Chapter # 43

RELATIONSHIP BETWEEN SCHOOL CLIMATE AND GRADE 9 LEARNER ACHIEVEMENT IN SCIENCE: COMPARING SOUTH AFRICA AND SINGAPORE

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ABSTRACT
South Africa scored worst in scientific achievement at the night-grade level in the Trends in International Mathematics and Science Studies (TIMSS) 2019. Singapore, the TIMSS 2019 leader, and South Africa are compared. Quantitative positivist design was applied. Multi-level models showed that, for both counties, learners with a higher sense of belonging performed better. In Singapore, school buildings, grounds, and audio-visual tools for instruction were significant predictors; however, in South Africa, appropriate instructional materials and technologically skilled staff were. Singaporean learners at schools where principals claimed their audio-visual resources for instruction were not affected by shortage or inadequacy performed significantly worse than those in schools where principals said it is affected. Several explanations were offered for this surprising discovery, but Singapore education officials and stakeholders may need to investigate more. Thus, for Singapore, we urge additional investigation of the surprising outcome while, for South Africa, prioritising schools with insufficient instructional materials and training all teachers in technology. Stakeholders should also invest in school climate surveys and other interventions supporting a healthy school environment. Additional research is encouraged to establish the nature of the impact that a healthy school climate has on learner achievement through longitudinal studies where causation can be proven.

Keywords: school climate, learner achievement, TIMSS 2019, multi-level models.

1. INTRODUCTION

In South Africa, poor learner achievement in science has occupied the centre stage with the release of the TIMSS 2019 results, where TIMSS refers to the “Trends in International Mathematics and Science Studies” (Reddy et al., 2021, p. 1). Although TIMSS studies are conducted on Grade 4 and Grade 8 levels, South Africa uses Grade 5 and Grade 9 as South African learners had participated at Grade 4 and Grade 8 levels in previous cycles of TIMSS and performed poorly (Reddy et al., 2015). The focus of this study is on Grade 9 level. TIMSS 2019 can be divided into low (under 400), intermediate (under 475), high (under 550), and advanced (under 625) benchmarks (Mullis, Martin, Foy, Kelly, & Fishbein, 2020) with learners achieving above 400 points being classified as “having acquired basic … science knowledge” (Reddy et al., 2021, p. 4) and only 36% of South African Grade 9 learners achieving this for science. At Grade 9 level, 39 countries participated, and South Africa was last in science achievement, whereas Singapore was first on the opposite end. Many comparative educational studies have been done between different nations and Singapore (even South Africa with Singapore (e.g. Chinengundu, Hondonga, Chakamba, Masina, & Mawonedzo, 2022; Milne & Mhlolo, 2021; Wolhuter & Russo, 2013), as Singapore is one of the top-performing nations globally; this is evidence by large-scale international studies such as TIMSS. Perhaps Singapore’s innovations in its science education curricula have led to their success. In Singapore, learners’ first encounter with a formal science class is at the age of nine (in Primary 3), and the science curriculum framework is implemented through a “science as an inquiry” (Tan, Teo, & Poon, 2016, p. 159) platform which explores learners’ attitudes toward science application in real-life situations. Science is made practical, and both the learner and the teacher are involved in the inquiry process, with the learner as the “inquirer who determines ways to solve problems by asking appropriate questions, planning and conducting experiments, analysing the data collected, drawing conclusions, communicating and defending their findings” (Tan et al., 2016, p. 159). In South Africa, as soon as learners enter the school at Grade R (age 5 to 6 years), they are introduced to science; however, the curriculum limits science learning to only one of the “Life Skills” topics for Grades R to 4 (Foundation Phase) and only moves to “Natural Sciences and technology” topic in Grade 5 (age 11 years) and, accordingly, “teachers seem to minimise early science learning opportunities” (Minnaar & Naude, 2016, p. 366). The latter authors concluded by stating that South African teachers find it challenging to teach science skills and concepts in such a way that is relevant to young children.

South Africa can learn many lessons from Singapore regarding science education. As scientific inquiry has the potential to make science more engaging for learners, South Africa’s science curriculum could benefit from Singapore’s expertise in these areas. South Africa should likewise embrace this method in which learning in the classroom is conducted to tackle real-world problems outside of the classroom. It’s also interesting that South African learners are exposed to science (or at least some form of it) at the early ages of five or six years of age, whereas learners in Singapore are only exposed the formal science learning at the age of nine, yet Singapore greatly outperforms South Africa in science achievement. This may be attributed to the fact that South African early-year teachers seem to have a lack of understanding of science concepts (Kazeni, 2021; Ogegbo & Ramnarain, 2020), find it challenging to teach science skills and concepts in such a way that is relevant to young children (Minnaar & Naude, 2016).

Although many studies have been conducted on how to improve South African learners' science achievement, the focus is mainly on their poor exposure to science topics during early childhood development and the fact that South African early-year teachers seem to have a lack of understanding of science concepts (Kazeni, 2021; Minnaar & Naude, 2016; Ogegbo & Ramnarain, 2020). In South Africa, early primary school (grades R to 3) scientific education has been in the limelight in recent years, as science education academics increasingly recognise the need to establish a solid foundation in science education in order to persuade learners to continue studying the topic in later grades; however, fewer studies focus on the later years by exploring factors negatively associated with South African learners science achievement in later years. Thus, in this study, Grade 9 is the focus, and since much literature has shown that school climate is associated with learner performance (this literature will be considered next), we included an investigation into this topic in this study. Furthermore, since it seems that South Africa can learn much from Singapore relating to science education, a comparative study between South Africa and Singapore is conducted. Thus, this study is taking a multi-faceted approach by not only conducting a comparative study between the country that performed the worst in science in TIMSS 2019 (South Africa) and the one that performed the best (Singapore) to explore what that worst-performing country can learn from the top-performing country, but it also explores the relationship between school climate and teaching outcomes. All this is done with the aim of exploring how all these issues can help improve South African science achievement. The association between school climate and learner performance is considered next.

School climate has become a staple of organisational-educational research and is considered here in relation to learner academic achievement. Many researchers have found school climate to be a predictor of learner achievement (Belton, 2021; Dolegowski, 2022;

Richard, 2021; Zysberg & Schwabsky, 2021). Belton (2021) conducted a study in Virginia, USA, using Grade 5 data from 97 schools, and found a strong correlation between school climate and learner achievement. In another American study using data from 6,670 fifth-graders, Richard (2021) found that a positive school climate had a significant relationship with English Language Arts achievement. Another American study (Dolegowski, 2022) which conducted qualitative research on teacher perceptions of the association between school climate and learner achievement in two rural schools in Western New York, found the school climate domains of engagement, safety and environment, to affect learner achievement significantly. Quansah (2022), who conducted a quantitative study in Ghana, found that many factors influence learner achievement, with school climate being one of them. In a study conducted in Brazil by Rizzotto and França (2022), who explored the association between school climate and science performance, they found that learners experiencing a positive school climate significantly outperformed learners experiencing a negative school climate. Within the South African context, Arends, Winnaar, and Namome (2021), using TIMSS 2015 data, showed that school climate and access to and use of school resources have a significant association with learner achievement. In two other South African studies, Winnaar (2021) and Graham (2022), both analysed TIMSS 2019 data using different statistical techniques, and both found that school climate was significantly associated with learner achievement. Maslow's hierarchy of needs (Maslow, 1943) was used as theoretical framework, as learners attending a school with a negative climate cannot devote their full attention to learning, which, in turn, negatively impacts learner achievement. The South African results are compared to the results of Singapore, as Singapore is the top-performing country in TIMSS 2019 (Reddy et al., 2021) concerning science achievement. South Africa and Singapore have many similarities; for example, both countries have a very similar colonial rule history and lacked inclusive quality education systems for many decades (Milne & Mhlolo, 2021). Also, classes in both nations are instructor-led and focus on learning pre-existing information, using a language, English, other than the mother tongue of most students, as the main media of instruction (Naroth & Luneta, 2015; Tan, 2017). The two countries followed different paths to accommodate all exceptional students rather than the select few favoured during the colonial era (DBE, 2011; Milne & Mhlolo, 2021). Singapore strove to create an inclusive education system driven by excellence, while the South African education model was based on ensuring equity (Milne & Mhlolo, 2021). The vastly different outcomes motivated more than 80 South African schools to attempt an intervention utilising the Singapore mathematics curriculum (SMC) to enhance students' mathematics proficiency (Naroth & Luneta, 2015) and motivated us to select Singapore for comparison purposes with South Africa. Perhaps if South Africa is following the lead of Singapore in mathematics, this could be considered for science as well with the aim of improving South African science achievement.

2. METHODOLOGY

2.1. Methods

Secondary data analysis refers to a research design that mostly uses existing data, mostly quantitative data, to reapply and reanalyse such data to test hypotheses or validate models (Mouton, 2001). We used a quantitative design with a positivist philosophical stance and a deductive approach. A secondary data analysis was run using Grade 9 TIMSS 2019 data from South Africa and Singapore.

2.2. Participants and instruments

In South Africa, a total of 519 schools and 20,829 learners participated in TIMSS 2019, whereas, in Singapore, it was 153 schools and 4,853 learners (LaRoche & Foy, 2020). Table 1 shows the TIMSS 2019 variables considered in this study; these are the independent variables (predictors), and the dependent variable is science achievement. Multi-level models were built using HLM software (Raudenbush & Bryk, 2002). Re-coding has to be done since, for the multi-level model, it's ideal to either use continuous or dichotomised variables in the analysis. The majority of the variables are categorical (with more than two response options), which makes interpretation of them challenging concerning achievement since we do not know what the reference categories are, and HLM will most likely read these variables as continuous variables. Accordingly, all variables have been re-coded to be binary. For binary variables, it is typical to use no centring at Level-1 (learner-level) and grand-centring at Level-2 (school-level) (Raudenbush & Bryk, 2002). Missing values were replaced using multiple imputation, which Van Ginkel, Linting, Rippe, and Van der Voort (2020) have shown is the best way to deal with missing values regardless of the type of missing value it is.

Table 1.
Details on the independent variables used in the multi-level models and information on re-coding.

Variable	Description	Response options	Re-coding done
	Level-1: Learner questionnaire answered by learners		
BSBGHER	"Home educational resources" (Martin, von Davier & Mullis, 2020, p. 16.168)	1 – 8.4 = "Few" 8.4 – 12.2 = "Some" > 12.2 = "Many"	1 – 12.2 = 0 = "Few or some" > 12.2 = 1 "Many" New variable name: BSBGHER ➔ L1V1
BSBG01	"Gender" (TIMSS, 2018b, p. 3)	1 = "Girl" 2 = "Boy"	0 = "Boy" 1 = "Girl" New variable name: BSBG01 ➔ L1V2
BSBGSSB	"Sense of school belonging" (Martin et al., 2020, p. 16.198)	1 – 7.8 = "Little" 7.8 – 10.7 = "Some" > 10.7 = "High"	1 – 10.7 = 0 = "Little or some" > 10.7 = 1 = "High" New variable name: BSBGSSB ➔ L1V3
	Level 2: School questionnaire answered by principals		
"How much is your school's capacity to provide instruction affected by a shortage or inadequacy of the following?"[i]			
BCBG13AA	"Instructional materials (e.g., textbooks)"	1 = "Not at all" 2 = "A little" 3 = "Some" 4 = "A lot"	0 = "Some or a lot" 1 = "Not at all or a little" New variable names: BCBG13AA ➔ L2V1 BCBG13AB ➔ L2V2 BCBG13AC ➔ L2V3 BCBG13AD ➔ L2V4 BCBG13AE ➔ L2V5 BCBG13AF ➔ L2V6 BCBG13AG ➔ L2V7 BCBG13AH ➔ L2V8 BCBG13AI ➔ L2V9
BCBG13AB	"Supplies (e.g., papers, pencils, materials)"		
BCBG13AC	"School buildings and grounds"		
BCBG13AD	"Heating/cooling and lighting systems"		
BCBG13AE	"Instructional space (e.g., classrooms)"		
BCBG13AF	"Technologically competent staff"		
BCBG13AG	"Audio-visual resources for delivery of instruction (e.g., interactive white boards, digital projectors)"		

Variable	Description	Response options	Re-coding done
BCBG13AH	"Computer technology for teaching and learning (e.g., computers or tablets for student use)"		
BCBG13AI	"Resources for students with disabilities"		

[i]All direct quotes from the school questionnaires are from TIMSS (2018a, p. 2)

3. ETHICAL CONSIDERATIONS

No permission was needed to analyse the TIMSS 2019 data, as it is available for public use on the IEA's website where IEA stands for "International Association for the Evaluation of Educational Achievement" (Fishbein, Foy, & Yin, 2021, p. II). The TIMSS 2019 data also has no identifiers, so schools and participants cannot be identified.

4. RESULTS AND DISCUSSION

The percentage responses for South Africa and Singapore for the re-coded variables are shown in Table 2, with the percentages for South Africa being in the first row and those of Singapore being in the second row. The differences in percentages are evident; for example, when considering the level-2 predictors, there is a clear pattern that, for South Africa, the distribution is roughly 50-50 between the categories of "some or a lot" and "not at all or a little", whereas, for Singapore, the distribution, this distribution is roughly 20-80 between "some or a lot" and "not at all or a little", indicating that, according to the principals, the majority of schools in Singapore is either not affected by shortages or inadequate resources or they are unaffected at all by shortages or inadequate resources, whereas, for South Africa, this is a very different picture with about half the schools being either not affected by shortages or inadequate resources or being unaffected at all by shortages or inadequate resources.

Table 2.
Percentage responses for South Africa and Singapore to selected predictors.

Variable	Response options	
	Few or some	Many
L1V1 "Home educational resources" (Martin et al., 2020, p. 16.168)	97.1 86.4	2.9 13.6
	Boy	Girl
L1V2 "Gender" (TIMSS, 2018b, p. 3)	46.7 51.2	53.3 48.8
	Little or some	High
L1V3 "Sense of school belonging" (Martin et al., 2020, p. 16.198)	53.3 72.2	46.7 27.8
	Some or a lot	Not at all or a little
"How much is your school's capacity to provide instruction affected by a shortage or inadequacy of the following?"[i]		
L2V1 "Instructional materials (e.g., textbooks)"	55.0 13.3	45.0 86.7

L2V2 "Supplies (e.g., papers, pencils, materials)"	49.1 11.3	50.9 88.7
L2V3 "School buildings and grounds"	50.0 15.8	50.0 84.2
L2V4 "Heating/cooling and lighting systems"	42.2 14.6	57.8 85.4
L2V5 "Instructional space (e.g., classrooms)"	52.3 17.2	47.7 82.8
L2V6 "Technologically competent staff"	54.0 22.5	46.0 77.5
L2V7 "Audio-visual resources for delivery of instruction (e.g., interactive white boards, digital projectors)"	52.0 14.5	48.0 85.5
L2V8 "Computer technology for teaching and learning (e.g., computers or tablets for student use)"	49.1 15.2	50.9 84.8
L2V9 "Resources for students with disabilities"	32.1 23.1	67.9 76.9

[i]All direct quotes from the school questionnaires are from TIMSS (2018a, p. 2)

Two multi-level analyses were conducted. Firstly, the null models without variables were created to indicate the variance in achievement amongst schools (see Table 3). For the South African null model, the variance at the learner level is 5,275.08, which signifies 47.5% of the total variance. The variance at the school level is 5,840.41, which represents 52.5% of the total variance, which is statistically significant (p < 0.001). For the Singapore null model, the variance at the learner level is 4,244.23, which signifies 53.8% of the total variance. The variance at the school level is 3,631.44, which represents 46.2% of the total variance, which is statistically significant (p < 0.001).

Table 3.
The null models.

		$\boldsymbol{var}$ component	$\boldsymbol{df}$	χ^2	$\boldsymbol{p}$	$\boldsymbol{var}$ explained
South Africa	Intercept	5,840.41	518	22,580.62	<0.001*	52.5%
	Level-1, r	5,275.08				47.5%
Singapore	Intercept	3,631.44	152	4,174.47	<0.001*	46.2%
	Level-1, r	4,224.23				53.8%

Note: *Statistically significant $\boldsymbol{p < 0.05}$, $\boldsymbol{var}$ = "variance", $\boldsymbol{df}$ = "degrees of freedom"

The parsimonious model was created by introducing all independent variables into the null model and then removing all insignificant variables one at a time, with only significant variables retained. Table 4 shows the results of the parsimonious model (also referred to as the final model).

Table 4.
The parsimonious models.

		$\boldsymbol{var}$ component	$\boldsymbol{df}$	χ^2	$\boldsymbol{p}$	$\boldsymbol{var}$ explained
South Africa	Intercept	5,240.22	516	20,749.54	<0.001*	50.0%
	Level-1, r	5,243.00				50.0%
Singapore	Intercept	3,328.34	152	3,887.41	<0.001*	44.5%
	Level-1, r	4,150.77				55.5%

For the South African parsimonious model, the variance at the learner level is 5,243.00, which signifies 50.0% of the total variance. The variance at the school level is 5,240.22, which represents 50.0% of the total variance, which is statistically significant ($p < 0.001$). For the Singapore parsimonious model, the variance at the learner level is 4,150.77, which signifies 55.5% of the total variance. The variance at the school level is 3,328.34, which represents 44.5% of the total variance, which is statistically significant ($p < 0.001$).

The average reliability estimate was 0.978 and 0.959 for the South African and Singapore final models, respectively, indicating that sample averages reflected the true school means. For South Africa, by comparing the variance components of the final models to those of the null models, the percentage reduction in the variance at learner-level was 0.6% (learner-level) and 10.3% (school-level). For Singapore, by comparing the variance components of the final models to those of the null models, the percentage reduction in the variance at learner-level was 1.7% (learner-level) and 8.3% (school-level). Table 5 shows the effect sizes (**β's**) of the significant predictors of the parsimonious models for South Africa.

Table 5.
Significant predictors of the parsimonious models for South Africa.

	β	$s.e.$	t	p
Intercept	352.41	6.83	51.59	<0.001*
Level-1/learner-level (Learner predictors)				
L1V1: “Home educational resources” (Martin et al., 2020, p. 16.168) 0 = *“Few or some”* 1 = *“Many”*	23.52	5.36	4.39	<0.001*
L1V2: “Are you a girl or boy” (TIMSS, 2018b, p. 3) *0 = “Boy”* *1 = “Girl”*	3.64	1.62	2.25	0.027*
L1V3: “Sense of school belonging” (Martin et al., 2020, p. 16.198) 0 = “*Little or some*” 1 = “*High*”	8.94	1.67	5.36	<0.001*
Level-2/school-level (School predictors)				
L2V1: “Instructional materials (e.g., textbooks)” (TIMSS, 2018a, p. 2) 0 = “*Some or a lot*” 1 = “*Not at all or a little*”	26.89	13.38	2.01	0.045*
L2V6: “Technologically competent staff” (TIMSS, 2018a, p. 2) 0 = “*Some or a lot*” 1 = “*Not at all or a little*”	30.17	12.68	2.38	0.018*

Note. *Statistically significant $p < 0.05$, $s.e.$ = “standard error”, t = “Approximate t-ratio”

Gender and socio-economic status were included in the model only as control variables and not discussed in detail here. At learner-level, learners who reported a high sense of school belonging performed significantly higher (on average by 8.94 points) than those that reported little of some sense of school belonging. This finding is not surprising, as Winnaar’s (2021) South African study also used the TIMSS sense of school belonging scale and had a similar finding. At school-level, there were two significant predictors. Learners from schools where the principals indicated that the school’s capacity to provide instruction is “not at all or a little" affected by a shortage or inadequacy of instructional materials performed significantly better (on average 26.89 points) than learners in schools where principals reported that it is affected "some or a lot". This result is not a surprising finding, as Arend et al.'s (2021) South African study also showed that access to and use of school resources has a significant association with learner achievement. Learners from schools where the principals indicated that the school's capacity to provide instruction is "not at all or a little" affected by a shortage or inadequacy of technologically competent staff performed significantly better (on average 30.17 points) than learners in schools where principals reported that it is affected "some or a lot". Table 6 shows the effect sizes (**β's**) of the significant predictors of the parsimonious models for Singapore.

Table 6.
Significant predictors of the parsimonious models for Singapore.

	β	$s.e.$	t	p
Intercept	599.21	5.59	107.03	<0.001*
Level-1/learner-level (Learner predictors)				
L1V1: "Home educational resources" (Martin et al., 2020, p. 16.168) 0 = *"Few or some"* 1 = *"Many"*	22.87	3.94	5.80	<0.001*
L1V2: "Are you a girl or boy" (TIMSS, 2018b, p. 3) *0 = "Boy"* *1 = "Girl"*	-8.02	2.55	-3.14	0.002*
L1V3: "Sense of school belonging" (Martin et al., 2020, p. 16.198) 0 = "*Little or some*" 1 = "*High*"	6.64	2.55	2.60	0.009*
Level-2/school-level (School predictors)				
L2V3: "School buildings and grounds" (TIMSS, 2018a, p. 2) 0 = "*Some or a lot*" 1 = "*Not at all or a little*"	34.85	12.71	2.74	0.007*
L2V7: "Audio-visual resources for delivery of instruction (e.g., interactive white boards, digital projectors)" (TIMSS, 2018a, p. 2) 0 = "*Some or a lot*" 1 = "*Not at all or a little*"	-44.12	14.04	-3.14	0.002*

*Note.**Statistically significant $p < 0.05$, $s.e.$ = "standard error", t = "Approximate t-ratio"

At learner-level, learners who reported a high sense of school belonging performed significantly higher (on average by 6.64 points) than those that reported little or some sense of school belonging. At school-level, there were two significant predictors. Learners from schools where the principals indicated that the school's buildings and grounds are "not at all or a little" affected by a shortage or inadequacy of it performed significantly better (on average 34.85 points) than learners in schools where principals reported that it is affected "some or a lot". Learners from schools where the principals indicated that the school's audio-visual resources for delivery of instruction (e.g., interactive white boards, digital projectors) are "not at all or a little" affected by a shortage or inadequacy of it performed significantly worse (on average 44.12 points) than learners in schools where principals reported that it is affected “some or a lot”. This result may seem counterintuitive; however, this result may be biased by the sparse responses in the category of “some or a lot”, with less than 15% of the principals in Singapore schools selecting this category. It is well-known that schools in Singapore use audio-visual resources for science teaching (see, e.g. Adams & Lim, 2020; Teo & Pua, 2021), so almost 15% of principals stating that there is a shortage may not have realised what is truly meant by the term “shortage”, as Singapore is the second richest country in the world (Global Finance, 2022) and ranks18th in the world according to the ICT Development Index (Machmud, Widiyan, & Ramadhani, 2021).

5. CONCLUSION

The multi-level analysis using HLM software showed that a high sense of belonging was a significant predictor of science achievement for both countries. For South Africa, schools with sufficient instructional materials, and technologically competent staff are significant predictors of science achievement. We recommend that South African schools with insufficient instructional materials be prioritised for receiving the necessary material and that all South African teachers be trained in the use of technologies, as these are significant predictors of learner achievement. This will, in turn, enhance learners’ sense of belonging, which is also a significant predictor. Another recommendation for South African schools is that stakeholders invest in school climate surveys and other interventions supporting a healthy school environment, as many researchers, including this study, have shown that a healthy school climate is a significant predictor of learner achievement. Additional research is encouraged to establish the nature of the impact that a healthy school climate has on learner achievement through longitudinal studies where causation can be proven. For Singapore, school buildings and grounds and audio-visual resources for the delivery of instruction were found to be significant predictors. It was also found that learners from schools where the principals indicated that the school’s audio-visual resources for delivery of instruction (e.g., interactive white boards, digital projectors) are “not at all or a little” affected by a shortage or inadequacy of it performed significantly worse than learners in schools where principals reported that it is affected “some or a lot”. We have tried to give some explanations as to why this counterintuitive result was found; however, it may not be up to us but rather to the policymakers and the stakeholders in the Singapore education system to further investigate this counterintuitive result.

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Short biographical sketch: From the start of her career, Prof. Graham focused on developing new statistical techniques, specifically in the research area of statistical quality / process control. In the last few years, she has deepened that focus to generate a more detailed understanding of how learning and assessment opportunities for students at all levels of the formal education system (early learning, primary, secondary and tertiary) and their overall mental health and well-being can be improved. She uses sophisticated, novel statistical techniques to inform that understanding. She is a Full Professor at the University of Pretoria and has contributed to many fields, including education, healthcare and social issues. She holds a doctoral degree in mathematical statistics from the University of Pretoria and is a Y1-rated researcher with the National Research Foundation (NRF), South Africa. She has published nearly 100 articles in peer-reviewed journals and regularly presents her findings at national and international conferences.