Table 2.**

Significant positive and negative relationships for different uses of educational technology at learner-level.

Different uses of educational technology	Significant positive relationships	Significant negative relationships
Availability of digital devices at home	[(Saal et al., 2019); TIMSS 2015; South Africa] [ PISA 2012; Turkey]	[(Geesa et al., 2019); TIMSS 2015; South Korea, Turkey, the United States] [(Hu et al. (2018); PISA 2015]
Own computer or tablet		[(Geesa et al., 2019); TIMSS 2015; South Korea, Turkey, the United States] [(Saal et al., 2019); TIMSS 2015; South Africa] [(Saal et al., 2020); TIMSS 2015; Germany]
Own mobile phone	(Ariyanto et al., 2018); quasi-experiment method by pre and post-test; Indonesia]	[(Geesa et al., 2019); TIMSS 2015; South Korea, Turkey, the United States] [(Saal et al., 2020); TIMSS 2015; Germany]
Shared computer/tablet with other people at home	[(Saal et al., 2019); TIMSS 2015; South Africa] [(Geesa et al., 2019); TIMSS 2015; South Korea, Turkey, the United States] [(Kruger, 2018); TIMSS 2015; South Africa]	
Internet connection	[(Erdogdu & Erdogdu, 2015); PISA 2012; Turkey]	[(Zhang & Liu, 2016); PISA 2000 to 2012]
Using computer/ tablet at home for schoolwork	[Tan & Hew, 2019); PISA 2012] [(Rodrigues & Biagi, 2017); PISA 2015]	[(Ayieko et al., 2017); TIMSS 2011; South Korea, Singapore, Chinese Taipei]
Using computer/tablet at school for schoolwork		[(Kruger, 2018); TIMSS 2015; South Africa]
Using a computer or tablet at other places for schoolwork		[(Saal et al., 2019); TIMSS 2015; South Africa]

### ***The relationships between using educational technology and mathematics achievement at learner-level***

The use of educational technology at learner-level also showed mixed results (see Table 2). In particular, Saal et al. (2019) found that South African learners in TIMSS 2015 with more digital devices at their homes outperformed their counterparts. A similar finding was observed in Turkey using PISA 2012 (Bulut & Cutumisu, 2017). In contrast, Geesa et al. (2019) found that learners from Turkey and the United States with more digital devices at home performed worse than their counterparts. Correspondingly, the findings of Hu et al. (2018) using PISA 2015 showed that learners with ICT available at home performed worse than those learners without ICT at home. What's more, is that learners who owned a computer or tablet in South Korea, Turkey (Geesa et al., 2019), South Africa (Saal et al., 2019) as well as in Germany (Saal et al., 2020) outperformed their counterparts. Furthermore, learners who owned a mobile phone in Turkey (KoVgar, 2019), the United States (Geesa et al., 2019) and Germany (Saal et al., 2020) achieved lower mathematics results than their counterparts. On the contrary, Ariyanto et al. (2018) found that learners from Indonesia achieved higher mathematics scores than their counterparts when they used mobile phone applications.

It seems as if learners with digital devices at home need to share these devices with others at their homes to improve their mathematics scores (Saal et al., 2019). For instance,

the learners from South Africa who participated in TIMSS 2011 and 2015, who shared a computer/tablet at home with other people in the home, outperformed their counterparts (Kruger, 2018). Geesa et al. (2019) observed a similar relationship in Turkey, South Korea and the United States.

The availability of the internet at home somehow positively influenced the mathematics achievement of learners, as found in (Erdogdu & Erdogdu, 2015). However, a contrasting finding emerged from the results of Zhang and Liu (2016), indicating that the use of the internet for schoolwork purposes at home correlated negatively with the mathematics achievement of learners.

Focusing on the frequent use of computers for schoolwork at home, Tan and Hew (2019) found a positive relationship when learners who participated in PISA 2012 used ICT at home for schoolwork and their achievement. Rodrigues and Biagi (2017) observed similar results, but only for European learners who sparingly used ICT at home for schoolwork who participated in PISA 2015. On the contrary, in Chinese Taipei and Finland (Ayieko et al., 2017) and in South Africa (Kruger, 2018), learner performances decreased the more often learners used computers for schoolwork purposes at home. Moreover, the regular use of computers for schoolwork purposes at school and other places also correlated negatively with learner performances in South Africa in TIMSS 2011 and 2015 (Kruger, 2018; Saal et al., 2019). Ayieko et al. (2017) observed similar results in Chinese Taipei regarding the use of computers for schoolwork at school. However, contrasting results were found in Singapore, Chinese Taipei and South Korea when these learners used computers for schoolwork at other places than at school or home (Ayieko et al., 2017). The reviewed literature at learner-level showed mostly negative relationships between using educational technology out of school time, especially for schoolwork. It, therefore, seems as if learners are using digital devices at home or other places for non-school related tasks, which could have influenced their mathematics achievement negatively.

The preceding discussion showed that both school- and learner-level factors influenced the mathematics achievement of learners. Therefore, an adaption of the comprehensive model of educational effectiveness created by Creemers (1994), which is an extension of Carroll's model of school learning (Carroll, 1963), guided this study (see Figure 1). The application of the four assumptions of the comprehensive model of educational effectiveness (Creemers, 1994) is shown in Appendix A.

## **Method**

### ***Sampling***

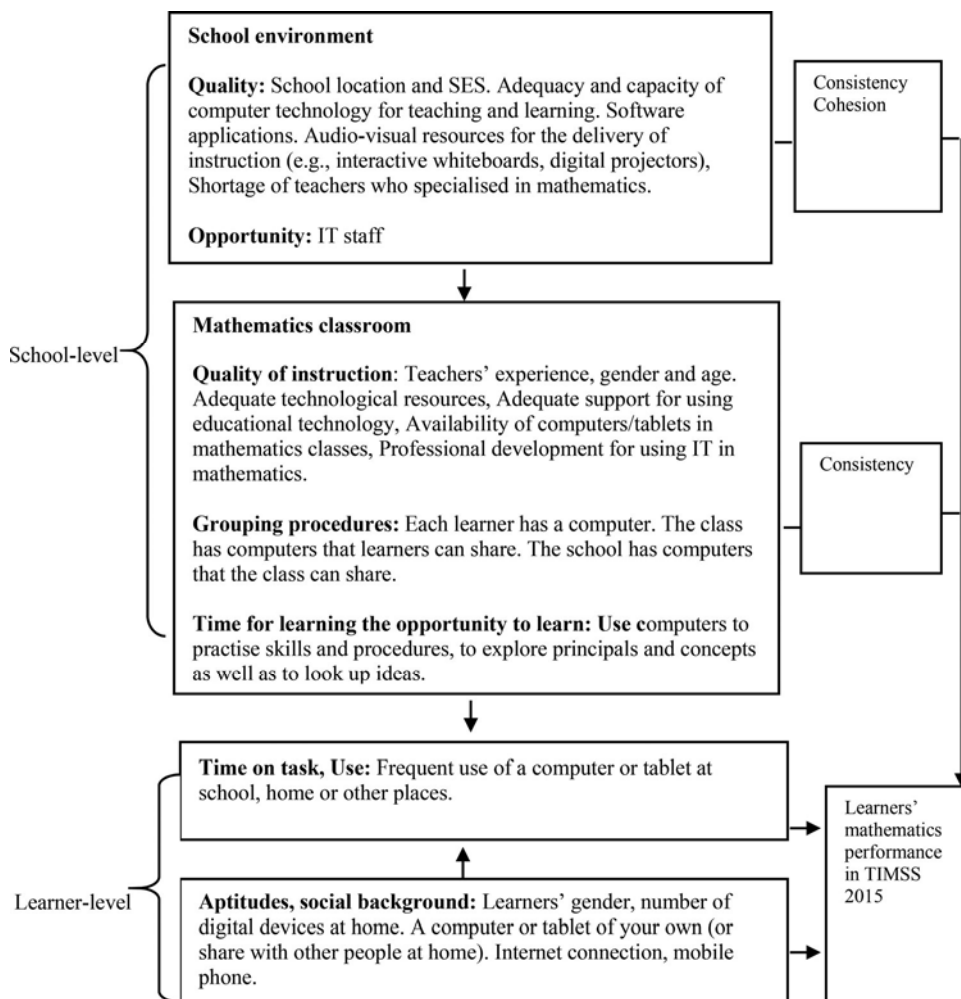
A secondary data analysis was conducted, drawing on the TIMSS 2015 Grade 5 mathematics dataset of South Africa and Grade 4 mathematics dataset of Germany. These datasets were retrieved in the Statistical Package for the Social Sciences (SPSS) format from the IEA data repository. In 2015, the IEA in conjunction with the TIMSS and PIRLS International Study Center at Boston College, gathered information in the form of questionnaires from Grade 4 learners, their parents, teachers, principals, and curriculum coordinators from 48 countries (Mullis et al., 2016b). Data was also gathered from Grade 5 learners in selected countries, for instance, South Africa and Norway.

Stratified sampling was used, to group schools with common attributes together, for example, by school type (LaRoche et al., 2016). During the first sampling stage, schools were sampled according to their size. The sample frame was then stratified. For example, in South Africa, schools were sampled based on province, the language of instruction and type of school, while schools in Germany were stratified based on the immigration status and category of the school. Stratification was regarded as an important element to "improve the efficiency of the sample design, thereby making survey estimates more reliable" also to "ensure proportional representation of specific groups of schools in the sample" (LaRoche et al., 2016, p. 3.12). Statistics Canada, with the help of IEA DPC, made use of systematic random sampling to sample each school, together with two replacement

schools (Johansone, 2016). In total, 10,376 parents, 10,932 Grade 5 learners, their mathematics teachers and principals from 298 schools in South Africa participated in this study (Reddy et al., 2016). In Germany, a total of 2,470 parents, 3,948 Grade 4 learners, their mathematics teachers and principals from 204 schools took part in this study (LaRoche & Foy, 2016).

**Figure 1.**

Adaption of creemers comprehensive model of educational effectiveness (Creemers, 1994).



### **Data collection**

The IEA administers the TIMSS assessment every four years in a consistent manner (Johansone, 2016). This means standardized procedures are followed in each cycle. For example, some of the TIMSS 2011 items were included in the TIMSS 2015 assessment, and some of these items will be included in the TIMSS 2019 assessment. Moreover, TIMSS 2015 ensured construct validity by applying item analysis (LaRoche & Foy, 2016). Data collection

for South Africa occurred during October and December 2014, while it took place from March until May 2015 in Germany (Johansone, 2016). This study included questions from the TIMSS 2015 school-, mathematics teacher-, learner-, as well as the home-questionnaire. To measure reliability, TIMSS 2015 also applied the Cronbach's Alpha test in all questionnaire items (Johansone, 2016). The mathematics achievement scores, which contained five plausible values (ASMMAT01-ASMMAT05), were also used. The National Research Coordinators (NRCs) assigned test administrators for each school who assigned one booklet to learners in a systematic manner. Every booklet contained 14 mathematics, as well as 14 science items, that learners completed within 36 minutes with a required interval of 30 minutes (LaRoche et al., 2016).

### ***Data analysis***

HLM version 7 was used to explore the relationship between the use of educational technology and the learners' mathematics achievement since it considered the nested structure of the TIMSS data (Raudenbush et al., 2013). The learners' gender was controlled for at level-1 (variables from the learner and home questionnaires), while the mathematics teachers' gender, the location of the school as well as the socio-economic status were controlled for at level- 2 (variables from the principal and mathematics teacher questionnaires). The expectation-maximization (EM) procedure was applied to deal with missing data. A two-level HLM model was created because the learners were nested within schools. The level-1 variables were centered around the group mean of the learners, while the level-2 variables were grand centered.

### **Results and discussion**

A null and full model were created (see Appendix B). Table 3 shows the relationships between the use of educational technology in mathematics education and the mathematics achievement of learners. The findings of the full model that illustrates the significance level, as well as coefficients for the variables, were used to address the research questions. Only the statistically significant results of each country are described in this study.

#### ***Similarities and differences at school-level***

Results showed that teaching experience did not influence the mathematics achievement of South African learners. On the other hand, teaching experience had somehow influenced the learners' mathematics achievement negatively in Germany ( $\beta = -1.27$ ,  $p = 0.001$ ). This finding disagrees with the findings of Sahin and Ozturk (2018), who found that teaching experience positively influenced the mathematics achievement of learners in Turkey and Chinese Taipei.

This study also found that learners taught by German teachers under 25 years old ( $\beta = 9.48$ ,  $p = 0.024$ ) outperformed those who were taught by teachers who were 60 years and older. This finding is supported by the results of Armstrong (2015), who found that South African learners taught by younger teachers who participated in the Southern and Eastern African Consortium for Monitoring Educational Quality (SACMEQ) 2007 study outperformed their counterparts.

Educational technology provides learners with visuals and customized learning environments that match their progress in mathematics (Zhu et al., 2016). It was thus no surprise when the results showed that South African learners with computers/tablets ( $\beta = 59.94$ ,  $p = 0.001$ ) in their mathematics classes outperformed their counterparts. This finding is, however, in contrast with the results of Bulut and Cutumisu (2017), who found a statistically negative relationship between the use of ICT at school, specifically in mathematics lessons for learner achievement in Turkey.

The findings also revealed that the South African learners who had computers available at the school that the class could use for mathematics lessons ( $\beta = 180.50$ ,  $p < 0.001$ )

achieved higher mathematics scores than their counterparts. A supporting finding emerged from the results of Hu et al. (2018), indicating that the mathematics achievement of learners from 44 countries positively correlated with the availability of ICT at school.

Furthermore, South African learners who were taught by teachers who let them use computers “every, or almost every day” to look up ideas and information ( $\beta = -166.48$ ,  $p = 0.008$ ) performed worse than those who “never, or almost never” use computers for this purpose. On the other hand, results that emerged from Falck et al. (2018) found that the more the learners who participated in TIMSS 2011, used computers to look up ideas and information, the higher their mathematics results were.

Similar to the findings of Caponera and Losito (2016) learners from both South Africa and Germany who were enrolled at schools that accommodated “0 to 10%” of learners that came from economically disadvantaged homes (South Africa,  $\beta = 44.26$ ,  $p = 0.007$ ; Germany,  $\beta = 17.42$ ,  $p < 0.001$ ), outperformed those who were enrolled at schools where “more than 50%” of learners came from economically disadvantaged homes.

As expected, the learners from South African schools, where the capacity to provide instruction was “not at all” affected by a shortage or inadequacy of computer software for mathematics instruction ( $\beta = 39.53$ ,  $p = 0.028$ ), achieved higher mathematics results than their counterparts. This result is on par with the findings of Visser et al. (2015), who found that the use of computer software in mathematics correlated positively with the mathematics achievement of South African learners.

**Table 3.**

Results from the full model of South Africa and Germany.

	South Africa			Germany		
	$\beta$	<i>s.e.</i>	<i>p</i>	$\beta$	<i>s.e.</i>	<i>p</i>
School-level predictors						
Mathematics teachers teaching experience Significant Coeff=1.27. Continuous ratio variable [e.g. learners taught by teachers with less teaching experience were outperformed by their counterparts on average with 1.27 points; thus, for every one year more experience the teacher has, the marks increase on average by 1.27]	1.41	2.28	0.536	-1.27	0.37	0.001*
Mathematics teachers' gender	-15.11	18.87	0.424	2.01	7.00	0.774
Mathematics teachers' age Significant Coeff= 9.48 [1: 60 or more; 2: 50–59; 3: 40–49; 4: 30–39; 5: 25–29; 6: Under 25] [e.g. learners taught teachers under 25 outperform their counterparts on average with 9.48 points]	-0.70	20.15	0.972	9.48	4.18	0.024*
Adequate technological resources at school	-9.36	11.52	0.417	1.89	2.92	0.519
Adequate support for using educational technology at school	9.88	13.08	0.451	-4.30	3.01	0.155
Availability of computers/tablets in mathematics classes Significant Coeff = 59.94 [1: No; 2: Yes] [e.g. learners taught by teachers with computers/tablets in their mathematics classes outperform their counterparts on average with 59.94 points]	59.94	18.39	0.001*	-2.30	4.39	0.600
Every learner has his/her own computer in the mathematics classroom	60.94	53.22	0.253	-8.65	23.64	0.715

The school has computers that the class can use Significant Coeff = 180.50 [1: No; 2: Yes] [e.g. learners taught teachers where the school has computers that the class could use outperform their counterparts on average with 180.50 points]	180.50	36.48	<0.001*	-6.43	6.61	0.332
Computers to practise skills and procedures	-5.10	28.63	0.059	-5.82	3.74	0.122
Computers to explore principles and concepts	86.08	58.91	0.145	3.02	4.04	0.455
Computers to look up ideas Significant Coeff = 166.48 [1: Never or almost never; 2: Once or twice a month; 3: Once or twice a week; 4: Every or almost every day] [e.g. learners taught by teachers who used computers to look up ideas “every or almost every day” were outperformed by their counterparts on average with 166.48 points]	-166.48	62.80	0.008*	3.71	4.63	0.424
Professional development for using IT in mathematics	23.21	29.06	0.425	7.03	7.77	0.367
Economically disadvantaged homes Significant Coeff = 44.26 [1: More than 50%; 2: 26 to 50%; 3: 11 to 25%; 4: 0 to 10%] [e.g. learners who attended schools that hosted “0–10%” of learners from economically disadvantaged areas outperformed their counterparts on average with 44.26 points]	44.26	16.23	0.007*	17.42	2.23	<0.001*
Economically affluent homes	-0.97	13.49	0.943	2.18	2.25	0.335
Technologically competent staff	-31.20	21.93	0.156	2.30	2.72	0.398
Audio-visual assets for teaching and learning	-15.28	11.38	0.181	1.27	3.01	0.674
Computer technology for teaching and learning for learner use	-19.47	13.22	0.142	0.35	3.44	0.919
Shortage of teachers who specialized in mathematics	-21.91	12.53	0.081	4.26	3.66	0.246
Computer software for mathematics instruction Significant Coeff = 39.53 [1: A lot; 2: Some 3: A little; 4: Not at all] [e.g. learners who attended schools where computer software for mathematics software was “not at all” a problem outperformed their counterparts on average with 39.53 points]	39.53	17.85	0.028*	-1.61	2.95	0.586
Learner-level predictors						
The gender of the learners Significant Coeff = 14.24 [1: Boys, 2: Girls:] [Read from down to up: for e.g. The girls mathematics achievement was 14.24 points on average more than that of the boys]	14.24	1.74	<0.001*	-8.40	3.06	0.008*
The learner own Computer/tablet Significant Coeff = -16.81 [1: No; 2: Yes] [e.g. learners who owned a computer/tablet were outperformed by their counterparts on average with 16.81 points]	-16.81	2.18	<0.001*	-8.29	3.65	0.039*
Shared Computer/tablet with other	0.39	1.76	0.826	15.38	2.65	<0.001*

people at home Significant Coeff = 15.38 [1: No; 2: Yes] [e.g. learners who shared a computer/tablet with other people at home outperformed their counterparts on average with 15.38 points]						
Internet connection at home Significant Coeff = 24.36 [1: No; 2: Yes] [e.g. learners with an internet connection at home outperformed their counterparts on average with 24.36 points]	6.13	2.77	0.054	24.36	3.51	<0.001*
Own mobile phone Significant Coeff = -22.63 [1: No; 2: Yes] [e.g. learners who owned a mobile phone were outperformed their counterparts on average with 22.63 points]	0.90	1.72	0.604	-22.63	3.61	<0.001*
Using computer or tablet at their homes for schoolwork Significant Coeff = -2.78 [1: Never or almost never; 2: Once or twice a month; 3: Once or twice a week; 4: Every or almost every day] [e.g. learners who used computers/tablets “every or almost every day” were outperformed by their counterparts on average with 2.78 points]	-2.78	0.90	0.006*	-3.80	1.16	0.001*
Using computer or tablet at school for schoolwork Significant Coeff = -13.45 [1: Never or almost never; 2: Once or twice a month; 3: Once or twice a week; 4: Every or almost every day] [e.g. learners who used computers/tablets “every or almost every day” were outperformed by their counterparts on average with 13.45 points]	-13.45	0.82	<0.001*	-12.26	1.90	<0.001*
Using a computer or tablet at other places for schoolwork Significant Coeff = -2.01 [1: Never or almost never; 2: Once or twice a month; 3: Once or twice a week; 4: Every or almost every day] [e.g. learners who used computers/tablets “every or almost every day” were outperformed by their counterparts on average with 2.01 points]	-2.01	0.70	0.005*	-8.00	1.56	<0.001*
Digital devices at home Significant Coeff = -8.51 [1: More than 10 devices; 2: 7–10 devices; 3: 4–6 devices; 4: 1–3 devices; 5: None] [e.g. learners with no digital devices at home were outperformed by their counterparts on average with 8.51 points]	-8.51	1.12	<0.001*	-11.66	2.25	<0.001*

### *Similarities and differences at learner-level*

Even though the study of Kaleli-Yılmaz and Hanci (2015) showed that the gender of learners doesn't relate to their mathematics achievement, we found that girls ( $\beta = 14.24, p < 0.001$ ) outperformed boys in South Africa. This finding is in contrast with the study of Meggiolaro (2018), which found that boys in Italy achieved higher mathematics than girls. In contrast to the finding of South Africa, girls were outperformed by boys in Germany ( $\beta = -8.40, p = 0.008$ ). The latter finding contradicts the results of Abdelfattah and Lam

(2018), who found that Arab girls achieved better mathematical results than boys.

Similarly, learners from both countries who owned a computer/tablet (South Africa,  $b = 16.81$ ,  $p$ -value  $< 0.001$ ; Germany,  $\beta = -8.29$ ,  $p = 0.039$ ) achieved lower mathematics results than those who didn't. This finding was in line with the results of Geesa et al. (2019), who found that learners from South Korea and Turkey achieved lower mathematics scores when they owned a computer/tablet.

In line with the findings of Saal et al. (2019) as well as Geesa et al. (2019), the German learners achieved higher mathematics scores than their counterparts when they shared a computer/tablet with other people at their homes ( $\beta = 15.38$ ,  $p < 0.001$ ). Furthermore, German learners who had an internet connection (Germany,  $\beta = 24.36$ ,  $p < 0.001$ ) at home achieved higher mathematics results than their counterparts. A supporting finding emerged from Yoo (2018), who found that learners with an internet connection at home out-performed those without an internet connection at home. Findings also showed that German learners who owned a mobile phone ( $\beta = -22.63$ ,  $p < 0.001$ ) achieved lower mathematics results than their counterparts. This finding is in contrast with the results of KoVgar (2019) and Geesa et al. (2019), who found a significant positive relationship between the use of mobile phones and the mathematics achievement of learners.

In contrast with the results of Yoo (2018) as well as Petko et al. (2017), learners from both countries who used computers/tablets "every, or almost every day" for schoolwork at home ( $\beta = -2.78$ ,  $p = 0.006$ , South Africa;  $\beta = -3.80$ ,  $p = 0.001$ , Germany), achieved slightly lower mathematics results than learners who "never, or almost never" used computers/tablets for schoolwork at home.

In agreement with the findings of Kruger (2018) as well as Zhang and Liu (2016), learners from both countries who used computers/tablets "every, or almost every day" for schoolwork at school ( $\beta = -13.45$ ,  $p < 0.001$ , South Africa;  $\beta = -12.26$ ,  $p < 0.001$ , Germany) were outperformed by learners who "never, or almost never" used computers/tablets for schoolwork at school.

Similar to the findings of Ayieko et al. (2017), learners from both countries who used computers/tablets "every, or almost every day" for schoolwork at other places ( $\beta = -2.01$ ,  $p = 0.005$ , South Africa;  $\beta = -8.00$ ,  $p < 0.001$ , Germany) achieved lower mathematics results than learners who "never, or almost never" used computers/tablets for schoolwork at other places.

Lastly, learners from both countries who reported that they have no digital devices at home ( $\beta = -8.51$ ,  $p < 0.001$ , South Africa;  $\beta = -11.66$ ,  $p < 0.001$ , Germany) achieved lower mathematics scores than those who indicated that they have "10 and more" devices at their homes. This finding is in agreement with the results of Geesa et al. (2019), who found that more digital devices at home resulted in lower mathematics achievement in Turkey and the United States.

The preceding discussion indicates that there is a statistically significant difference between using educational technology at school- and learner-level and the mathematics achievement of learners in South Africa and Germany.

**Table 4.**

Summary of statistically significant relationships at school-level.

	Statistically significant negative relationship	Statistically significant positive relationship	No statistically significant relationship
Differences			
Using computers to look up ideas	South Africa		Germany
Availability of computers at school		South Africa	Germany
Using computers/tablets in the mathematics class		South Africa	Germany
Using computer software in the mathematics class		South Africa	Germany
Teaching experience in years		Germany	South Africa
Teachers age	Germany		South Africa
Similarity			
Economically disadvantaged homes		South Africa Germany	

**Conclusion**

The purpose of this study was to compare the relationship between the use of educational technology in mathematics education and learner performances in South Africa and Germany. The first research question was: *What are the similarities and differences regarding the relationship between using educational technology at school-level and the South African and German learners' mathematics performance?* Findings showed more statistically significant relationships at school-level in South Africa than in Germany, as shown in Table 4.

More differences than similarities were observed at school-level between these countries. For example, a negative relationship was found between the use of computers to look up ideas in South Africa, whilst it did not influence the mathematics results of German learners. The South African learners most probably could not apply the ideas and information retrieved from computers/internet in mathematics, which could have resulted in lower mathematics scores. A contrasting finding emerged from the studies of Falck et al. (2018) and (Zhang & Wang, 2020).

**Table 5.**

Summary of statistically significant relationships at learner-level.

	Statistically significant negative relationship	Statistically significant positive relationship	No statistically significant relationship
Differences			
The gender of the learners	Germany	South Africa	
Shared Computer/tablet with other people at home		Germany	South Africa
Internet connection		Germany	South Africa
Own mobile phone	Germany		
Similarity			
The learner own Computer/tablet	Germany South Africa		
Using computer or tablet at their homes for schoolwork	South Africa Germany		
Using computer or tablet at school for schoolwork	South Africa Germany		
Using a computer or tablet at other places for schoolwork	South Africa Germany		
Digital devices at home	South Africa Germany		

Furthermore, the availability of computers at school, as well as using computers/tablets and computer software in the mathematics class, positively predicted the mathematics scores of South African learners. It is worth to note that the education system in South Africa is highly unequal. The variance amongst the schools in South Africa was also higher than in Germany, which also points to the inequality in South African schools. One can therefore assume that these learners whose mathematics achievement improved with the availability and use of computers and software/programs are most likely from economically affluent homes. Again, no significant relationship was found between these predictors and the mathematics achievement of the German learners, which correlates with previous research (Wittwer & Senkbeil, 2008). This relationship might be explained by the findings of TIMSS 2015 that indicated that fewer German than South African teachers used computers in mathematics instruction, even though German schools are more equipped with computers than the schools in South Africa (Mullis et al., 2016a).

Some predictors were also significant in Germany, but not in South Africa. For example, results indicated that teaching experience influenced the mathematics achievement of German learners negatively, and the teachers' age correlated positively with learners' performances. Conversely, no statistically significant relationship was found in South Africa. The finding that learners taught by younger teachers achieved higher marks in mathematics could be explained that younger teachers perhaps used innovative ways of teaching mathematics. The only similarity between these countries at this level was "economically disadvantaged homes" that positively associated with the mathematics achievement in both countries. In line with Caponera and Losito (2016), this finding indicated that learners from both countries who attended schools which hosted "0–10%"

learners from economically disadvantaged homes achieved higher mathematics scores than their counterparts. A possible explanation for this positive finding could be that learners from schools who host “0–10%” of learners from economically disadvantaged homes have more home resources, such as educational technology to assist them with mathematics-related tasks.

Next, we look at the second research question: *What are the similarities and differences regarding the relationship between using educational technology at learner-level and the South African and German learners’ mathematics performance?* South Africa and Germany had more similarities than differences at learner-level (see Table 5). In line with Geesa et al. (2019) the “shared use of computers with people at home,” as well as an “internet connection” positively influenced the mathematics scores of German learners, while it did not influence the learners’ achievement in South Africa. The fact that an internet connection had no influence on learner achievement could be due to the finding of TIMSS 2015 stating that less than 40% of these learners have internet connection at their homes (Mullis et al., 2016b). Whereas close to 80% of German learners reported to have an internet connection at home (Mullis et al., 2016b). This means that these learners could have used, for example, YouTube, to deepen their understanding of mathematics, which could have improved their achievement scores (Daoud et al., 2020).

Similar to the findings of Saal et al. (2020), German learners who owned a mobile phone achieved lower results than their counterparts, while owning a mobile phone had no influence on the mathematics results of South African learners. The German learners could have used their phones mostly to play games, which could have interfered with their concentration in mathematics that resulted in lower results. Also, the gender of the learners positively associated with the South African learners’ mathematics results, while a negative relationship was detected in Germany. This means that the girls achieved higher mathematics scores than boys in South Africa, while the opposite was observed in Germany. The difference in mathematics performance based on the learners’ gender could be linked to the teachers’ characteristics that might have influenced the mathematics achievement of learners in these countries. What’s interesting is that learners from both countries without digital devices at home achieved lower mathematics scores than their counterparts. However, when learners own a computer/tablet as well as using it frequently for mathematics schoolwork at home, school and other places, their mathematics scores decrease. These learners might have used their computers/tablets for social media instead of mathematics-related tasks, which could have influenced their results. Also, when learners used computers/tablets at other places (most of the time), their parents or teachers might not be with them to guide or assist them with schoolwork, which could have influenced their results.

This study was limited to the TIMSS 2015 datasets for South Africa and Germany. Consequently, future researchers could add more countries, perhaps ten high, middle and low-performing countries to allow three-level HLM. It would also be interesting to conduct a mixed-method study to find out why these predictors influenced learner performances in mathematics. This study contributes to the literature on international and intercultural comparative studies focusing on educational technology in mathematics education. The findings that emerged support the use of computers and software in the mathematics classroom but caution against the frequent use of computers at home, school and other places for schoolwork. In sum, even though the availability of educational technology at school and learner-level improved the scores of South African learners, their results remain lower than the German learners, where educational technology did not influence their performances.

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## Appendices

### *Appendix A: Theoretical model*

The four assumptions of the comprehensive model of educational effectiveness (Creemers, 1994) were applied in this study in the following manner:

Firstly, time on task as well as opportunity used at the learner-level influence learner achievement. This study assumed that the extent to which South African learners who participated in the TIMSS 2015 mathematics assessment used a computer or tablet at school, home or other places influenced their performance in mathematics. Creemers (1994) further explained that the quality of instruction, the curriculum and the grouping procedures in the classroom, influence the time on task and opportunity to learn. This is because some teachers spend more time educating the learners, while others spend most of their time organizing and managing their classroom. In this study, the curriculum aspect was omitted because the purpose was not to investigate how the curriculum influences the learners' mathematics achievement.

Secondly, the context-, school-, and classroom-levels influence the time on task and opportunities used at learner-level. Even though the teachers have the ability to influence the time on task and opportunities to learn through their quality of instruction and grouping procedures, learners' aptitude, motivation and social background may determine to what extent they complete school-related tasks. In this study, we assume that learners' social background which includes variables related to their gender, digital devices at home, ownership of computers/tablets, as well as an internet connection, influence their time on task, opportunities, as well as their mathematics achievement.

Thirdly, higher levels make provision for lower levels. For instance, factors at context-level make provision for school-level, factors at school-level support the classroom-level and the factors at classroom-level support the learner-level. As a result of this relationship, the mathematics performance of learners should be related to factors at all levels. However, due to the nature of this study, the learners' achievement for this study is not linked to context-level factors. In this study, home and learner-level factors are referred to as learner-level predictors, and school and classroom-level variables are referred to as school-level predictors.

Fourthly, in an attempt to improve learner achievement, variables at all levels should support one another. Creemers (1994) also refers to this as the consistency principle. Consequently, consistency should be evident within and amongst all the levels. Creemers also argue that all teachers or members of the schools should demonstrate features of effective teaching, which he refers to as cohesion. Furthermore, constancy, which is another principle, implies that effective education should be provided to learners during their academic career (Creemers, 1994). Lastly, the model indicates that the goals and climate of the school should be controlled. Arguably, one notes that it might be difficult to evaluate or investigate these principles in a study, especially in this study which is based on secondary data from TIMSS 2015. However, Kyriakides et al. (2000) argue that these principles are present "when the same factors operate across instructional components, subjects, classes, and grades" (p. 504). In this study, we assumed that these principles are present across instructional components and classes since the study is based on one grade and one subject.

### *Appendix B: Null and full model*

Firstly, a null model was created for each country. The null model did not include any variables since the purpose was just to determine the variance at each level (school- and learner-level) (Garson, 2013). The results showed that the variance of the null model is 57.84% and 17.07% for South Africa and Germany, respectively. Furthermore, the variance at school-level, for both countries, is significantly different from zero ( $p$ -value  $< 0.001$ ).

Secondly, a full model was created for both countries, which included both school- and learner-level variables,

to investigate the relationship between these variables. The variance at school-level is 38.76% and 12.23% for South Africa and Germany, respectively. Consequently, the variance at learner-level is 61.24% for South Africa and 87.77% for Germany. Furthermore, the variance at school-level (both countries) is significantly different from zero ( $p$ -value  $< 0.001$ ).