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HOW WELL IS THE SOUTH AFRICAN EDUCATION SYSTEM PREPARING STUDENTS FOR THE FOURTH INDUSTRIAL REVOLUTION?

John Nyamunda
Management College of Southern Africa, 26 Samora Machel Str., Durban, 4001 South Africa
johnnyamunda@gmail.com

ABSTRACT

The COVID-19 pandemic has highlighted that schools and universities were operating as if there had not been any technological revolution before the pandemic. Their approach to education has not changed for the past 100 years, despite the dramatic changes in the world culminating in the Fourth Industrial Revolution. In the South African context, despite poor international comparative results in Mathematics, Science and Literacy, there is no sustained effort to use available technology to improve education outcomes. Using Trends in International Mathematics and Science Study (TIMMS) and the Progress in International Reading Literacy Study initiatives, this study revealed the fault lines of Education 4.0 in South Africa. More than 76 % of students achieved below the low international benchmark as measured by TIMMS in Maths and Science. On average, South African students are 180 points below the international literacy centre-point of 500. Socio-economic and other factors play a critical role in student performance. Unless there is a transformation in Education 4.0, South Africa will continue to lag behind other countries and Industry 4.0 will be devastating as the country fails to adequately train people for the future. It is recommended that South Africa explores making technology a key piece of pedagogical interventions to improve education outcomes.

Keywords: Digital literacy; education; literacy; professional development; real-life problems; science.

1. INTRODUCTION

The way schooling is conducted today is a relic of the 16th century, where it was primarily seen as a means to teach people to read the Bible to save their souls (Gray, 2008). It remains steeped in some of that history like compulsory education (Gray, 2008) and dependence on a knowledgeable teacher in front of a classroom.

The South African education outcomes are worsened by the specific historical context of its colonial and apartheid past. Before 1994, the country operated under two racially segregated education systems (Cross, 1986) where education expenditure was along racial lines (Dass & Rinquest, 2017). So, when democracy was achieved, one of the immediate goals was to dismantle racially segregated education and establish a single education system (Mouton et al., 2012).

Notwithstanding the efforts to deracialise education, the effects of those apartheid years on education remain. There are a few well-resourced functioning schools but a vast majority of South African schools are dependent on the state for guidance and financing. Though there is more equity in allocating educational resources,

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South Africa still performs poorly in Mathematics, Science and Literacy compared to other countries with comparative per capita GDP.

The world has drastically changed since 1994. It is at the cusp of a revolution characterised by a "fusion of technologies that are blurring the lines between the physical, digital and biological spheres" (Schwab, 2015: 2). This Fourth Industrial Revolution (Industry 4.0) is characterised by "ubiquitous mobile internet; cheaper, smaller, and stronger sensors; and artificial machine learning" (Lee et al., 2018: 2).

Considering the challenges highlighted above, this article seeks to determine if the South African education system can use technologies made possible by Industry 4.0 to improve its education outcomes under the Trends in International Mathematics and Science Study (TIMMS) and Progress in International Reading Literacy Study (PIRLS) initiatives. Improving education outcomes is critical in South Africa due to its high unemployment (Statistics South Africa, 2020a) and deep inequality and poverty (Statistics South Africa, 2020b). How can education bridge the gap that is characterised by thousands of youths from impoverished backgrounds who leave school without basic digital literacy (Violence Protection Through Urban Upgrading, 2019) in addition to being linguistically and mathematically illiterate? More specifically, how can technology be used to improve outcomes in Maths, Science and Literacy as measured by comparative studies of TIMMS and PIRLS?

2. LITERATURE REVIEW

The following literature review introduces key concepts for this study. These are the Transformation of Education, Education 4.0., Literacy and Education, Numeracy and Education, and Technology and Education.

The transformation of education from Education 1.0 to Education 4.0

In the past two decades, education has been conducted in a drastically transformed world. Students live in a world that is highly networked, virtualised and globalised (Wallner & Wagner, 2016). However, the underlying delivery of education has not changed much (Salmon, 2019). Most educational systems are still premised on a more than hundred-year model (World Economic Forum, 2017). Anggraeni (2018) and Salmon (2019) discuss the evolution of education from Education 1.0 to Education 4.0 (Table 1):

It is apparent that the current technological capability can deliver Education 4.0, but with significant constraints (Table 1). The discrepancy between education delivered and what the world needs is significant in countries with a dual economy of schooling like South Africa (Shalem & Hoadley, 2009).

In South Africa, schools can be divided into "schools for the poor" and "schools for the rich" (Taylor & Yu, 2009; Van der Berg & Louw, 2006; Woolman & Brahm, 2006). The Department of Basic Education calculates a poverty index for each state-owned school and places it into 1 of 5 quintiles (Reddy et al., 2015). Quintile 1–3 schools are non-fee-paying in poorer communities, while Quintile 4 and 5 are fee-paying schools in better-off communities (Reddy et al., 2015).

Table 1: Evolution of education from Education 1.0. to Education 4.0. Source: Adapted from Salmon (2019) and Anggraeni (2018).

Education Stage	Characteristics
Education 1.0: Going to University	• Fewer people going to university • The numbers start to increase > lectures necessary • Textbook publishers are pivotal • Television made Open University possible • Virtual learning environment began > educators started enhancing their teaching with the web (in 1990s) • Libraries became progressively more digital
Education 2.0: Social (from 2005)	• More collaboration through websites • Great democratisation of information with everyone having the power to express opinions • Podcasts became important • Fewer educators started experimenting with social media • Information transfer moving out of the classroom • Potential for Massive Open Online Courses reached
Education 3.0: Digital Lives and Mobility	• The web is integrated and ubiquitous • Students growing up in a world which has always had internet • Students connected all the time and in constant interaction • Most students have a smartphone • Potential for mobile learning not yet realised
Education 4.0: Human-machine interdependence	• Students will expect to learn what will enhance their lives in the real world • Ubiquitous connectivity and the interdependence between humans and machines • Students can learn anything from anywhere by clicking the features of a learning platform (Anggraeni, 2018) • Requirements for life-long learning (Wallner & Wagner, 2016)

In addition to income inequality, the legacy of apartheid persists. The previously dysfunctional "black schools" remain dysfunctional, characterised by severe underperformance, higher grade repetition, high school dropout and high incidences of teacher absenteeism (Spaull, 2012). While most of these factors cannot be divorced from the socio-economic realities of communities where these schools are found (Spaull, 2012), it is the culture of resistance to apartheid that led to a complete breakdown of schooling and anarchy (African National Congress, 1994).
To further complicate the current reality, the world in which education attempts to prepare these students for continues to evolve.

The need for Education 4.0

Significant trends are shaping how people need to be developed and deployed. These trends are globalisation and technology (World Economic Forum, 2017),

which shape business models and create new types of jobs while making others redundant (Willige, 2017). Reinventing education needs to start in the early years and continue for life, with workers not only relying on one set of skills due to the rapidly changing nature of the world of work (Willige, 2017).

Industry 4.0 will have a significant impact on the nature of employment. Experts propose three possible scenarios; pessimistic, optimistic and sceptical (Blit et al., 2018). Under the pessimistic scenario, close to 50 % of work tasks will be replaced by artificial intelligence and robotics resulting in massive unemployment (Blit et al., 2018). The optimistic scenario projects that new technology will lead to the creation of new industries which offer better opportunities (Chala & Poplavska, 2017). Under the sceptical scenario, though technology will put pressure on jobs, the resistance by society will slow the devastating loss of jobs (Blit et al., 2018). Notwithstanding, all jobs will go through a fundamental change with about one-third of the skillsets required to perform the same jobs having changed by 2020 (Zahidi, 2017). In 2021, the World Economic Forum has listed those jobs that will be in demand in 2030 with the dominant theme being technology-based (Brown, 2021).

In addition to the changed world order, the nature of students has significantly changed. Most students in the education system, including higher education, have grown up in the world of the Internet (Salmon, 2019). They are more hands-on and want to be involved in the learning process (Hussin, 2018). They expect a learning process that makes use of digital tools (Hussin, 2018) to mimic their lived environment.

In addition to a lower cost, Education 4.0 is needed to impart the foundational literacies for the 21st century which are literacy, numeracy, scientific literacy, ICT literacy, financial literacy, cultural and civic literacy (World Economic Forum, 2015). These foundational skills are in addition to critical thinking, problem-solving, persistence and collaboration (World Economic Forum, 2015). In light of the value of Education 4.0 as discussed above, the following section covers the specific issues faced by South Africa.

The specific need for Education 4.0 in South Africa

The need for Education 4.0 in South Africa was highlighted in the 2007 Southern and Eastern African Consortium for Monitoring Educational Quality (SACMEQ). In that study, they found that of the Grade 6 Maths teachers evaluated, 79 % had content knowledge at Grade 4 or 5 level and below (Venkat & Spaull, 2015). In fact, Maths teachers whose knowledge level was below the Grade 6 level taught per school quintile were; quintile 1 (89 %), quintile 2 (86 %), quintile 3 (92 %), quintile 4 (77 %) and quintile 5 (50 %) (ibid.).

In other words, students struggle in Maths because most of the teachers do not have the skills to teach the subject. The TIMMS 2019 survey showed that over 63 % of learners in Grade 5 had not acquired basic mathematics knowledge. We now turn our attention to some of these foundational literacies, namely, literacy and numeracy.

The importance of literacy in Education 4.0

The term literacy refers to the ability to read and write and is at the heart of digital literacy (Loewus, 2016). Digital literacy, in turn, refers to the ability to use information technologies to communicate, which includes finding, evaluating, and creating information (Loewus, 2016). In addition to being able to read and write, to be "digitally literate" students need to be able to assess the credibility of the source (Editors, 2016).

Industry 4.0 places a significant emphasis on digital literacy. One of the hallmarks of Industry 4.0 is the fragmentation of work into small tasks and the loss of secure full-time jobs (Farrell & Corbel, 2017). The loss of full-time jobs will require additional skills, like the ability to negotiate contracts, and to appropriately engage with texts and presentation skills just to be hired (Farrell & Corbel, 2017). Technological advances make it possible to present the entire production environment digitally, able to be operated from anywhere (Chromjakova, 2019). This makes digital literacy critical in the future.

In the South African context, the country will not be able to fully benefit from its infrastructure development without literate citizens (Chetty et al., 2017). This is highlighted by the 2019 General Household Survey from Statistics South Africa (2019) which showed that 12.1 % of adult South Africans are illiterate. This study considered PIRLS, a large-scale international study of reading literacy that is conducted every five years, since 2001 (Howie et al., 2017), to assess general literacy in schools.

The importance of Numeracy and Science in Education 4.0

Numeracy is the ability to cope with the mathematical demands of everyday life (Bennison, 2014). It is more than just understanding numbers, it also influences the processing of other non-numeric information (Peters, 2012).

Maths is at the core of what computers do; however, its growing importance is hidden in many different tools (Gravemeijer et al., 2017). The nature of Maths required in the world is changing as users need to be able to formulate mathematical problems for the computer to solve (Gravemeijer et al., 2017). Science, Technology, Engineering and Maths (STEM) initiatives are gaining popularity in many countries, based on the belief that they are a pathway to a brighter future (Williams, 2011).

In the South African context, only 16 % of students in Grade 3 are performing at the Grade 3 level in Maths (Spaull & Kotze, 2015). The poorest 60 % grade 3 students are three grades behind the wealthiest 20 % in the same grade (Spaull & Kotze, 2015). The three-grade gap widens to four grades by the time students are in Grade 9 (Spaull & Kotze, 2015). Visser et al. (2015) argue that the Maths and Science outcomes of students in South Africa are not only driven by socio-economic factors, but also by the parents' level of education.

Having discussed the literacy and numeracy challenges, in light of this paper's goals, the next section discusses whether technology can reduce the disadvantages experienced by students from impoverished backgrounds.

Technology and Education 4.0

Advances in technology have not just impacted industries, the effects have also been felt in educational institutions (Abd Karim et al., 2018). There has been significant growth in the mobile learning environment, supported by digital media (Abd Karim et al., 2018) which enables the collection and analysis of learning processes (Ciolacu et al., 2017).

South Africa has a mobile connection rate of over 150 %, with 20 to 22 million people using smartphones (O'Dea, 2020). This means that South Africa has considerable potential for Education 4.0, but the cost of data is high. While the median price of data has fallen since 2015, the cost of data has not been reducing in US dollar terms in South Africa (Competition Commission South Africa, 2019). The cost of data remains a major stumbling block for Education 4.0, especially for the poor.

Besides the cost of data, schools will fully benefit from technology if people are digitally literate (Chetty et al., 2017). In South Africa, thousands of youths from poor backgrounds leave school without basic digital literacy (Violence Protection Through Urban Upgrading, 2019).

On a positive note, Mhlanga and Moloi (2020) report pockets of technology excellence exposed by COVID-19, where educational institutions successfully implemented communication technologies to continue learning. They expressed optimism in what it might mean for the perennial problems of limited numbers of higher education spaces. However, Teräs et al. (2020) bemoan the potential of unintended consequences where technology and capitalism will take a leading role in education with no regard for sound pedagogical principles and practices. The next section briefly discusses the methodology used in this study.

3. METHODOLOGY

This section presents the methodologies used for the different studies that were acquired as data sources. The data for this study is extracted from the following studies: The Progress in International Reading Literacy Study (PIRLS) and Trends in International Mathematics and Science Study (TIMMS).

The Progress in International Reading Literacy Study (PIRLS)

PIRLS is a project by the International Association for Evaluation of Educational Achievement, that has run every five years since 2001 (Howie et al., 2017). Its core purpose is to evaluate the purpose of reading which is "to acquire and use information" (Howie et al., 2017: 6). In 2016, about 50 countries participated in the PIRLS survey. The sample is selected using a stratified cluster sampling design, from Grade 4 in schools in different provinces, representative of the 11 official languages of South Africa. In South Africa alone, 18,092 students from 293 schools participated and were tested in their school's language of learning and teaching (Howie et al., 2017).

Trends in International Mathematics and Science Study (TIMMS)

TIMSS was developed by the International Association for Evaluation of Educational Achievement and aims to make it possible to compare educational achievement between different nations (Reddy et al., 2016). It is a survey specifically focused on Maths and Science achievements in about 59 participating countries (ibid.). A two-stage random sampling technique was used, with school selection as the first stage and class selection as the second stage of sampling. Internationally, TIMMS has been tested on Grade 8 learners but in the 2015 survey, to achieve better completion rates, South Africa used Grade 9 students. In South Africa, a total number of 12,514 Grade 9 students from 292 schools participated in the 2015 survey. In the bigger scheme of things, it has been shown that higher levels of achievements in Maths are positively correlated to the human development index (Reddy et al., 2015).

4. RESULTS AND DISCUSSION

In this section, the key findings from PIRLS and TIMMS, relevant to Education 4.0 are presented.

Results from PIRLS 2016

South Africa participated in the less demanding PIRLS Literacy version of the assessment and is compared to countries that participated in the less demanding test (Fig. 1).

South Africa achieved the lowest score of 320, for all the countries that participated in PIRLS Literacy survey. The South African students who participated were Grade

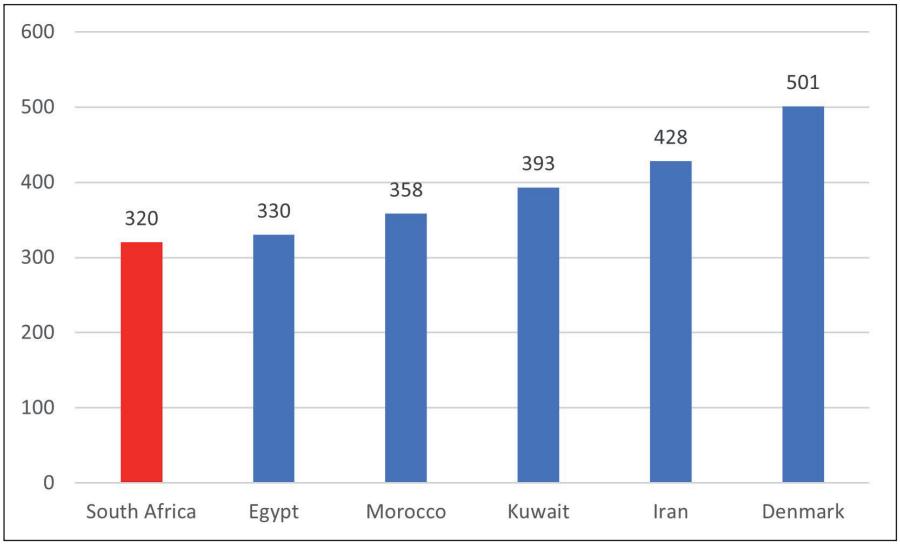

Figure 1. Mean achievement scores (PIRLS Literacy). Source: Howie et al. (2017: 48).

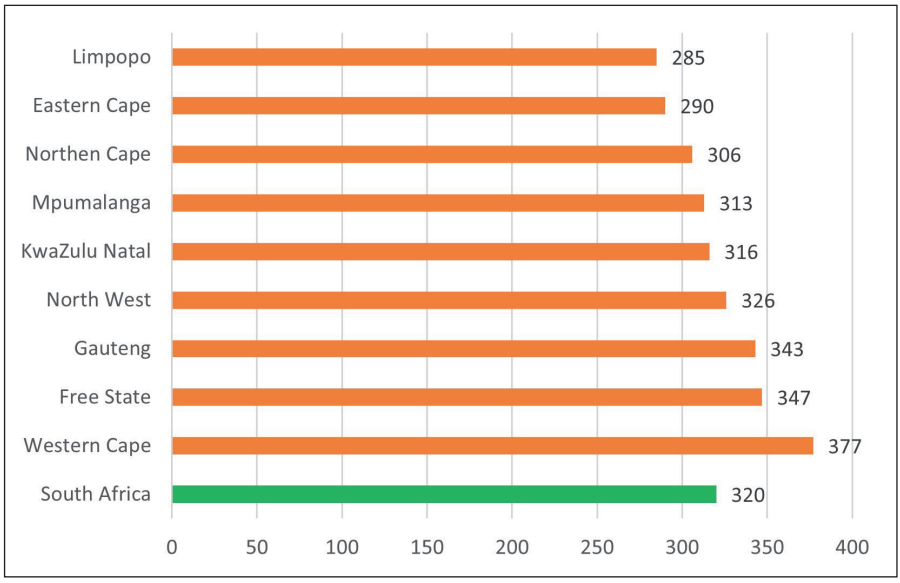

Figure 2. South African Grade 4 learner achievement in PIRLS 2016 by province. Source: Howie et al. (2017: 50).

4 and on average 10.6 years old. The Denmark students who participated in the same assessment were Grade 3 and on average 9.8 years. Though the score for Egypt is 10 points higher than South Africa, the difference is not statistically significant.

At an average score of 320, South Africa is 180 points below the average of all participating countries and 261 points behind the leading Russian Federation. Locally, at a provincial level, Western Cape was the best performing province (Fig. 2).

Limpopo and Eastern Cape were the worst-performing provinces, with both being below 300 and more than 20 points below the national average of 320 (Fig. 2). However, statistical analysis revealed that Western Cape had a score statistically higher than all other provinces except Gauteng. Gauteng's score, despite being the 3rd highest, was only statistically significantly higher than Eastern Cape and Limpopo.

In terms of gender variation, the national average score for girls was 347, more than 20 points above the national average and the boys' average score was 297. Since PIRLS 2016 was tested in all official languages, it meant that the performance of students could be analysed by language. Students with English as their language of learning performed best at an average score of 372 (Fig. 3).

All other languages except English and Afrikaans performed below the national average of 320 (Fig. 3). Sepedi and isiXhosa speaking learners are about 40 points below the national average. Statistically, English and Afrikaans learning students' performance was significantly higher than all other languages. Sepedi learning students' performance was significantly lower than other languages except for

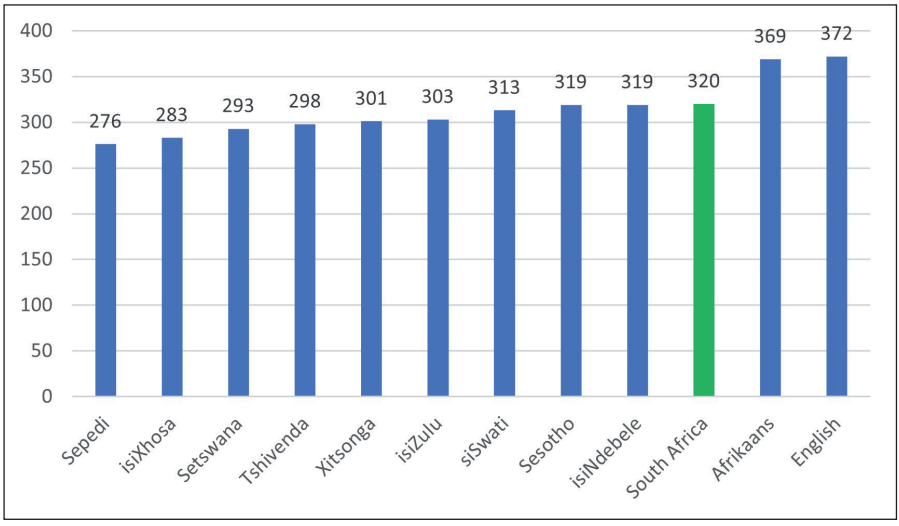

Figure 3. South African Grade 4 Achievement in PIRLS Literacy 2016 by Test Language. Source: Howie et al. (2017: 54).

Setswana and isiXhosa. From these results, it can be deduced that the language of instruction matters in terms of school literacy performance.

Behavioural and socio-economic factors affected literacy in South African schools as could be expected. A school's quintile was a good predictor of literacy performance (Table 2).

Despite the government assistance, the lower the quintile, the lower the score. Schools in Quintile 5 are almost 140 points above those in Quintile 1. An interesting outcome also is the 100-point difference between schools in quintile 4 and 5. This might be reflective of the economic gap between quintile 4 and 5 schools. Van Dyk and White (2019) argue that Quintile 4 schools receive much less school funding compared to Quintile 1 to 3 schools, even though they have an average number or more of disadvantaged families.

Table 2: South African Grade 4 achievement in PIRLS literacy 2016 by quintile.

Quintile	% of learners	SE %	Score SE	SE
Quintile 1	27 %	2.9	288	5.3
Quintile 2	18 %	2.4	299	7.6
Quintile 3	22 %	2.7	303	7.5
Quintile 4	19 %	3.0	328	8.6
Quintile 5	12 %	2.1	426	16.1

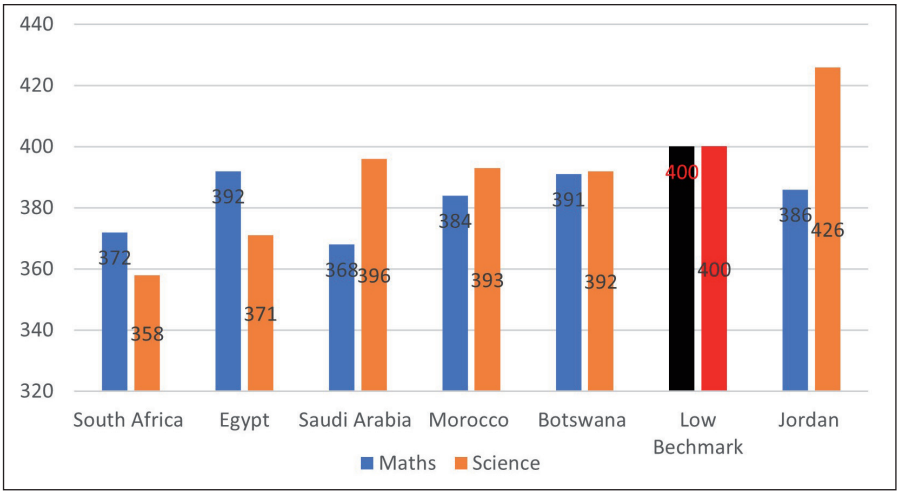

Figure 4. Bottom Countries for TIMMS 2015 vs Low Benchmark.

Results from TIMMS 2015

TIMMS has set four achievement benchmarks as follows: 400–475, low level; 475 to 550 points, intermediate; 550 to 625 points, high level and above 625, advanced (Reddy et al., 2015). Of the 39 countries that participated in TIMMS, South Africa, Botswana and Norway were the three that tested Grade 9 students (Fig. 4).

South Africa is positioned as the lowest of the bottom five countries participated in TIMMS 2015 (Fig. 4), bypassing only Saudi Arabia in Maths. Despite being the lowest, its score is only statistically different from Botswana for both subjects, and Jordan for Science. South Africa, together with five other participating countries are below the Low Benchmark of 400. The score is worse for South Africa and Botswana as the tested students who were in Grade 9 were compared to Grade 8 for other countries.

Though the average score for South Africa is below the low benchmark, it is a vast improvement from its previous scores. For Maths, in 2003 close to 90 % of students were below the low benchmark, which improved slightly to above 75 % in 2011 and about 65 % in 2015. For changes to Science scores, just over 85 % were below the low benchmark in 2003, reducing to 75 % in 2011 and about 67 % in 2015.

When classified according to non-fee paying and fee-paying public schools and independent schools, both fee-paying and independent schools scored above the low benchmark of 400 but were still below the centre-point of 500. Non-fee-paying public schools were more than 50 points below the low benchmark of 400 (Fig. 5).

It can be argued that the economic conditions at home had a negative influence on performance (Fig. 4). The TIMMS survey report illustrates that students with more than 25 books at home, and at least a parent with a tertiary qualification, perform better than their counterparts.

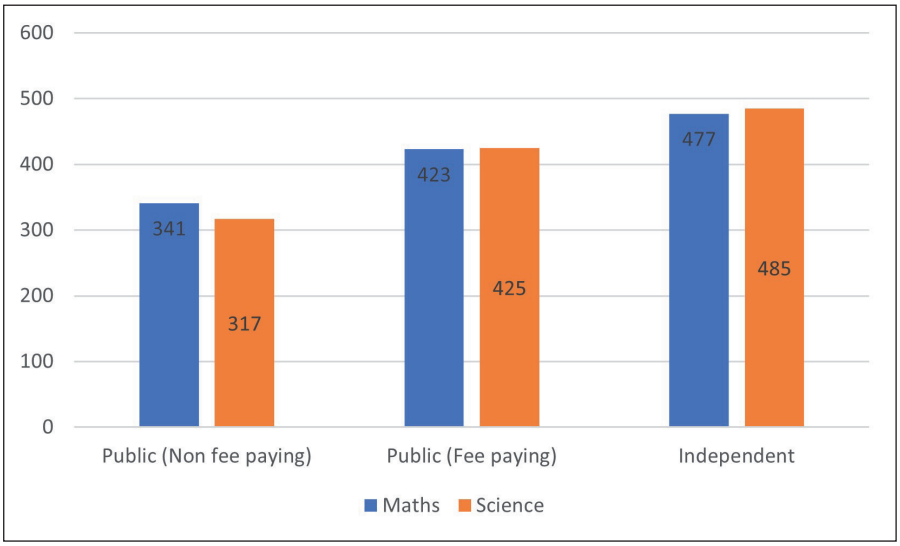

Figure 5. TIMMS 2015 Maths and Science scores by school type. Source: Reddy et al. (2015).

A school's quintile is a good predictor of performance (Table 3). There is not much difference in the average performance in Maths and Science between quintile 1 and 2 schools. The differences increase slightly with each quintile from 2 to 4, jumping significantly to about 25 % difference between quintile 4 and 5 schools. The difference between quintile 1 and 5 schools is 144 average points (48 %), and 59 % for independent schools.

Table 3: TIMMS 2015 Maths and Science scores by quintile.

Quintile	Maths	Science	Average
Quintile 1	316	279	298
Quintile 2	318	285	302
Quintile 3	336	314	325
Quintile 4	360	348	354
Quintile 5	438	445	442
Independent	474	479	477

Discussion

From the results above, it is apparent that South Africa is poorly performing in terms of literacy, numeracy and science. One of the drivers of underperformance is socio-economic factors (Reddy et al., 2015; Howie et al., 2017). The economic status of students is a good predictor of comparative performance between quintiles.

For literacy, only 22 % of students reached the low benchmark and 78 % were below the low benchmark. Internationally, only 4 % of students were below the low benchmark. When evaluated based on quintiles, Quintile 5 schools had about 65 % of students reaching the low benchmark, compared to less than 24 % for Quintile 4 and below schools. Not reaching the low benchmark points to a lack of basic reading skills (Howie et al., 2017).

With an average score of 372 for Maths and 358 for Science, South African students "have not demonstrated knowledge of the most basic skills" in Maths and Science (Howie et al., 2017: 4). It is important to note that, even the well-resourced schools in Quintile 5 or independent, are not performing well, scoring slightly above the low benchmark of 400 for Maths and Science, with their scores of 442 and 472, respectively. Though above the low benchmark, they are below the intermediate international benchmark of 475 (Howie et al., 2017). This means that even the affluent schools are only just knowledgeable of the basics and are not competent to do more complex operations, like applying Maths skills to real-life problems (Howie et al., 2017).

These results are not surprising considering the 2007 SACMEQ study which showed that 79 % of Grade 6 Maths teachers had content knowledge at Grade 5 or below (Venkat & Spaull, 2015). This points to a cascade throughout the system where Maths competence is a problem among the educators who are supposed to impart it. It would be unreasonable to expect students to excel under such realities.

The next section provides recommendations on how the South African educational system could be leapfrogged to Education 4.0 to enhance performance.

5. RECOMMENDATIONS

Firstly, it is recommended that South African schools should focus attention on improving literacy and numeracy. The first step would be to upskill teachers through ongoing professional development. This professional development should be linked to writing ongoing subject-specific competence tests.

Secondly, technology should be used as both a teaching and a learning tool. Digital literacy should be the focal point of education and not multiple languages as per the current thrust. Teachers should be trained to effectively use ICT tools as teaching and learning tools. In addition, teachers should be given technology tools to track the progress of students, including obtaining early warnings about at-risk students.

Thirdly, the government should utilise computers and tablets as learning tools, which should be compulsory at all independent and fee-paying schools. This would start the education system slowly moving into Education 4.0. With time, the successes in fee-paying schools would be expanded to non-fee-paying schools.

Lastly, schools should be obliged to maintain meticulous records for every student. The records should pertain to numeracy, literacy, and other critical demographic scores, like attendance and their socio-economic situation. These scores will need to be monitored on an ongoing basis, at least once every school term. This information

should be submitted to school districts to be captured for the ongoing management of schools.

6. CONCLUSIONS

The TIMMS and PIRLS surveys have highlighted an improving, but poor state of South African education. South African students significantly underperform their counterparts in other countries, even when the socio-economic factors are considered. The main drivers of poor outcomes being socio-economic factors and the low levels of teacher competencies in desired areas. This does not bode well for the future, especially in terms of Industry 4.0. It is recommended that South Africa should reduce its focus on languages and focus on digital literacy, especially in fee-paying and independent schools, to start the path to Education 4.0. This would improve outcomes and better prepare students for Industry 4.0. In addition, the country must move towards a data-driven approach to education management, where schools collect and retain critical student data for decision-making.

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