Development of a model of effectiveness in science education to explore differential science performance: A case of South Africa

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Abstract

This paper reports on secondary analysis of TIMSS 2003 data, based on a sound conceptual model, aiming to explain differential science achievement in South Africa from the perspective of educational effectiveness research. The conceptual framework was developed by refining existing school effectiveness models and including factors related to science achievement. The refined model integrated psychological and sociological aspects and reflected the multilevel-structure of schools. The model added resources and climate to the quality factors at class/school level. It was applied to the South African results of TIMSS 2003. Data from the student (n=8,952), teacher (n=255) and school questionnaires (n=255) were analysed in conjunction with achievement data by means of factor, reliability, correlation and multilevel analysis. The multilevel analysis revealed that at student level the strongest predictor of science achievement is attitude towards science. At classroom/school level, the strongest predictors are resource- and climate-related factors such as the safety in school, physical resources and class size. Factors at class/school level influenced performance more than student level factors with 59% of the total variance in science achievement occurring at class/school level. Such results indicate that the model developed is well suited to science education in developing countries.

Keywords: educational effectiveness model; science education; South Africa; multilevel analysis; TIMSS

Introduction

Educational systems aspire to maximise educational effectiveness, measured by student outcomes assumed to be gained by schooling. Educational Effectiveness Research (EER) has shown that many factors are likely to influence student achievement directly and indirectly and has formulated theories and developed models designed to account for the effectiveness of schools. Such theories and models can guide policy-makers around the world to develop and implement appropriate interventions to improve the quality of education. EER tends to measure educational effectiveness by using language or mathematics as an outcome.

On the other hand, high-quality science education is regarded as an indicator of economic success around the world as shown in findings that performance in science has a strong relationship with economic growth (Baker, Goesling & LeTendre, 2002; Hanushek, Jamison, Jamison & Woessmann, 2008). For this reason, educational systems want to monitor science education and improve its quality. The Trends in International Mathematics and Science Study (TIMSS) provides participating countries with valuable information that help them evaluate the standard of mathematics and science education.

South Africa has been frustrated by its poor performance in consecutive administrations of TIMSS, for both mathematics and science (Reddy, 2006). Specifically for science, South Africa was ranked last amongst 49 participating countries in TIMSS 2003 (Martin, Mullis, Gonzalez & Chrostowski, 2004). The poor performance of developing countries has often been attributed to poor infrastructure and teacher quality (Reddy, 2006). This is particularly true for South Africa, as the legacy of the Apartheid system has resulted in unequal distribution of resources (Howie, Scherman & Venter, 2008). Apart from the above-mentioned factors, the rich contextual data captured by TIMSS could be explored to obtain a broader view of the effectiveness of science education in the country. Such holistic understanding of the status quo could provide a broad basis for future development to improve the quality of science education in South Africa,

The current research aimed to develop a model to monitor effectiveness of science education and apply the model to explore effectiveness of science education in South Africa. Based on existing EER models and including factors related to science achievement, the new model was utilized in multilevel analysis of TIMSS 2003 data. The following questions were investigated:

1. How can the effectiveness of science education be modelled at different educational levels?
2. Which factors influenced differential performance in South Africa's TIMSS 2003 results for science?

The new model for effectiveness of science education can contribute to provide in the need for rational models based on theory in EER (Creemers & Kyriakides, 2006) and be useful to explore effectiveness of science education in different countries, including developing countries. In addition, the in-depth examination of TIMSS 2003 results for South Africa, comparing the main factors and explaining variances between students or schools, can make some recommendations to improve science education in South Africa.

Development of educational effectiveness models based on empirical evidence

Since Coleman and his colleagues reported that school made little difference in terms of student achievement when compared to family factors (Coleman, Campbell, Hobson, McPartland, Mood, Weinfeld & York, 1966), researchers have shown that many factors influence student achievement directly and indirectly. Specifically, they focused on effective schools in an attempt to identify the common characteristics that make some schools more effective than others. A meta-analysis of the previous literature undertaken by Walberg (1990) identified nine factors which influence educational productivity from a comprehensive psychological perspective. These factors were the ability or prior achievement of students, biological development, motivation, quantity of instruction, quality of instruction, home environment, classroom or school environment, peer group environment, and mass media environment. He excluded such organisational factors of schools as size, and individual characteristics such as gender.

Taking into consideration the process factors leads to another framework, namely instructional effectiveness theory. The most widely adopted theory of instructional effectiveness is Carroll's school learning theory, which consists of five factors all linked to the use of time (Carroll, 1963). Considering Carroll's learning model, Creemers (1994) developed a comprehensive model of educational effectiveness from a review of the empirical research on effective instruction and attempted to explain variances in student outcomes by such factors as aptitude, time on task, and opportunity to learn. The Creemers model focuses on the teaching-learning process in the classroom. Together with considering instructional effectiveness, the economic input-output paradigm was translated into an organisational paradigm, concerned with the hierarchical and multivariate nature of the school system (Zuzovsky & Aitkin, 1990). The Scheerens model (1990) attempts to explain school effectiveness from a systemic point of view namely the school as an organisational system, as opposed to Creemers' teaching and learning perspective.

Some research tested the conceptual models discussed above to offer empirical evidence (Reezigt, Guldemond & Creemers, 1999; Kyriakides, Campbell & Gagatsis, 2000; De Jong, Westerhof & Kruiter, 2004). Creemers' model has been tested against integrated and multilevel educational effectiveness models. The results confirmed multilevel influences on achievement, greater effect of classroom than school, with three key constructs such as time spent, opportunity to learn, and quality of instruction being strong predictors of achievement. However, findings from research do not always support Creemers' model. Reezigt et al. (1999) tested its main assumptions on the expected effects on student achievement of individual classroom and school level factors in language and mathematics. The results revealed inconsistency across the subjects, and that time for learning and opportunity to learn, which are essential factors in Creemers' model, had negative effects attributable to the mismatch of the language and mathematics tested and the actual content taught by the teachers. The study implies that the possibility of different effective factors not presented in Creemers' model should be considered (Creemers, Scheerens & Reynolds, 2000).

The research delineated above revealed some important common points, viz., effects on student performance are multilevel and the relationship between factors at different levels is likely to be more complex than the integrated models assumed. Creemers and Kyriakides (2006) proposed a more advanced educational effectiveness model in which factors are not uni-dimensional, but multi-dimensional, such as frequency, focus, stage, quality, and differentiation. They contend that each factor be measured in terms of these five dimensions in the model.

A refined model for effectiveness of science education

The model developed for the current study is based mainly on Creemers' model and some organisational characteristics in Scheerens' model, such as resources as input or climate, are adopted as well. Creemers' model was used in many studies that investigated educational effectiveness (Bos & Kuiper, 1999; van der Werf, Creemers, de Jong & Klaver, 2000; Isac, Maslowski & van der Werf, 2011) and it was recommended that Creemers' model is appropriate for secondary analysis of TIMSS results (Kyriakides & Charalambous, 2005). Like the Creemers model, the key concepts in the model developed are time, opportunity, and quality as shown in Figure 1 (see Cho (2010) for further details).

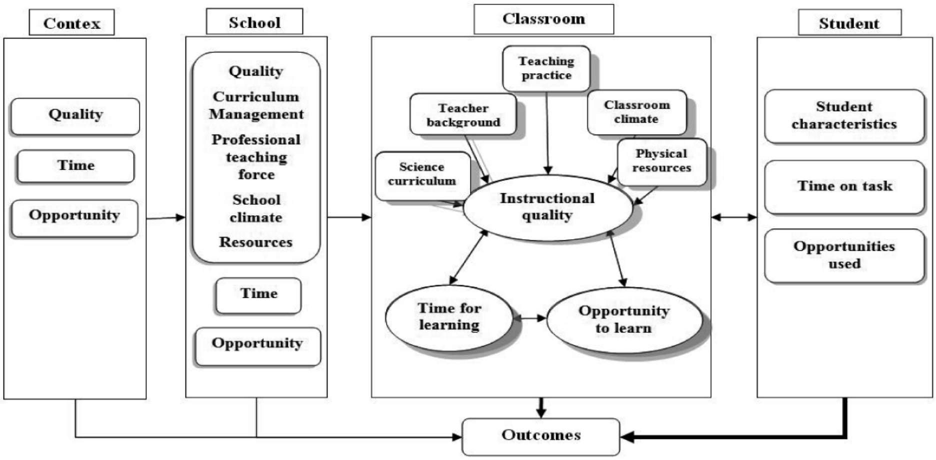

Figure 1: A proposed model of effectiveness of science education

However, there are some differences. First of all, the model developed for this study covers many aspects, such as human, material, and time. Specifically, the model includes resources and climate at each level, reclassifying sub-components of quality at classroom and school level. The quality of teaching and learning in classrooms needs to be examined from a micro level perspective (such as teaching strategies), but also from a macro level perspective, i.e. the environment surrounding students and teachers. Thus, the model should be based on teaching and learning theory as well as physical and psychological environments. Resources such as the physical environment are important in the current research as the study concerns a developing country, in which resources are more likely to influence student achievement than in developed countries (Scheerens, 2001; Reddy, 2006). Moreover, learning of science is more likely to depend on physical resources than other subjects (Rogan, 2000). Classroom climate and school climate, as psychological learning environments which can be developed in a dynamic relationship by teachers, students, and school atmosphere, has been acknowledged to some extent as determinants of educational effectiveness (Schoen & Teddlie, 2008). UNICEF (2000) also includes a safe environment as a factor to ensure quality of education.

Another difference is that the quality of instruction can be determined in more complex ways. The main assumption in the previous multi-level educational effectiveness models is that higher levels facilitate operations of lower levels (Scheerens, 1997). In contrast, all factors as shown in Figure 1 are interactive and interrelated. Specifically, teaching-related factors such as teaching practice and teaching conditions determine instructional quality, but this cannot depend only on teacher behaviour and curriculum at classroom level. Other factors at school and student level also influence the quality of instruction (Shavelson, McDonnell & Oakes, 1989) because capacity to be successful in terms of curriculum implementation depends on various factors such as resources, teacher, student, and school support (Rogan & Grayson, 2003; Rogan & Aldous, 2005). In addition, many studies based on constructivism have evidenced that the active role of the learner is important to good subject matter teaching (Tytler, Waldrip & Griffiths, 2004; Taraban, Box, Myers, Pollard& Bowen, 2007).

The model was applied to explore data from TIMSS 2003. Table 1 shows details of factors as proposed by the new model, corresponding with items from the TIMSS 2003 questionnaires.

Table 1: ***Classified factors at the student, classroom, school, and context level***

Levels	Factors		Details of factors
Student	Time on task		The time spent on homework, Private tutoring, and outside-school activities related to science
	Opportunities used		Absenteeism, Participation in science course, Homework, Tutoring, Attendance
	Student characteristics	Aptitudes towards science	Prior achievement
		Attitudes towards science	Self-confidence, Motivation, Enjoying science, Valuing science
		Social context	SES, Parent education, Books in home, Parent involvement, Peer environment, Ethnicity, Language, Gender, Age, Home possession
Classroom	Instructional quality	Science curriculum	Science textbook and workbook
		Teacher background	Academic skills, Teaching assignment, Teacher experience, Degree, Certification, Major area of study, Professional development, Gender
		Teaching practice	Direct instruction-Structured teaching, Questioning, Manipulation-practical work, Enhanced material, Assessment-test, feedback, reinforcement, Inquiry-problem solving, Enhanced context-linkage with daily life, Collaborative learning
		Classroom climate	High expectations, relationships between teachers and students, and among students, Management /orderly and safety atmosphere Teachers' attitudes towards student and science teaching Students' attitudes towards class, Student disruption, intrusion, and interruption
		Physical resources	Lab, Equipment and materials for science experiments, Computer, Software, Internet access, Video-audio facility, Teaching condition, Class size
	Time for learning		The time assigned by science teacher to teach science contents, Instructional time
	Opportunity to learn		The science contents taught by science teachers

School	Quality	Curriculum management	Rules and agreements about classroom instruction, science-related extracurricular activities, Curriculum-related task or decision-choosing textbook, determining course content, course offerings, student grading policies, assigning teachers to science classes, and instructional days or hours per year
		Professional teaching force	Educational leadership, Consensus or cohesion among school staffs including teachers, Stable body of teachers, Regular meeting of teachers
		School climate	High expectation, Achievement orientation, Community SES or School location, School discipline-student disrespect for teachers, absenteeism, tardiness, bullying, fighting, and theft, Higher student body mobility, Orderly and safety atmosphere
		Resources	Building, Grounds, Gymnasia, Library, Heating/cooling and lighting, Budget for science supplies, General instructional material, Budget-related resources-teacher salary, student-teacher, expenditures per pupil, administrative inputs, and facilities
	Time		Time schedule per week and per year, Duration of class, Rules and agreements about time use, Frequency of field trips
	Opportunity		School science curriculum offered, Science field trips Rules and agreements about how to implement the school science curriculum Curricular differentiation in science
Context	Quality	Curriculum	Policy focusing on effectiveness Indicator system/policy on evaluation / National testing system Training and support system, Policy on science curriculum
		Resources	Expenditures per pupil, Expenditures as a percentage of per capita income Average teacher salary, Pupil/ teacher ratio , Funding based on outcomes
	Time		National guidelines for time schedules Supervision of time schedules
	Opportunity		National guidelines for curriculum

Application of the model developed: A South African case

The current study applied the model refined above to South African results of TIMSS 2003. South African students were ranked among the lowest-performing countries in three consecutive administrations of TIMSS. In TIMSS 2003, South Africa performed worst amongst all participating countries, scoring 244 (SE 6.7) compared to the international average of 474 (SE 0.6) for science. Although the backlogs and inequalities resulting from the Apartheid era are still creating problems such as under-qualified teachers and poor resources contributing to the poor state of science education (Reddy, 2006), there is a need to investigate the contextual background of the results in TIMSS in order to improve student achievement in science.

TIMSS 2003 was tested with approximately 9,000 learners of 265 schools in South Africa from 21 October to 1 November 2002 (Reddy, 2006). TIMSS 2003 consisted of science achievement test items, as well as questionnaires. The achievement test assessed science knowledge and skills based on school curricula for Grade 8 learners. The questionnaire data provided a context for the performance scores, focusing on students' backgrounds and attitudes towards science, the science curriculum, teachers of science, classroom characteristics and instruction, school context and instruction (Martin, Mullis, Gonzalez & Chrostowski, 2004). Three questionnaires for student, science teacher and principal were examined in the current study. The school questionnaire comprised of 25 items and was addressed to the principal of the schools sampled. The science teacher questionnaire was made up of 34 items and addressed to the science teachers of the classes sampled. The student questionnaire comprised of 23 items and was completed by students in the classes sampled. Some items of questionnaires have various sub-items that constituted item sets. All questionnaires were based on Likert scales to record the self-reported information.

Data analysis

A good instrument depends on internal consistency and unidimensionality of items constituting scales (Gardner, 1995). Whereas internal consistency is commonly determined by calculating Cronbach alpha, the unidimensionality of scales can be tested using a statistical technique such as factor analysis (Osborne, Simon & Collins, 2003). The data was explored to identify factors that may affect achievement in science in South Africa according to those described in Figure 1 and Table 1. Factor analysis and reliability analysis were carried out on sets of items in order to find internally consistent items. Principal components analysis was applied to extract the factors, which were rotated using varimax rotation. The Kaiser-Meyer-Olkin (KMO) was examined to measure the sampling adequacy for each question analysed as well as the communalities. The researcher also evaluated components' loading value above 0.3 as a criterion. Sets of items with a reliability coefficient Cronbach alpha of at least .50 were selected and thereafter the correlation matrix was used to identify possible variables associated with achievement and their interrelationships. For the reliability coefficient, ranging from 0.00 to 1, values of 0.70 to 0.90 are acceptable (McMillan & Schumacher, 2006). However, as this is an exploratory study, a coefficient as low as 0.5 for the questionnaire is considered acceptable (Howie, 2002).

Once factor and reliability analyses confirmed the items are unidimensional and internally consistent, the scores were added together to construct scales, and variable names and labels were assigned for further analysis. Thereafter, correlation analysis was undertaken to ascertain the relationship between the scales or factors identified. The study adopted a correlation coefficient with an absolute value above 0.2 and the significance level, 0.01 (0.99, confidence interval) as criterion to include the scales for further analysis. From a general point of view, where the coefficient is below 0.35, the relationship is low. However it is justifiable considering that the current research involves a large-sampled exploratory study where correlations ranging from 0.20 from 0.35 may be slightly statistically significant and valuable to explore the interconnection of variables (Howie, 2002; Cohen, Manion & Morrison, 2007; Creswell, 2008).

For the study to reflect on such hierarchical structure of the data influencing student achievement, the research method adopted a multilevel approach to the analysis, making it possible to examine influences between the levels as well as each level's impact on student achievement. In addition, the multilevel analysis involves the interaction between and within each level, allowing factors specific to students, classroom, and school to be studied simultaneously.

Entering individual variables into the multilevel model, by the so-called 'step up method', the significance test was addressed by the Wald test referred to as the Z-test. Any change in the deviance was examined by making use of Chi-square if the variable contributes to the multilevel model (Hox, 2002). The multilevel model developed here is to explain the variation in science scores between students (within schools) and between schools by the explanatory variables. The MLwiN software was used to specify the two-level model.

Results of multilevel analysis

As a result of the reliability, factor, and correlation analyses, 27 variables, shown in Table 2, were identified as important and were retained for the multilevel modelling: nine variables at the student level, 10 variables at the class level, and eight variables at the school level. Thereafter, the variables included in MLwiN were renamed and classified according to the category of the model.

As a result of multilevel analysis, the intercept of the null model for South Africa is 245 (7.223), which is almost equivalent to the science achievement in TIMSS 2003. The variance of the residual error term is 7034 (122.582) for the student level and 10109 (1037.217) for the class/school level respectively. The result of the Z-test indicated that all parameters were statistically significant at $p<0.001$. For the first level or student-level model students' background variables were included (see Table 3). The results revealed the factors such as 'attitudes towards science', 'social context', and 'time on task' are significant. These factors can be improved by teachers or schools, thereby improving student achievement (Odom, Stoddard & LaNasa, 2007). Specifically, 'attitudes towards science' proved to be the strongest predictor between-students. A student who is extremely self confident in science may score 74 points higher than a student with low self confidence, (8.162*9 = 73.458), indicated by the product of the coefficient from Table 3 and the range from Table 2.

As regards social context, it was revealed that factors concerning ethnicity, such as 'born-in country' and 'language at home', had an influence on science achievement. Factors like 'watch TV or video after school' and 'home possession' also turned out significant.

Table 2: ***Variables included in MLwiN***

Factors in the research framework	Variable in MLwiN	Description of variables	N	Mean	SD	Range
Time on task	Extutor	Extra tutoring in science	6784	1.47	1.09	0-3(3)
Attitude toward science	Selfcon	Self-confidence in science	6784	7.41	2.42	3-12(9)
Social context	Agestu	Student age	6784	3.26	1.20	1-5(4)
	Boncnty	Country of birth	6784	0.65	0.48	0-1(1)
	Languag	Student language at home	6784	1.33	0.94	0-3(3)
	Bokhom@	Books at home	6784	1.97	1.13	1-5(4)
	Hompos	Home possession	6784	6.13	2.99	0-11(11)
	Media	Watch TV or video after school	6784	1.67	1.41	0-4(4)

Science curriculum	Textuse	Textbook use	198	0.92	0.27	0-1(1)
Teacher background	**Agetch**	Teacher age	198	3.05	0.82	1-5(4)
	1stdeg	Complete the first degree	198	0.18	0.38	0-1(1)
		Interaction by visit or observation	198	1.20	1.45	0-6(6)
Teaching practice	**Basichw#**	Use of homework(basic homework)	198	3.72	0.60	1-4(3)
	STS	STS-centred teaching	198	7.13	2.40	2-12(10)
Physical resources	**Phyres**	Physical resource for science lesson	198	9.94	4.16	0-15(15)
	Clasize	Number of students in class	198	4.41	1.58	1-7(6)
Time for learning	**Timspw#**	Scheduled time/week	198	2.87	1.38	1-5(4)
	Ttimpw#	Science teaching time/ week	198	4.40	1.86	1-8(7)
Professional teaching force	**Admindt**	Principal administrative duty	198	3.33	1.55	1-7(6)
	Supevdt	Supervise or evaluate as principal duty	198	2.05	1.05	1-7(6)
	Proftchf#	Professional teaching force	198	13.97	2.46	7-20(13)
School climate	**Schsize#**	Enrolment of all grades	198	3.04	1.35	1-7(6)
	Citysize#	Type of community	198	3.12	1.58	1-6(5)
	Disadva	Percentage of disadvantaged students	198	3.76	0.68	1-4(3)
	Hixpect#	High expectation	198	5.67	1.64	2-10(8)
	Lomoral	Severity of low morale	198	4.37	2.16	0-8(8)
	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

Among 19 class/school variables tested, 11 variables remained statistically significant. At the class/school level, an aggregated variable, 'safety in school'[1] reported by students was the strongest predictor. A student who thinks that he attends a school where less bullying happens may perform better by 130 points (49.986*2.6 =129.9636), indicated by the product of the coefficient from Table 3 and the range from Table 2. Other climate-related variables such as 'percentage of disadvantaged students' and 'severity of low morale' were also significant.

1 Data about safety in school was collected at the student level, but aggregated at the school level as the characteristic is more likely to represent school environment.

With regard to resource variables, 'physical resource for science' and 'number of students in class' turned out to have significant effects. A science curriculum variable, 'textbook use', was statistically significant. Among the teacher background variables, there were two variables that were statistically significant, namely 'completion of the first degree' and 'teacher age'. For professional teaching force related to school principals, there were two variables that explained student achievement with statistical significance, namely 'administrative duty' and 'supervising or evaluating teachers'. Of interest is that resource- and teacher background-related factors such as 'physical resource for science lesson' or 'completion of first degree' influenced student science achievement in South Africa. The final model contained 18 variables in total.

Table 3: ***Results of multilevel analyses***

Model	Null model	Student model	Class/school-model
Fixed effects			
Student 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, # Deviance from null model to present model is significant at 0.01
** t-value > 1.96 a confidence interval of 95%, ** t-value > 2.58 a confidence interval of 99%*

By examining the change occurring in the estimates of variance after adding each set of variables, the researcher analysed the effects of different level variables on student science achievement. The results of the initial model revealed the class/school level variables accounted to a large extent for the South African science achievement. The explained proportion of the total residual variation, 41% of the variation in science achievement is attributable to student level and 59% is derived from between-schools variance (see Table 4). This is the opposite of what was observed in the developed world (O'Dwyer, 2005; Kupari, 2006) and consistent with previous research in South Africa (Howie, 2002). Howie (2002) found that 55% of the variance explained was on the school level, and 45% of the variance was on the student level in South Africa using mathematics in TIMSS-R.

Table 4: ***Explained proportion of variance by consecutive models***

	Null model	Student model	Class/school model
Student level variance	0.410(41.0%)	0.203(20.3%)	0.203(20.3%)
Class/school level variance	0.590(59.0%)	0.542(54.2%)	0.892(89.2%)
AIC	80124.13	78495.77	78252.48

The student-level model explains 54% of the between-South African school variance, whilst only 20% of the within-school variance is explained. In the class/school model, a higher proportion of the variance is explained between South African schools (89%), while the variance explained within-schools is not different, as expected. A higher proportion of variance explained between schools than within schools was explained in the final model of South Africa, implying additional factors to be explored at each level to account for the unexplained variance.

In South Africa, the largest contributory predictor at the class/school level is ‘safety in school’ as perceived by students and to a lesser extent ‘attitudes towards science’ at the student-level model. ‘Language at home’ and ‘physical resource for science lesson’ also increased the percentage of explained variance on the class/school-level model.

Discussion

Some factors were significant as expected from the perspective of the model developed for the current research. For example, at the student level, attitudes towards science are the strongest predictors of science achievement between individuals in South Africa according to the results of multilevel analyses. This result is in agreement with previous findings reported in the literature (Shen & Pedulla, 2000; Papanastasiou & Zembylas, 2004; Chang & Cheng, 2008; Howie, Scherman & Venter, 2008; Shen & Tam, 2008).

Additional significant factors are related to ethnicity and SES at the student level such as ‘student age’, ‘language at home’, ‘home possession’, ‘born-in country’, and ‘media’. Student ethnicity, home possession, and language at home also confirmed previous research which revealed that minority-ethnic groups fared worse than majority groups (Von Secker, 2004; Howie et al., 2008). This phenomenon is understandable as students from minority ethnic groups have to learn science knowledge in an instruction language that is different from mother tongue (Rollnick, 2000). There are 11 official languages in South Africa and the poor command in the language of instruction complicates conceptual understanding and affects science performance negatively (Dempster & Reddy, 2007). It is evident that students who are not familiar with the language of instruction cannot understand content taught in class.

The older the students, the poorer they performed in South Africa. This is inconsistent with Walberg’s productivity model (1990), which assumed older students should perform better than younger ones as they are readier to learn. Lower student age in South Africa, however, has a positive relationship with achievement. It may be related to student SES along with home possessions which showed a positive relationship with science achievement. Students from educationally and economically poor-resourced homes are likely not to attend school regularly. As a result, they have less opportunity to learn and have to repeat grades because they failed to pass the standard demanded by the curriculum (Fiske & Ladd, 2004). Likewise, mass media such as TV or video showed a positive relationship with performance, contrary to Walberg’s assumption. In the South African context, mass media may provide information related to science and help students improve their understanding of the English language.

The finding that climate-related factors are important at the class/school level supported the model developed for the current study, in which climate is one of the factors to determine quality at classroom and school levels. At the class/school level, according to the results of multilevel analysis, ‘safety in school’ is the strongest predictor of science achievement, explaining the high variance between schools in South Africa. This finding may indicate South African specific, educational, and social contexts along with ‘low morale’ that was also significant. During the Apartheid regime, discriminatory education policies based on segregation resulted in resistance to education and a negative ethos about schooling. As expected, ‘percentage of disadvantaged students' is important. As the relationship between SES and achievement, it has been well documented in EER that it is likely a stronger predictor at the school level than student level (Beaton & O'Dwyer, 2002). It was reported that the SES of a school[2] influenced teaching practice more than either principal supportiveness or available resources influenced teaching practice (Supovitz & Tuner, 2000). Therefore, students attending schools having more advantaged students can benefit in many ways, like more opportunity to learn content or highly-qualified teachers (Ramírez, 2006).

The classroom/school level also showed other significant factors such as 'textbook use', 'teacher age', 'teacher qualification', and 'STS-based teaching'. With respect to the science curriculum, textbook use is significant but the use of textbooks showed a negative relationship to performance in South Africa. 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 an effective way to access scientific knowledge, particularly in developing countries (Fiske & Ladd, 2004). The negative impact of 'textbook use' might be an indication that teachers use textbooks without reconstructing content for students to make meanings for themselves. Furthermore, teaching practice such as 'practical work', which is recommended by researchers for effective group learning (Harskamp & Ding, 2006; Odom, Stoddard & LaNasa, 2007), operates in reverse to general research findings. These findings can be reconsidered in terms of teacher qualification that is significant in South Africa along with teacher age (Sayed, 2002). Heyneman and Loxley (1983) have found that teacher quality along with school quality was more important in developing countries.

Resource-related factors such as 'physical resource' and 'class size' which appear in the new model are significant in South Africa. As Scheerens (2001) put forward, material and human resource factors showed strong effects in developing countries compared to developed countries. It is suggested that the current finding also reflects the backlog resulting from unbalanced financing support under the apartheid regime.

At the class/school level, educational leadership is also identified significant as was within effective schools in early EER (Edmonds, 1979; Mulford, 1988; Scheerens & Bosker, 1997; Tate, 2001). South African results showed a school performed better when the principal was involved in administrative duty rather than supervising and evaluating teachers. The finding about education leadership may indicate that schools are more effective when principals play a role to support teachers rather than supervise them.

Despite all the factors above, the unexplained variance in South Africa may imply that other variables not included but significant do exist in particular at the student level. Specifically, TIMSS does not collect information related to student aptitude. It was documented that students' aptitude, such as cognitive ability, explained a great deal of the variance at the student level (Van den Broek & Van Damme, 2001).

Conclusions

EER tends to use language or mathematics as student outcomes to identify effective factors in an educational system. The current study started with the first question, how can the effectiveness of science education be modelled at different educational levels, developed an effectiveness model in particular for science education, and explored the South African case. The conceptual

2 the proportions of students receiving free or reduced lunch was used as a proxy

model focused on three key factors influencing student achievement, namely time, opportunity, and quality. *Time* indicates students' time on task, teachers' time for teaching and learning, and instructional time allocated by school regulation. *Opportunity* covers learning opportunity used by students, teachers' opportunity to teach, and opportunity provided by school. *Quality* includes student background, teacher and teaching background, and school support for teaching and learning. Under the quality category, the new model includes resource- and climate-related factors such as physical and psychological environments.

The second question, which factors influenced differential performance in South Africa's TIMSS 2003 results for science, was answered by the results of multilevel analyses. Within the social context of students, attitudes towards science, ethnicity and SES –related factors were significant in South Africa. At the classroom/school level, in particular in terms of quality, teacher qualification, physical resources, and climate-related factors are important in South Africa.

Many studies pertaining to students' outcomes have found home characteristics to be more highly associated with student achievement than school characteristics. As a result, a great deal of research has highlighted the need to examine the influence of students' background characteristics. However, it does not hold true around the world, in particular in less-developed countries judging from the findings above. Earlier evidence indicated that the economically developed countries show the pattern of a large influence by family SES with smaller school impact, and a reverse pattern in less-developed nations (Heyneman & Loxley, 1983). The current research developed a model for effectiveness of science education and it confirmed the Heyneman-Loxley effect empirically from the TIMSS results of South Africa. There are considerable differences between schools in South Africa. In addition, material resources, school climate, and teacher background are important in South Africa unlike in the developed world.

In conclusion, the new model, which places more emphasis on class and school level and delineates additional effective factors, seems more applicable to science education in the developing countries. Lastly, the factors identified from the TIMSS dataset did not explain all the variances in student achievement, indicating the possibility for further research.

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