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Exploring differential science performance in Korea and South Africa: A multilevel analysis

Mee-Ok Cho

Vanessa Scherman

Estelle Gaigher

This paper reports on secondary analysis of TIMSS 2003 data with the aim of explaining the difference in science achievement of Korean and South African learners. The question asked by this research, i.e. which factors at various educational levels influence science achievement in Korea and South Africa respectively, is addressed from the perspective of school effectiveness. Data from Korea included 5 300 learners from 151 schools, while approximately 9 000 learners from 265 schools were tested in South Africa. The background data were analysed in conjunction with the achievement data by means of factor, reliability, correlation and multilevel analysis. The multilevel analysis revealed that the strongest predictor of science achievement is attitudes towards science in both countries at learner level while, at classroom/ school level, the strongest predictors are learner background in Korea and safety in school in South Africa respectively. In addition, factors specifically significant in Korea included educational resources, out-of-school activities, high expectation, professional development, and school size, while South Africa showed factors such as ethnicity and SES-related factors, textbook use, teacher age, teacher qualification, STS-based teaching, physical resources, and class size.

Keywords: science education; school effectiveness; South Africa; Korea; multilevel analysis; TIMSS.

Mee-Ok Cho
Faculty of Education
University of Pretoria
Pretoria 0001
e-mail: meeokcho@yahoo.com

Vanessa Scherman
Faculty of Education
University of Pretoria
Pretoria 0001
e-mail: vanessa.scherman@up.ac.za
Tel: 012 420 2498

Estelle Gaigher
Faculty of Education
University of Pretoria
Pretoria 0001
e-mail: estelle.gaigher@up.ac.za
Tel: 012 420 5663

Introduction

High-quality science education is an indicator of economic success around the world as research has shown that scientific literacy has a strong relationship with the level of economic growth (Hanushek, Jamison, Jamison & Woessmann, 2008). For this reason, education systems want to monitor science education and improve its quality. In the Trend in International Mathematics and Science Study (TIMSS), administered in 49 countries in 2003 under the auspices of the International Association for the Evaluation of Educational Achievement (IEA), South Korea and South Africa were found to be at the opposite ends of the spectrum. While South Korea is ranked among the higher-performing countries, South Africa is ranked among the lower-performing countries in both science and mathematics. Korea has a centralised education system and a homogeneous population with a single race, language and culture. Aspirations for higher education have led to intense competition (Paik, 2001). However, in contrast to their high performance, Korean students have low self-confidence and negative attitudes towards science (Martin, Mullis, Gonzalez & Chrostowski, 2004b). On the other hand, South Africa is a multicultural country characterised by poor resources, reform endeavours, multiple official languages and poor performance.

This article aims to explore factors related to science education at various levels, from the perspective of school effectiveness research (SER). The following research question was addressed: Which factors at various educational levels influence science achievement in Korea and South Africa respectively? The identification of effective factors at the various levels can lead to recognising similarities and differences that are related to learner achievement from a perspective of international comparative studies.

Literature review

In light of teaching and learning theory (Creemers, 1994), time on task and opportunity to learn have been emphasised as factors that influence learner performance. 'Time on task' refers to time spent on the learning task by learners and is also called 'effective learning time' (Scheerens & Bosker, 1997: 125) or 'academic learning time' (Creemers, 1994: 28). At the learner level, time on task contains the time spent on doing homework, private tutoring or outside-school activities (Cooper, Lindsay, Nye & Greathouse, 1998).

Opportunity to learn, as opposed to learning time, is defined mostly as content covered or curriculum alignment, and is measured in terms of the correspondence between learning tasks and the desired outcomes (Scheerens & Bosker, 1997). Wang (1998) found that content exposure, i.e. opportunity to learn, was the most significant predictor of learner test scores, especially written test scores, in Grade 8 science.

Aptitude, sometimes known as prior knowledge, refers to what the learner already knows and has been identified as the most important factor that influences achievement (Lindemann-Matthies & Kamer, 2006). The ability to understand instruction depends on learner aptitude (Creemers, 1994). Brookhart (1997) found that prior science achievement and general reading ability had the greatest impact on science achievement.

Attitude can be defined as a tendency or propensity to react to situations and ideas (Simpson, Koballa, Oliver & Crawley, 1994). Bloom (1976: 104) reports that 25% of the variance in school achievement could be accounted for by attitudes; research has consistently shown a correlation between attitudes and achievement (Shen & Tam, 2008).

Learners' social contexts refer to their socio-economic status (SES), ethnicity, language and gender. Goldhaber and Brewer (2000) report that family background variables explain a considerable amount of the variance in Grade 12 mathematics and science test scores. Besides, the SES of learners is determined by their parents' occupation and educational level. Factors at classroom and school levels also influence learner outcomes, particularly in developing countries where teacher and school factors prove to have a deeper effect on learners' science achievement than in developed countries (Heyneman & Loxley, 1983). Moreover, factors such as teacher academic skills, teacher experience, teaching assignment, and professional development were documented as effective (Mayer, Mullens, Moore & Ralph, 2000). High-quality professional development that is provided consistently improves science teachers' instruction (Desimone, Porter, Garet, Yoon & Birman, 2002). Educational leadership by principals has also been consistently reported to be an effective factor of achievement (Tate, 2001).

Effective teaching practice and teacher background in science can influence learner achievement directly (Johnson, Kahle & Fargo, 2007). Scheerens and Bosker (1997) propose structured instruction, including structure and preparation of lessons, direct instruction and monitoring as important factors.

Physical resources assist in understanding scientific knowledge and developing skills by means of hands-on activities (Rogan, 2000). While textbooks are important, class size has been shown to influence learner achievement (Blatchford, Russell, Basset, Brown & Martin, 2007). Most teachers use a textbook as the primary basis or a supplementary resource for their lessons (Martin *et al.*, 2004b), which helps them to make decisions on the implemented curriculum (opportunity to learn). The literature mentions many other factors such as classroom and school climates (Scherman, 2005); an orderly school atmosphere and a positive disciplinary climate (Mulford, 1988); high expectations from the school, community and home (Phillips, 1997); and the location of the school (Park & Park, 2006).

Conceptual framework for the study

The conceptual framework developed for the current research (see figure 1) is based on the Creemers (1994) and the Scheerens (1990) models, known as integrated and multilevel educational effectiveness models. The key concepts in this framework are time, opportunity and quality (see Cho, 2010 for further details). School-level and context-level factors are defined in terms of quality, time and opportunity which, in turn, influence the classroom and learner levels. Teacher experience or budget as inputs, and educational leadership, opportunity to learn, structured teaching and curriculum as process are seen to be important (Scheerens, 1990). For a detailed discussion, please refer to Cho (2010).

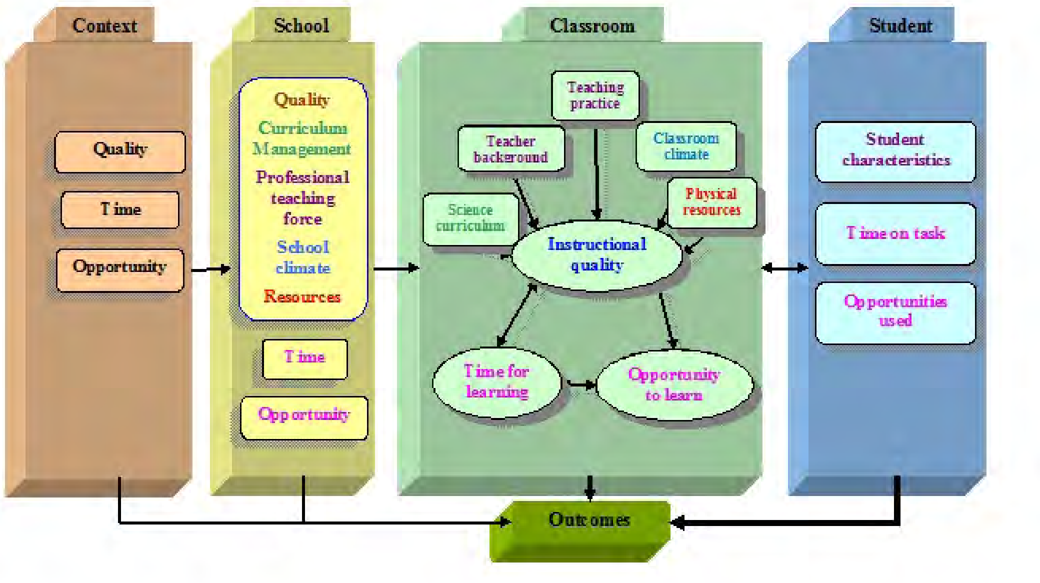

Figure 1: A proposed model of effectiveness of science education

Methodology

Sample and data collection

This research is a secondary analysis of the survey for TIMSS 2003. This survey was undertaken with 5 300 learners from 151 schools sampled from 14 to 19 April 2003 in Korea, and with approximately 9 000 learners of 265 schools in South Africa from 21 October to 1 November 2002 (Martin, Mullis & Chrostowski, 2004a).

Instruments

TIMSS 2003 consisted of achievement test items and questionnaires. The science achievement test assessed knowledge and skills based on school curricula for Grade 8 learners. The questionnaire data provided a context for the performance scores, focusing on learners' backgrounds and attitudes towards science, the science curriculum, teachers of science, classroom characteristics and instruction, school context and instruction (Martin et al., 2004a).

Data analysis

Factor and reliability analyses confirmed that the items are unidimensional and internally consistent. Scores were added to make scales, and variable names and labels were assigned for further analysis. Correlation analysis was undertaken to ascertain the relationship between the scales or factors identified so that these factors could be included in the multilevel analysis (table 1).

Table 1 The variables included in model

Korea South Africa

Factors in the research framework	Variable in preliminary analysis	Variable in MLwiN	Description of variables	N	M	SD	Range	Variable in preliminary analysis	Variable in MLwiN	Description of variables	N	M	SD	Range
Time on task	Tutorsci	Extutor	Extra tutoring in science	4876	1.51	1.33	0-3(3)	Tutorsci	Extutor	Extra tutoring in science	6784	1.47	1.09	0-3(3)
	Studyafsch	Timafsch	Study after school	4876	2.40	1.32	0-8(8)							
Attitude toward science	Likescience	Liksci	Liking science	4876	16.67	4.12	7-28(21)	Selfconsci	Selfcon	Self-confidence in science	6784	7.41	2.42	3-12(9)
Social context	Bookhom	Bokhom	Books at home	4876	3.21	1.28	1-5(4)	Agesy	Agestu	Student age	6784	3.26	1.20	1-5(4)
	Edudad	Edudad	Education level of father	4876	5.13	1.65	1-8(7)	Stucon	Boncnty	Country of birth	6784	0.65	0.48	0-1(1)
	Edustu	Edustu	School level expected by student	4876	3.99	0.74	1-5(4)	Languas	Languag	Student language at home	6784	1.33	0.94	0-3(3)
	Comuse	Comuse#	Computer use	4876	4.73	2.44	0-12(12)	Bookhom	Bokhom@	Books at home	6784	1.97	1.13	1-5(4)
								Hompos	Hompos	Home possession	6784	6.13	2.99	0-11(11)
								Watvi	Media	Watch TV or video after school	6784	1.67	1.41	0-4(4)
Science curriculum	Textuse	Textuse	Textbook use	198	0.92	0.27	0-1(1)	Textuse	Textuse	Textbook use	198	0.92	0.27	0-1(1)
Teacher background	Tchtotchpm	Tchtchpm#	Teacher interaction by information or pedagogy	137	2.80	1.26	0-6(6)	Agetcher	Agetch	Teacher age	198	3.05	0.82	1-5(4)

								Reqgrad	1stdeg	Complete the first degree	198	0.18	0.38	0-1(1)
								Tchtotchvo	Tchtchvo#	Interaction by visit or observation	198	1.20	1.45	0-6(6)
Teaching practice	Lectureag	lecturag*#	Lecture-centred teaching	137	2.39	0.22	1.66-2.8(1.14)	Useofhw	Basichw#	Use of homework(basic homework)	198	3.72	0.60	1-4(3)
								STS	STS	STS-centred teaching	198	7.13	2.40	2-12(10)
Classroom climate	Hixpect	Hixpect	High expectation	137	15.28	2.80	8-24(16)							
Physical resources	Phyresource	Phyres	Physical resource for science lesson	198	9.94	4.16	0-15(15)	Phyresource	Phyres	Physical resource for science lesson	198	9.94	4.16	0-15(15)
	Clasize	Clasize	Number of students in class	198	4.41	1.58	1-7(6)	Clasize	Clasize	Number of students in class	198	4.41	1.58	1-7(6)
Time for learning	Ttimew	Timspw#	Time scheduled/ week	137	2.25	0.37	1.5-3.5(2)	Ttimew	Timspw#	Scheduled time/week	198	2.87	1.38	1-5(4)
								Ttimts	Ttimpw#	Science teaching time/ week	198	4.40	1.86	1-8(7)
Professional teaching force	Profdevelop	Profdeve	Professional evelopment	137	4.48	1.65	1-10(9)	Pcaddu	Admindt	Principal administrative duty	198	3.33	1.55	1-7(6)
								Pcsuevt	Supevdt	Supervise or evaluate as principal duty	198	2.05	1.05	1-7(6)
								Proftchingf	Proftchf#	Professional teaching force	198	13.97	2.46	7-20(13)
School climate	Enrtot	Schsize	Enrolment of all grades	137	4.25	1.36	1-7(6)	Enrtot	Schsize#	Enrolment of all grades	198	3.04	1.35	1-7(6)
	Citysize	Citysize#	Type of community	137	5.05	1.21	1-6(5)	Citysize	Citysize#	Type of community	198	3.12	1.58	1-6(5)

	Studis	Disadva	Percentage of disadvantaged students	137	2.01	0.91	1-4(3)	Studis	Disadva	Percentage of disadvantaged students	198	3.76	0.68	1-4(3)
								Hixpect	Hixpect#	High expectation	198	5.67	1.64	2-10(8)
								lowmorals	Lomoral	Severity of low morale	198	4.37	2.16	0-8(8)
								Safeschag	Safschag*	Safety in school	198	2.39	0.54	1.27-3.87(2.6)

Note: * aggregated variable

non-significant variables according to the multilevel analysis

@ deleted variable due to low deviance improvement

One class in a school was sampled to allow data to be collected in a natural situation, although effects of both individual and group level variables need to be taken into account (Keeves & Sellin, 1997). The research method entailed a multilevel approach to analysis, allowing the researchers to examine influences between the levels as well as each level's impact on learner achievement. In addition, the multilevel analysis involves the interaction between and within each level, allowing factors specific to learners, classroom and school to be studied simultaneously.

Since TIMSS 2003 addressed one classroom per school, there are no between-class variations. Therefore, a two-level model was compiled that represents the learner and class/school level. Based on the null model, the explanatory variables from the learner and class/school levels were entered step by step into the null model, thus, compiling the full model by adding cross-level interactions. The model developed here is to explain the variation in science scores between learners (within schools) and between schools by the explanatory variables. The MLwiN software was used to specify the two-level model.

Results

Korean learners scored an average of 558 (SD 1.6), while South African learners achieved an average score of 244 (SD 6.7) in science in TIMSS 2003. As a result of the factor, reliability and correlation analyses, effective factors were identified for the two countries. Fifteen variables in the Korean data were identified as important and selected for the multilevel modelling: eight variables, including one aggregated variable at the learner level, three variables at the class level, and four variables at the school level.

As for South Africa, 27 variables were identified as important and remained for the multilevel modelling: nine variables, including one aggregated variable at the learner level, 10 variables at the class level, and eight variables at the school level. There is a large discrepancy in the number of significant factors for the two countries at the class and school level. A possible explanation might be that more factors at the class and school level influence learner achievement in South Africa than in Korea.

Table 2 Multilevel analyses of the Korean data

Model	*Null model*	*Learner model*	*Class/school model*
Fixed effects			
Learner level			
	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)
Intercept	558.307(1.878)	329.016(5.459)	319.418(9.634)
Attitude toward science			
Liksci		4.821**(0.212)	4.759**(0.211)
Social context			
Bokhom		11.901**(0.701)	11.779**(0.698)
Edustu		18.901**(1.199)	18.993**(1.195)
Time on task			
Timafsch		5.715**(0.659)	5.683**(0.656)
Social context			
Edudad		3.352**(0.551)	2.878**(0.554)
Time on task			
Extutor		3.360**(0.639)	3.309**(0.636)
Class/school level			
School climate			
Disadva			–5.417**(1.181)
Schsize			1.656*(0.776)
hixpect			0.747*(0.371)
Professional teaching force			
Prodeve			1.305*(0.614)
Random effects			
σ2e	4646.078(95.445)	3225.629(66.264)	3223.994(66.223)
σ2u0	350.446(58.353)	91.298(22.076)	43.997(16.357)
Deviance	55187.250	53325.210#	53281.750#

Note: N=4876 learners in 137 schools, ** t-value > 2.58 a confidence interval of 99%,

* t-value > 1.96 a confidence interval of 95%, # Deviance from null model to present model is significant at 0.01

In the final model of eight class/school-level variables in the Korean data, only four variables were statistically significant, as shown in table 2. Among 19 class/school variables tested for in the South African data, 11 variables remained statistically significant, as depicted in table 3. An aggregated variable, 'safety in school' as reported by learners, was the strongest predictor at the class/school level, while variables concerning school climate, such as 'percentage of disadvantaged learners' and 'severity of low morale' were also significant.

Table 3 Multilevel analyses of the South African data

Model	*Null model*	*Learner model*	*Class/school model*
Fixed effects			
Learner level			
	Coefficient(SE)	Coefficient(SE)	Coefficient(SE)
Intercept	245.040(7.223)	92.750(7.032)	135.674(29.915)
Attitude toward science			
Selfcon		8.162**(0.412)	8.102**(0.411)
Social context			
Boncnty		43.060**(2.204)	41.934**(2.183)
Agestu		10.809**(0.739)	10.868**(0.733)
Time on task			
Extutor		–10.638**(0.967)	–9.983**(0.963)
Social context			
Media		6.360**(0.701)	6.453**(0.699)
Languag		13.319**(1.351)	13.029**(1.323)
Hompos		2.805**(0.413)	2.809**(0.408)
Class/School level			
School climate			
Safschag			49.986**(5.295)
Disadva			–27.896**(4.566)
Physical resource			
Phyres			–3.050**(0.703)
Teacher background			
1stdeg			16.977**(7.322)
Professional teaching force			
Admindt			3.809*(1.813)
Teacher background			
Agetch			10.891**(3.171)

Science curriculum			
Textuse			−28.560**(10.153)
Resource			
Clasize			−2.878*(1.598)
Teaching practice			
STS			−2.197*(1.109)
Professional teaching force			
Supevdt			−6.592**(2.718)
School climate			
Lomoral			−2.165*(1.217)
Random effects			
σ^2_e	7034.088(122.582)	5609.017(97.749)	5608.399(97.738)
σ^2_{u0}	10109.060(1037.217)	4633.674(482.463)	1089.370(126.504)
Deviance	80118.130	78475.770#	78210.480#

*Note: N=6784 learners in 198 schools, * t-value > 1.96 a confidence interval of 95%, ** t-value > 2.58 a confidence interval of 99%, # Deviance from null model to present model is significant at 0.01*

With regard to resource variables, ‘physical resource for science’ and ‘number of learners in a class’ turned out to have significant effects. A science curriculum variable, ‘textbook use’, was also statistically significant. Among the teacher background variables, ‘completion of the first degree’ and ‘teacher age’ were statistically significant. For school principals, ‘administrative duty’ and ‘supervising or evaluating teachers’ explained learner achievement through statistical significance.

South Africa has more variables that are significant at the class/school level than Korea. Particularly, resource- and teacher background-related factors such as ‘physical resource for science lesson’ or ‘completion of first degree’ influenced learner science achievement in South Africa. Interestingly, only a single variable, ‘percentage of disadvantaged learners’, is significant in both countries in the classroom/school model.

For Korea, 93% of total variance in science achievement occurred at the learner level, while only 7% was attributed to the classroom/school level, as shown in table 4. For South Africa, 41% of the total variance was assigned at the learner level and 59% at the class/school level. In the learner-class/school model, the class/school-level variance is estimated at 87%, whereas 31% is estimated on the learner level in Korea. For the South African data, 20% of the variance can be attributed to the learner level, while 89% of the variance was attributed to the class/school level. The unexplained variance in both Korea and South Africa might imply that other variables which are not included but significant do exist, particularly at the learner level.

	Korea			*South Africa*		
	Null model	*Learner model*	*Class/school model*	*Null model*	*Learner model*	*Class/school model*
Learner level variance	0.930(93%)	0.306(30.6%)	0.306(30.6%)	0.410(41.0%)	0.203(20.3%)	0.203(20.3%)
Class/school level variance	0.07(7%)	0.739(73.9%)	0.874(87.4%)	0.590(59.0%)	0.542(54.2%)	0.892(89.2%)
AIC	55193.25	53343.21	53307.75	80124.13	78495.77	78252.48

Table 4 Explained proportion of variance by consecutive models

Discussion

While the learner level contributed more than the class/school level to variance for Korea, the opposite held for South Africa. This pattern aligns with earlier evidence indicating that the economically developed countries show a pattern of large influence by family SES with smaller school impact, and a reverse pattern in less-developed nations (Heyneman & Loxley, 1983).

Some factors were generic in both Korea and South Africa. Firstly, at the learner level, attitudes towards science are the strongest predictors of science achievement between individuals in both countries according to the results of multilevel analyses. This result also confirmed previous findings that were reported in the literature (Howie, Scherman & Venter, 2008; Shen & Tam, 2008). At the school level, the percentage of disadvantaged learners is important in both countries. The relationship between SES and achievement has been well documented in SER and is likely a stronger predictor at the school level than at learner level (Beaton & O'Dwyer, 2002). It was reported that the SES of a school influenced teaching practice more than either principal supportiveness or available resources (Supovitz & Tuner, 2000). Therefore, learners attending schools that have more advantaged learners can benefit in that they have more opportunity to learn content because the school offers more content and highly qualified teachers than do ones in disadvantaged areas (Ramírez, 2006).

On the other hand, each country showed unique patterns. At the learner level, Korean data revealed that educational resources in the home influence learner achievement. The results show that the father's education, school level expected by the learner, and books at home are significant in contributing to the model. With respect to time on task, out-of-school activities are significant in which more time on task is associated with learner achievement. Many Korean parents force their children to take extra tutoring in private institutes, called *Hakwon*, after school. Nonetheless, from a teaching and learning perspective, it is obvious that more time on task increases achievement (Šetinc, 1999). At the classroom level in Korea, it is argued that teachers' high expectation towards learners in class could be one of the ways that facilitates and increases learners' self-concepts (Muijs, Campbell, Kyriakides & Robinson, 2005).

At the school level, 'professional development', and 'school size' are specific to Korea. High-quality professional development improves teaching and prepares teachers to meet the diverse needs of today's learners which, in turn, closes achievement gaps (Desimone *et al.*, 2002). As it is a single alterable factor that can be manipulated by policymakers, high-quality professional development in science should be provided intensively and steadily, and teachers should be immersed in inquiry-based and subject matter tasks. 'School size' remained significant in Korea, because this influenced learners' and parents' educational zeal.

In South Africa, more significant factors include 'learner age', 'language at home', 'home possession', 'born-in country', and 'media', while educational factors are important in Korea. Some researchers document that minority ethnic groups fare worse than majority groups (Adigwe, 1997). This phenomenon is understandable, because learners from minority ethnic groups have to learn science knowledge in an instruction language that is different from their mother tongue (Rollnick, 2000). Such language barriers hold true for South Africa, which has 11 official languages and where language was found to be a strong predictor of learner achievement (Howie, 2002).

The older the learners, the less well they performed in South Africa. Lower learner age in South Africa, however, has a positive relationship with achievement. It might be related to learner SES along with home possessions, which showed a positive relationship with science achievement. Learners from educationally and economically poorly resourced homes are likely not to attend school regularly, or go to school later than supposed. As a result, they have less opportunity to learn and have to repeat grades because they have failed to pass the standard demanded by the curriculum (Fiske & Ladd, 2004). The classroom level has even more significant factors that are more specific to South Africa than Korea, notably textbook use, teacher age, teacher qualification, 'STS'-based teaching, physical resource, and class size. Textbook use is significant in South Africa; however the use of textbooks showed a negative relationship to performance. This was a surprising result because, in terms of opportunity to learn, textbooks can provide content of what should be taught in classrooms (Valverde & Schmidt, 2000) as well as the methods to be employed. The negative impact might be an indication that teachers use textbooks without reconstructing content for learners to make meanings for themselves. These aforementioned findings can be reconsidered in terms of teacher qualification and age, which is significant in South Africa and in agreement with Heyneman and Loxley (1983), who found that teacher and school quality was more important in developing countries.

At the school level, educational leadership, safety in schools and learner morale are good predictors of learner achievements in South Africa. Educational leadership has been proven to influence learner achievement since it was identified within effective schools in early SER (Scheerens & Bosker, 1997; Tate, 2001). South African results showed that a school performed better when the principal was involved in administrative duty instead of supervising and evaluating teachers. Previous findings (Reynolds, Creemers, Stringfield, Teddlie & Schaffer, 2002) have indicated that, where education systems are more decentralised, less engineered and less ordered, principals' leadership is more important than in centralised and better organised systems. It was found that South African schools were *closer* to the former.

According to the results of multilevel analysis, 'safety in school' is the strongest predictor of science achievement at the class/school level, which explains the high variance between schools in South Africa. This might indicate South African-specific educational, social contexts and 'low morale' as also significant.

Recommendations

From this comparative study, it is recommended that learner-centred teaching practices be developed to address negative attitudes to science at the context level in Korea, because it was proved that 'professional development' at the class/school level influences learner achievement. The professional development opportunities have to inform pedagogical content knowledge and teachers who are encouraged to change their practice to meet learners' needs, especially with regard to high achievement and positive attitudes at the context level. On the other hand, basic issues such as improving teachers' subject knowledge, developing language skills, and fostering a culture of learning should be addressed to improve science performance in South Africa.

Endnotes

1. The proportion of learners receiving free or reduced lunch was used as a proxy.
2. Mother education level also showed a strong relationship with science achievement but not as much as father education level. Accordingly, father education level was selected.

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