NATIONAL EDUCATION COLLABORATION TRUST

HRDC: TASK TEAM 1

SOCIAL COMPACT APPROACH

BUILDING THE FOUNDATION FOR A TRANSFORMED ECONOMY AND SOCIETY

CONTENTS

STEM

3. STEM

PROFESSOR

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STEM is the popular abbreviation of SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS

INTRODUCTION
AND BACKGROUND

Nurturing, attracting and retaining talent reside at the heart of any capable, developmental state. The 2011 Diagnostic Report of the National Planning Commission, and the National Development Plan refers. It behooves to:

- Maintain the social contract: protect individuals and all assets, including schools
- Terminate cadre deployment
- Ensure meritocratic appointment to the public service by means of a state examination
- Invoke transparency in the procurement process
- Professionalize teaching as an admired and essential service
- Build respect to the rule of law and accountability

All effort should be given to building social cohesion.

The national flag enjoys high esteem, but when it comes to that which binds, namely language, we lag, trapped in the legacy of 'separate development' that used language and tribe as a means for division.

The Constitution, in 'recognizing' eleven official languages (should this perhaps be twelve?), both validates identity, and continues the division. Post 1994 administrations have done little to close the language gap. In many respects we are a state without a nation, and walk past one another.

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- Social disadvantage and exclusion, that manifest in poverty and inadequate education, will plague us for years to come.

Accordingly, we must

- Ensure that all are able to communicate in an indigenous African language plus English or Afrikaans
- Eradicate written literacy
- Build a wide social safety net, including a basic income grant, support for those injured by the pandemic, a just transition fossil fuel transition, participation in, and mitigation of the 4th Industrial Revolution

It is the task of the Human Resource Development Council (HRDC) to build the talent that will enable and sustain a capable state and the transition from a resource-driven to a knowledge economy. The HDR Council is tasked with increasing productivity and facilitating the development of human resources needed to substantively improve national economic growth and development, and successfully transform South Africa into a knowledge economy.

The Department of Basic Education (2014) initiated a review of the National Strategy to improve Science, Mathematics and Technology (Department of Education, 2000). The Review found that:

- Human and financial resources provided to achieve the objectives are inadequate
- It is therefore urgent to prioritise the large number of objectives and to develop plans that can be implemented substantially and successfully.
- The first and most critical priority to address is to do with teachers and teaching related issues. The Review also made recommendations regarding the Dinaledi Programme, that had become the key initiative arising from the National Strategy of 2000.

For its part, the HRDC National Integrated Human Resource Development (NIHRD) Plan (2014-2018) duly set out its strategic objectives as:

Strengthening basic education and foundation programmes in *Science, technology, engineering, mathematics, languages and life orientation/skills;*

- *Expanding access to quality post-schooling education and training;*
- *Improving research and technological innovation outcomes;*
- *Producing appropriately skilled people for the economy;*
- *Advancing the formation of the developmental/capable state.*

The National Education Collaboration Trust (NECT), in support of the HRDC Summit and as the leader of Human Resource Development Council (HRDC) Task Team 1, has requested a set of reflective papers (think pieces) on programmatic areas deemed key to the skills development path.

These are to cover Early Childhood Development; Reading improvement; STEM; Pathways (3 stream curriculum, Focus Schools); and Competencies for a changing world. The think pieces are to present the state of affairs in the programmatic areas, identify gaps in policy and practice levels, and make recommendations for strategic steps that the various players should take.

90% LEARNERS
WILL PASS MATHEMATICS

This Think Piece addresses matters concerning Science and Mathematics Education (STEM) that are major concerns of the NECT, as reflected in its strapline that the NECT is 'committed to ensuring a South Africa where **90% of learners pass mathematics, science and languages with at least 50% by 2030.'**

In the short time since the Terms of Reference were issued, the world has plunged into a crisis not experienced for a century.

At the time of writing, we remain in **lockdown,** and critically aware of our vulnerabilities in the context of infectious disease morbidity, and social and economic exclusion.

We are entering a period of social disruption and economic depression of an extent that will stretch all nation-states. To these pressures should be added the imperatives of climate change, globalization, the emergence of multiple geopolitical power blocs, deindustrialization, the ongoing ICT revolution in the form of the Fourth Industrial Revolution (4IR) and the rise of the surveillance state.

- Talent, ingenuity, compassion and creativity, embodied in science, technology and innovation (STI) must rise to the challenges posed by this, the Age of Crisis.
- Technology and Innovation are understood to encompass hard and soft technologies, as codified and tacit forms of knowledge.
- While responsible research and innovation (RRI) are elements for building a developmental state, good governance, the rule of law, meritocratic appointment, and accountability are essential to public support.

Given the increased complexity facing all policy formulation, futures thinking will inform this work. To this end a situational, anticipatory, and outcomes-oriented methodology is followed. The methodology employs a systems approach informed by a situational analysis, and scientometric analysis. This is followed by a brief Anticipation, and a SWOT analysis. A targeted set of recommendations is tendered.

2.0 THE STATE OF AFFAIRS

2.1 SITUATIONAL ANALYSIS

To scope possible SME interventions, it is necessary first to understand the underlying ecosystem in which these are to be progressed. Politically, South Africa is a relatively young state, being unified through the 1899-1902 war that gave rise to the accommodation between Boer and Briton, and exclusion of the Black majority. The constitutional settlement of 1994 marked agreement on a new accommodation.

Both accommodations were shaped by the resource-based economy, the power of local and international capital, and organized labour. A century of industrialization made South Africa the most diversified African economy, but at huge social cost.

UP TO 5 MARCH 2020

, when the first local COVID-19 case was reported, the main concern of government was the need to confront poverty, unemployment and inequality. How this will change once a 'new normal' comes into play is an open question. A return to business as usual is unthinkable.

- On the economic front, the mixed economy has continued, with the private sector free to invest globally, but shackled locally.
- Monetary and fiscal policy have maintained the neo-liberal stance of the National Party governments. The short period of the Growth, Employment and Redistribution strategy and the commodities super-cycle notwithstanding, economic growth has been lack-lustre, and even prior to the pandemic, averaged but 1% p.a. Measured in 2010 US Dollars, GDP/capita has remained at roughly USD 7 400 over the last fifteen years.

Compared with commodity-exporting peers, South Africa has performed poorly, in that the composition of her exports has remained largely unchanged, bar that of automotive exports. A strong path dependence is evident.

Economic inclusion has seen limited gains through the exclusion of the previously entitled, and this more through substitution than expansion and innovative entrepreneurship. Weak industrial performance has been compensated by expansion of the public sector, that has doubled in size. South Africa's rank on the World Economic Forum Global Competitiveness Index (GCI) fell from 45th in 2006 to 67th in 2018 (WEF, 2019).

Regarding social development, the Human Development Index (HDI) fell from 0.65 to 0.62 over 1995 to 2005, due to the collapse in life expectancy from AIDS-mortality.

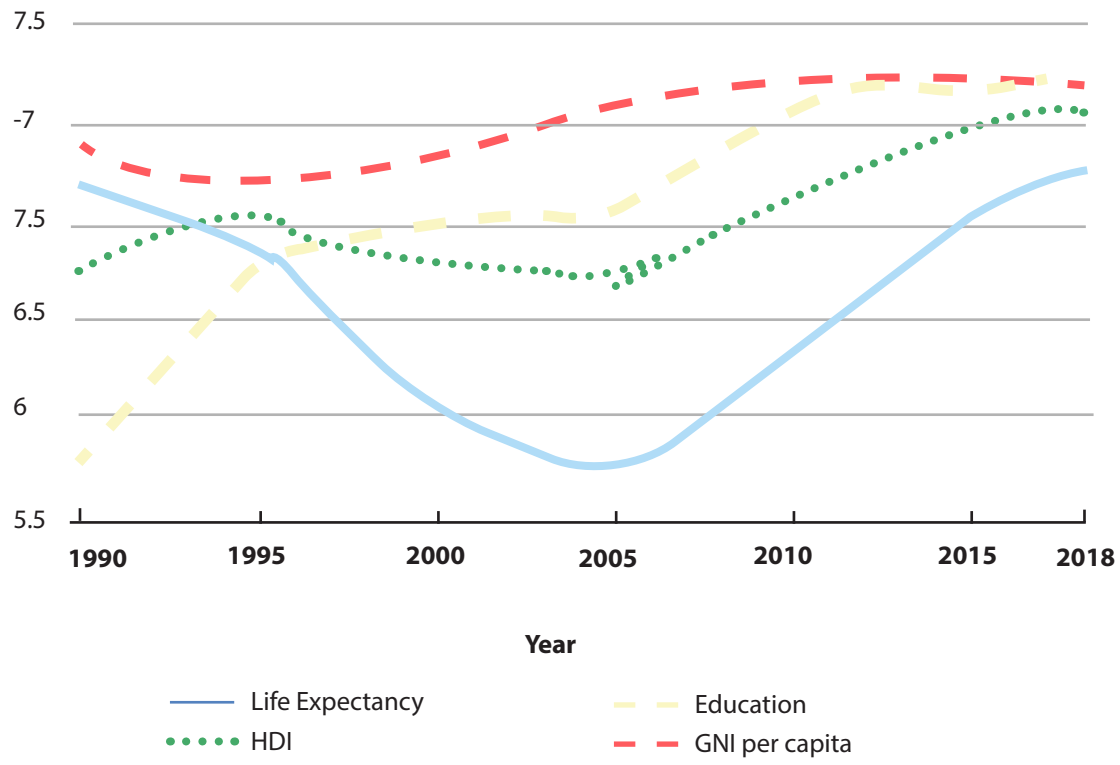


Figure 1: Human Development Index, 1990-2018

Gains in school participation (orange dashed line) have been cancelled by decreased life expectancy. At the aggregate level, mean years of schooling have increased, having saturated at 10.2 years.

Net primary enrolment is now close to 100%, with Grade 1 enrolments steady at around 1 million over the last two decades. Those writing the National Senior Certificate show a small variation around the 530 000 level, indicating that progression through the school system has remained static. Illiteracy of those aged 15 years and above has settled at around 5%.

- Apartheid, cynically known as 'separate development' was a variation on the theme of 'divide and rule.' This rested on race classification and forced removals, against the backdrop of the chieftaincies and tribal reserves that were designated a century earlier.

- The democratic government set out to remove restrictions on place of abode, remuneration and movement. An unintended consequence was increased migration from the rural areas to the uncertain prospects of peri-urban life. Huge informal settlements sprang up on the veld; some provinces saw reduced demand for schooling; others struggled to keep pace with the flow of new entrants.

On the positive side, a system of social grants has been deployed, and those living in absolute poverty have declined. But childhood stunting and high levels of foetal alcohol syndrome persist, and obesity and other non-communicable diseases are increasing.

Unemployment has risen toward 30%, with youth unemployment at 50%. The Gini coefficient remains around 0.65, placing South Africa and its periphery among the most unequal societies in the world. It is perhaps cold comfort to note that South Africa hosts the world's largest Anti-retroviral and tuberculosis treatment programmes, alongside world-class research on infectious disease, immunology, and public and environmental health.

However, the 2016 WHO Joint External Evaluation of health security preparedness revealed important systemic weaknesses.

- The cultural dimension includes the legal system and societal values. A useful way of linking culture and education, is to return to the insights of sociologist Bernstein who suggested that curriculum is an extract from culture, mediated by the dominant power and class structure
- We are a set of multi-ethnic, multilingual communities, gathered together within borders laid out in colonial times. Constitutional democracy is articulated in Roman-Dutch law, and co-exists with traditional ways and means. Land deeds apply to some; the nod of a chief to others.

From this, a curriculum that favours the written over the oral. From these intended, or unintended structures, divisions that are propagated and perpetuated by language barriers. If we cannot understand what the other is saying, do we hear them at all?

Previously disadvantaged individuals are empowered above their former bosses with their restricted language skills. If I speak five indigenous languages, and you speak none, who is disadvantaged? The role of mother tongue as the language of instruction is an essential shaper of school performance.

The technological is taken to refer to the global currents of science, technology and innovation insofar as these shape, or are shaped by the local environment. In the last half century, a number of innovations have changed workplace and social interchange, with formal education demonstrating the least change.

These existing system chokes should be seen in the context of the ICT revolution that gained pace in the early 1970s, and now comprises the Internet, portable read/write memory and communication devices, mapping and location systems, robotics, social media, big data, geo-positioning and surveillance. The rapidity of change in artificial intelligence prompts the claim that we are entering the fourth industrial revolution (4IR).

These changes have propelled globalization, de-industrialization, the expansion of the services industries, and monetization of intangible assets and services. South Africa's domestic contribution to the new technologies, gaming and mobile apps aside, has been marginal.

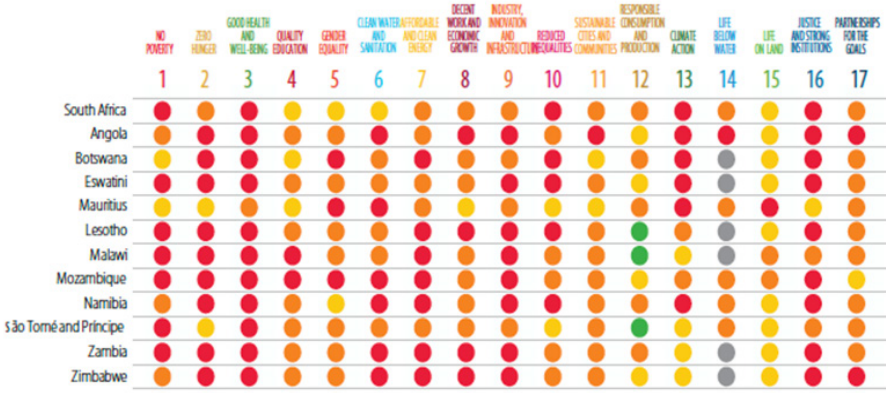
As to the environmental, 'King Coal' dominates the electricity, chemical and cement industries, with the Highveld hosting the highest nitrous oxide emissions in the world. The weakness of environmental controls gives rise to poaching of animals and marine life, this alongside world class research in ecology and environmental science.

- A compact summary of the environmental and other issues that contribute to sustainable and harmonious development is provided as Figure 1 that shows progress toward the attainment of the SDGs. South Africa shows no green scores, but progress in education (SDG 4), gender equality (SDG 5), clean water and sanitation (SDG 6), and life on land (SDG 15).

- There is stasis for zero hunger (SDG 2), work and economic growth (SDG 8), sustainable cities (SDG 11), responsible consumption and production (SDG 12), life below water (SDG 13) and partnerships (SDG 17).

Country scores on affordable and clean energy (SDG 7) and innovation (SDG 9) indicate stasis. The overall picture is that of sideways movement. the SDGs speak to a patchy record, with a decline in climate action (SDG 13)

Source: 2019 Africa. SDG Index and Dashboard. Sustainable Development Solutions Network, New YorkSSDSustainablG Center for Africa and Sustainable Development Solutions Network



Legend: green for attained; yellow rising; orange steady; red declining; grey no data
Figure 2: Attainment of the SDGs, Southern Africa, 2018

2.2 SCIENTOMETRIC ANALYSIS

Scientometric analysis entails quantitative analysis of the science system. This is based on widely accepted STI indicators compiled by the Government UNESCO system, African Union, and the multilateral organizations.

2.2.1 SCHOOL ASSESSMENT

Analysis of the education system draws on a number of secondary sources: PIRLS, SACMEQ, TIMSS, Education Statistics, HEMIS, the National R&D Survey, unpublished material provided by the Department of Higher Education, Science and Innovation, and international sources. The Annual National Assessments of the Department of Basic Education were terminated after 2014, and are not referred to here.

As of 2019 there were 12,8 million pupils attending 25 000 schools served by 437 448 educators.
Post-secondary education and training involved 1,2 million students and 676 000 staff. South Africa participates in the Progress in International Reading Literacy Study (PIRLS), that at five-year intervals assesses grade 4 pupils of sixty countries. PIRLS assesses reading comprehension and reading literacy on a 1000-point scale. A comparative snapshot is shown as Figure 2. South Africa was placed last of the fifty countries assessed in 2016.

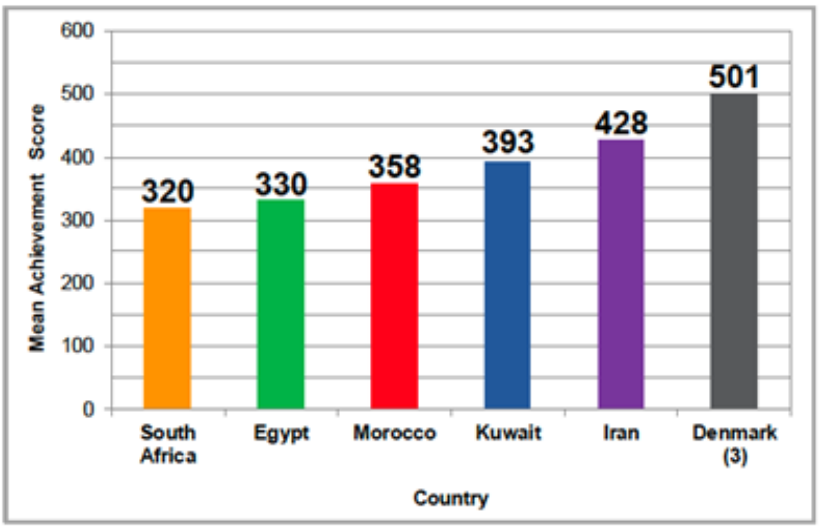


Figure 3 :PIRLS scores, comparative
Pupils were assessed in mother tongue. Achievement for each official language is shown as in Figure 3

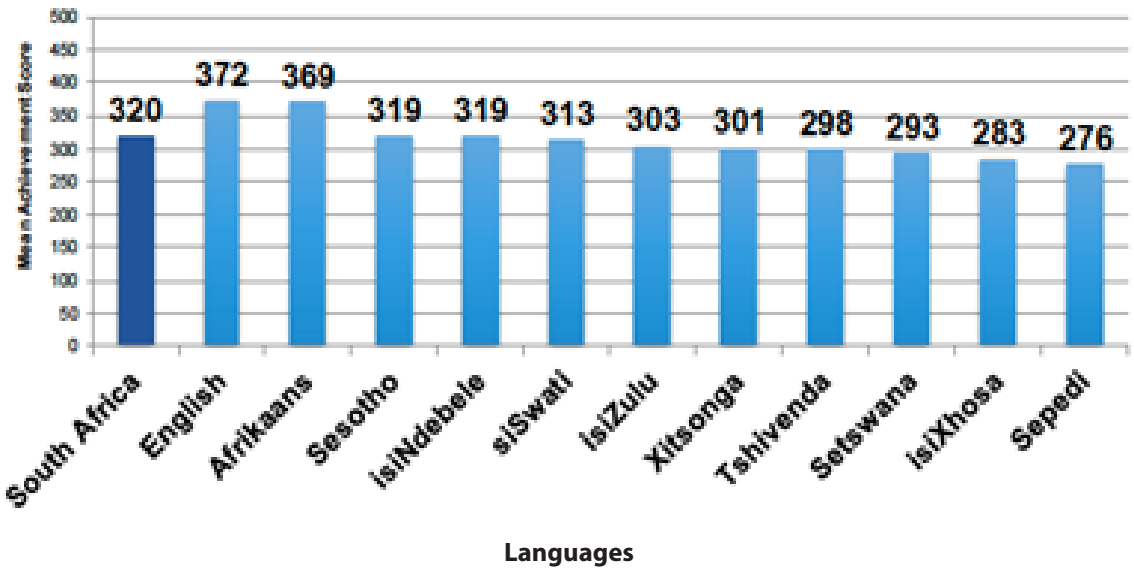


Figure 4: PIRLS, mother tongue scores

Scores below 400 indicate that the pupil cannot read for meaning or retrieve basic information from text to answer simple questions. In effect, '… 78% of South African Grade 4 children were not able to reach the lowest benchmark compared to 4% internationally' (Howie et al, 2017: 4). Pupils from impoverished and rural backgrounds scored poorly. Females scored slightly higher than males.

However, the Southern African Consortium for Measuring Education Quality (SACMEQ) IV grade 6 study suggests a steady improvement in basic learning resources across the provinces. On the other hand, less than 40% of school buildings were rated to be in good condition.

- As to achievement in reading and mathematics, Table 1 shows the rising trend across the three SACMEQ rounds attributed to a) the streamlining and strengthening of the national curriculum between SACMEQ III and SACMEQ IV, b) the focus on monitoring teaching and learning through the National Strategy for Learner Attainment and c) regular exposure to standardised assessments through the Annual National Assessment.

Learners	READING			MATHEMATICS		
	SACMEQ II	SACMEQ III	SACMEQ IV	SACMEQ II	SACMEQ III	SACMEQ IV
South Africa	492	495	538	486	495	552

Table 1: SACMEQ III and IV

However, the proportion of pupils who reached the stage of reading with meaning was barely 40%, whilst but 61% of grade 6 pupils exhibited basic numeracy. Female pupils performed slightly higher than males; likewise, urban-rural and high-low income differentials. Teacher scores were some 200 points higher, with 98% of teachers functioning at reading levels 7 and 8. By contrast, only 65% of teachers showed competence in mathematics at levels 7 and 8.

The most recent TIMMS survey was that for 2015, and surveyed a set of 36 countries, 33 at grade 8 and 3 at grade 9 level (South Africa, Norway and Botswana). The set is dominated by the OECD members states and countries of the European Union. South Africa was ranked 35th for mathematics and 36th for science, retaining its low rank in the earlier TIMSS series of 1999, 2003, and 2011.

It must be noted that there is some correlation between GDP/capita and country TIMMS performance. High income correlates with high performance. It should be noted that South Africa's absolute scores have risen significantly, by 87 points in mathematics and 90 for science. There was a 24% rise in pupils scoring above 400 points.

2.2.2 NATIONAL SENIOR CERTIFICATE

Regarding the National Senior Certificate, from 2008 onward it became a requirement that all candidates wrote Mathematical Literacy or Mathematics. This amounted to a system shock, in that all pupils were to be taught these subjects; up to 2006 the uptake into Mathematics higher and standard grades was around 60% of NSC entrants.

The system shock was obvious: were sufficient teachers with the necessary pedagogic subject knowledge available to face the new classes? Table 2 provides information on entry for, and performance on the National Senior Certificate.

	Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	Total	554	552	537	496	511	562	532	645	610	534	513	504
Life	Enter	287	299	285	265	226	302	284	348	345	318	310	301
Science	Pass	39.7	39.8	51.6	46.2	43.4	47.8	48.9	46	45.2	52.1	51.7	49
Maths	Enter	299	290	263	225	226	242	235	264	266	245	234	222
	Pass	30.1	29.3	30.8	30.1	35.7	40.5	35.1	31.9	33.5	35.1	37.1	35
Maths	Enter	263	278	281	275	291	324	312	389	362	313	294	299
Literacy	Pass	55.1	51.1	64.8	65	61.4	62.4	59.5	44.3	46.4	45	45.4	54.5
Physical	Enter	218	221	205	181	179	184	168	193	193	180	172	164
Science	Pass	28.9	20.4	29.8	33.8	39.1	42.7	36.9	36.1	39.5	42.2	48.7	51.7

Source: Department of Basic Education
Note: Pass denotes performance at 40% or higher
Table 2: NSC entry (000s) & performance (%), 2008-2019

ACCORDING TO THE MINISTRY OF BASIC EDUCATION,

The achievements of the class of 2019 confirm that the standard and quality of the South African examinations system is improving annually and stabilising. The proficiency of our education system is confirmed by:

- An improvement in the pass rate and quality of passes in many gateway subjects.
- A noteworthy and credible increase in the percentage of learners who achieved the NSC.
- A significant increase in the percentage of learners qualifying for Bachelor's Studies.
- Phenomenal gains in the margins of improvement among Quintile 1 to 3 schools.

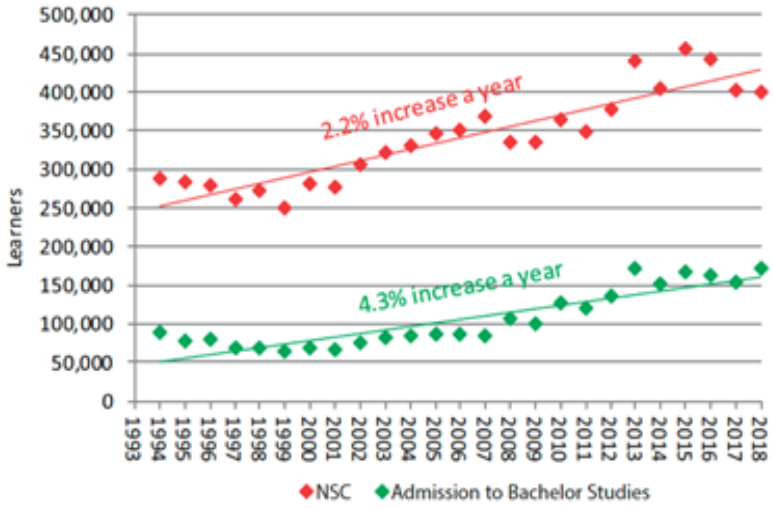


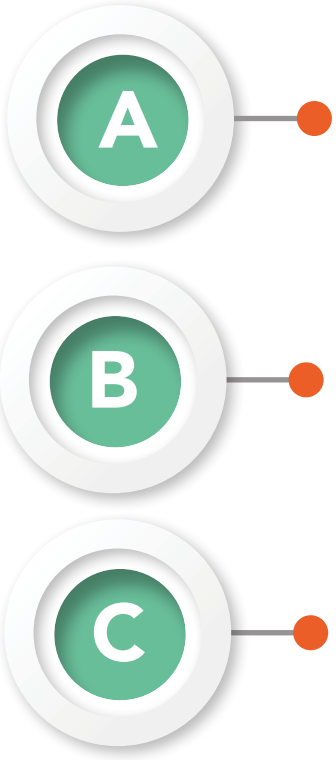
Figure 5: National Senior Certificate trends

Closer analysis of subject entry data shows that Mathematical Literacy is favoured above Mathematics, with median entry levels of 296 500 and 243 500 respectively. Entry for Life Sciences is preferred to Physical Science.

Performance also reveals stark differences. The first is the variation in the proportion of those scoring above 40%. The simplest measure of variation is the standard difference, that is lowest for Mathematics (3.36), followed by Life Sciences (4.26), then Mathematical Literacy (7.78) and finally Physical Science (8.66), where the performance has risen considerably.

- The reasons for such dispersion warrant further investigation. Some explanation of the 2013 results is also called for – why the upward jump in the subject pass rates other than in Mathematical Literacy? Males pupils outperform the female pupils in the above STEM subjects (data not shown).

In terms of the Action Plan of the Department of Basic Education (DBE, 2019), the following three key targets are to be directly measured through the performance in the National Senior Certificate:



Action Plan targets show:

- Bachelor Pass 4,3% growth p.a
- No increase in the Mathematics pass rate; declining rates for Mathematical Literacy
- The pass rate for Physical Science has risen strongly.

The data of Table 2 and Figure 5 suggest that target (a) shows 4,3% growth p.a. (b) the pass rate for Mathematics is flat; that for Mathematical Literacy is declining (c) the pass rate for Physical Science has risen strongly. The Department goal to reduce the number of students opting for Mathematical Literacy has not been met.

2.2.3 THE TEACHING PROFESSION

The Occupation Specific Dispensation of 2008 made provision for 110 000 teachers to attain Relative Education Qualification Level (REQV) 14 by the year 2012. This represented 41% of the non-graduate teaching force. It was estimated that the increase in salary costs would amount to R 3 billion by that year (DBE & DHET, 2011).

These qualified teachers are now in the education system, having obtained the necessary add-on certification. Projecting forward, the proportion of unqualified teachers in the system would now be below 5%, down from the 36% of 1994. Simkins (2015) had found some 14% of teachers were unqualified.

- The higher pay that possession of REQV 14 dictates, together with annual increments above CPI, has led to the situation where teachers work shorter hours and are better paid than private sector workers with similar qualification levels.
- In 2014 an entry level REQV 14 teacher earned R198 888 basic salary, plus another R73 588 benefits, totaling R272 476. By 2019, the total cost of employment of that teacher would be in the order of R380 000.

In 2014 an entry level REQV 14 teacher earned R198 888 basic, plus another R73 588 benefits, totaling R272 476.

The consequence of the ballooning salary bill is that provincial education budgets are mainly committed to personnel costs, with infrastructure being last on the list.

A second problem relates to the allocation of teachers to subject areas for which they are not qualified (CHEC, 2009). This in turn raises questions regarding the level of mathematics, physics, chemistry or biology required to prepare secondary level teachers. Should senior secondary level teachers attain the equivalent of university first year subject matter, or is a higher level needed?

- Whether these rewards are accompanied by improved learner performance is an open question.
- The shortage of subject teachers is especially acute in SME, where subject specialists are often allocated to other roles, especially as department heads or headteachers.
- Mlachila and Moeletsi (2019) maintain that the mismatch between the level of education expenditure and system performance is associated with 'insufficient subject knowledge of some teachers, history, race, language, geographic location, and socio-economic status.'

2.2.4 HIGHER EDUCATION

Table 3 provides a snapshot of STEM in the university sector. Total university enrolments rose 50% over the decade, with the proportion in STEM increasing from 25.7 to 29.9%.

This falls short of the 35% target of the Ten-Year Innovation Plan (DST, 2018). The same Plan had set a target of 3000 STEM PhD graduates by 2018. The achieved total was in the order of 1500, of whom a third were foreign students on student visas who would be expected to leave the country on graduation.

Year	2007		2012		2017	
	Enrol	Grad	Enrol	Grad	Enrol	Grad
All fields	760889	126618	953373	165995	1036894	210931
STEM undergraduate	174119	28319	243767	43495	270500	53163
STEM Masters	16760	2767	22499	4370	28512	6964
STEM doctoral	4616	590	7016	984	11103	1454
STEM Total	**195495**	**31676**	**273282**	**48849**	**310115**	**61581**
% STEM	25.7	25.0	28.6	29.4	29.9	29.2

Table 3: Higher education enrolments and graduates, 2007, 2012 & 2017

It is important to situate the above in a larger context, namely the personnel that embody the national system of innovation. The data of Table 4 are provided from the annual R&D Surveys that are conducted according to the guidelines of OECD (2015). A convenient snapshot provides headcount (HC) and full-time equivalent (FTE) values of 'researchers,' roughly equivalent to what HEMIS records as 'research and instruction' personnel (Table 4).

YEAR	2003/04		2007/08		2011/12		2016/17	
	HC	FTE	HC	FTE	HC	FTE	HC	FTE
SECTOR								
Business	5058	4153	8336	6048	6191	4452	6463	4777
Government	929	443	1138	758	1411	1010	1677	969
Science Councils	2414	1900	2594	2300	1803	1635	2189	1941
NPOs	305	258	264	216	251	191	404	341
Higher Education	14055	3374	17008	3672	16294	4356	18900	4900
Total	*22761*	*10128*	*29340*	*12994*	*25950*	*11644*	*29633*	*12928*

Source: R&D Survey series
Note: 2016/17 Higher Education adjusted to exclude foreign staff employed on contracts > 6 months.
Table 4: Researchers by sector, 2002-2017

- The 2016/17 university researcher headcount is not strictly comparable with earlier years, and has thus been adjusted for continuity. The trend line suggests that this cadre has increased by barely thirty percent over the period 2003/04 to 2016/17.

- In contrast, over the same period, student enrolments rose by fifty percent. The shortfall in teaching and research staff is being filled by an increasing number of doctoral and post-doctoral students that totaled 25 600 such 'researchers' in 2017.

Doctoral and post-doctoral students are substituting for the teaching and supervision role of permanent staff

The FTE count of doctoral and post-doctoral students was in the order of 14 950, representing a massive resource, twice the size of the permanent cadre. It may be noted that sixty percent of post-doctoral students are foreign.

Lastly a comment on university staff costs. Over the ten-year period 2005/6 to 2015/16, the average cost per FTE of university research personnel rose from R245 000 to R503 000, representing an annual average compound growth rate of 7,5%. An adjustment based on CPI would have yielded a package of R440 000. Research personnel have thus enjoyed the benefits of the political power of public sector unions to achieve wage settlements above inflation.

The research enterprise has become increasingly dependent on cheaper cost doctoral and post-doctoral students to fill the staff gap.

2.2.5 TECHNICAL AND VOCATIONAL EDUCATION AND TRAINING

Last for consideration is the Technical and Vocational Education and Training (TVET) sector. This is seen as a motor for skills development. Total enrolments are shown as Table 5.

Qualification Category	2010	2011	2012	2013	2014	2015	2016	2017
NC(V)	130 039	124 658	140 575	154 960	166 433	165 459	177 261	142 373
Report 191 (N1-N6)	169 774	222 754	359 624	442 287	486 933	519 464	492 026	510 153
Occupational Qualifications	23 160	20 799	62 359	19 000	19 825	20 533	13 642	10 969
Other	35 420	32 062	95 132	23 371	29 192	32 424	22 468	24 533
Total	358 393	400 273	657 690	639 618	702 383	737 880	705 397	688 028

Table 5: TVET enrolment, 2010-2017

For the year 2010, Cosser et al (2011) recorded that 96% of TVET students were Black, by 2017 this had risen to 99% (DHET, 2014), with seventy percent of students being younger than twenty-four years of age. This concentration implies that working age persons are still not using TVET for skills upgrading, a problem previously noted by (Cosser et al, 2011: 38). TVET thereby functions as a continuation of schooling, serving as a holding zone for youth.

- In 2017 the most popular NC(V) subject was Office Administration (21.3%), followed by Engineering and Related Design (12.4%) and Electrical Infrastructure and Construction (11.9%). Some 27% of female students enrolled for Office Administration while 22% of male students enrolled for Engineering and Related Design and Electrical Infrastructure Construction (17%).

  Females dominated enrolment in Office Administration and Education and Development; males in Engineering and Related Design programme (DHET: 2019, 37).

A TOTAL 19 100
CANDIDATES RECIEVED THE
NATIONAL TRADE CERTIFICATE FOR
ARTISANAL
TRAINEES

Two thirds of these graduates were in the manufacturing or utilities sectors. This represents a significant increase on the 2 500 artisans who qualified in 2004 (Cosser et al, 2011). The group composition of TVET lecturing staff rose from 63% Black in 2010 to 96% Black in 2014.

The qualification profile of 2010 showed 43% as degree holders; by 2014 this stood at 56%, though only 31% were fully qualified as college lecturers. TVET demonstrates the highest intensity of transformation of all sectors. It appears that staff do not hold the qualifications needed to deliver the curriculum.

3.0 STEM: BLOCKAGES, GAPS AND ANTICIPATION

3.1 STEM RESEARCH FINDINGS

A concise bibliometric analysis of the Clarivate Analytics Web of Science database category: Education, Educational Research refers. Over 1995 to 2019, the number of whole count articles and book chapters indexed to South African authors in Education, Educational Research amounted to 4 341 publications, or 2,2% of all national publications. Over 2009-2019 Education, Educational Research ranked in 8th position, accounting for 2,6% of all publications (Figure 6).

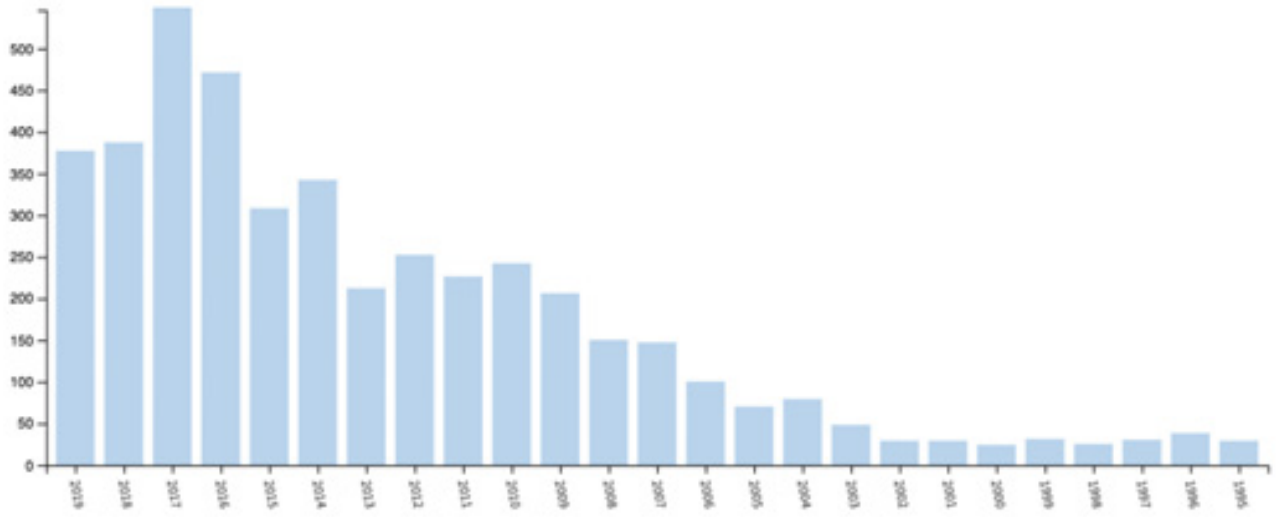


Figure 6: Education Educational Research, whole count

This increase is claimed to be a result of the increased Journal Subsidy allowance from 2003 onward (Mouton, 2015). This is particularly true for the social sciences and humanities. Kahn (2018) suggests that internal co-authorship may be a more powerful factor driving the increase in output. The period under review also saw the establishment of the SA Research Chairs Initiative in 2010, that included six well-resourced chairs in mathematics education.

Over 2009 to 2019 some 200 papers per year were dedicated to various aspects of education – learning, curriculum theory, comparative and sociological matters, engineering and medical education, continuous professional development, and so on.

The area of STEM research may be further examined by including the keyword 'mathematics' in the database search. This search generated 273 records.

Ranked according to the number of citations received, the works of Spaull (2013), Spaull and Kotze (2015), and Planas (2014), stand out. Fleich (2016), Planas (2018) and Phakeng (2013) are also cited more than 9 times. Spaull and co-workers provide a careful analysis of disadvantage in mathematics in the foundation phase, arguing that this disadvantage persists through to higher levels.

Fleich considered system-wide aspects; Planas and Phakeng investigate language and concept formation in the foundation years. This study finds a gap in the consideration of language in the senior phase of education. On the other hand, cognition and concept formation has long been a focus area as for example the work of Rollnick, Adler and others.

3.2 A LANGUAGE BARRIER

The ANC Policy Framework for Education and Training of 1994 declared that … appropriate varieties of science and mathematics will be integrated into all levels of the national curriculum. This would be achieved by offering core modules and 'additional science and mathematics courses … as options for students wishing to specialise in science and mathematics.

In the event, science was not made a compulsory subject beyond Grade 9, and as noted earlier, 'mathematics' only became compulsory from 2006 onward, with the introduction of the two new offerings, Mathematical Literacy and Mathematics.

- These replaced the previous Mathematics Higher and Standard grade options. However, performance in Mathematical Literacy has not met expectations. It is reasonable to inquire as to what might account for this?

What is missing from the body of research is consideration of the curriculum as a whole, meaning delivery in the classroom. The most obvious problem is the supply and appropriate deployment of teachers with mathematics pedagogic competence, and the necessary communication skills.

The typical Mathematical Literacy (ML) classroom involves a dialogue in English or Afrikaans, involving teachers and learners for whom in most cases neither language is their mother tongue. The communication problem is exacerbated by an apparent rise in cognitive demand, as the results in Table 6 suggest. The proportion of candidates attaining a score greater than 80% declined markedly over the period of observation.

Moreover, comparison between the two subjects suggests that the cognitive demand of ML could now be higher than that expected of candidates in Mathematics, in that 3,3% of these score >80% compared with 2,4% of the ML candidates.

	2008	2009	2010	2011	2012	2013	2014
Mathematics							
Wrote	301987	304159	263341	224635	225954	241509	225522
> 50%	21.1%	17.7%	19.1%	18.5%	22.7%	26.1%	22.3%
> 80%	4.3%	2.9%	3.6%	2.5%	2.9%	3.4%	3.2%
Mathematical literacy							
Wrote	268022	281623	280877	275385	291468	324097	312103
> 50%	37.5%	30.7%	40.6%	40.6%	35.8%	35.5%	34.3%
> 80%	6.3%	3.2%	3.5%	2.7%	2.5%	1.8%	2.4%

Table 6: Performance in NSC subjects
Source: Amalusi (private communication)

- The ML teacher is further expected to master the 107-page Curriculum Assessment Policy Statement (CAPS); by contrast, the Mathematics CAPS is but 62 pages long. For the ML examinees, a similar imbalance. ML paper 1 comprises 14 pages plus annexures, and entails the decipherment of some 1800 words. In contrast, Mathematics paper 1 is 9 pages long, with 950 words.

Mathematical Literacy is language rich; pupils must puzzle out lines of text to determine what the actual question entails. All very politically correct, but so often obscure. Pity the teacher, pity the pupil. ML tests communication skills, and then logical skills.

It tests the communication skills of the teacher, and the pupil, and of course the examiner and marker. A teacher who battles to communicate in general will be unable to teach ML and understand the difficulties that their learners experience. Mathematics largely strips away language to get at the logical essence. ML adds language and obscures the problem at hand. So, an ML examiner might set the question Thumi is a crop farmer. She is inspecting her fields one day and sees six crows sitting on the barbed wire fence that surrounds the 1-hectare field.

She is worried that the scavengers will eat the maize heads and that her income will be reduced. She quickly fetches her properly-licensed shotgun, loads it, and after ensuring that no-one is in the intended line of fire, shoots one crow, that falls dead on the ground. How many crows are left on the wire?

The 'mathematically correct' answer is 5; the real-life answer is 0 since the surviving crows will have flown away, leaving a bare fence wire This parody gets to the essence of the ML problem.

Great in principle; difficult in practice. The mathematics paper would simply instruct: 'Calculate 6 – 1 = ?' The problems associated with Mathematical Literacy provide insights into the functioning of the curriculum as a whole. Pedagogic subject knowledge, and language competence on the part of teacher and pupil are barriers to the learning enterprise.

3.3 SHOOTING STARS

For close to fifty years concerned parties have sought to build capacity in our science and mathematics classrooms, through the work of NPOs, as well the efforts of education departments. Notable efforts on the NPO side include SACHED, Star Schools, the Science Education Project, CASME, PROTEC, and Primary science Project.

For its part, government introduced the SYSTEM Initiative that operated from 1995-1999, the 500 Dinaledi Schools from 2002-2014, and more recently, the Funza Lushaka teaching bursary programme. Efforts to improve computer literacy were driven by the ICT in Schools Strategy. Of the above interventions, it is only the Dinaledi Schools that were subjected to full evaluation using the difference-in-difference approach (Blum et al, 2010). The evaluation found … that the program was effective in improving Senior Certificate results in Higher Grade (HG) physical sciences and mathematics.

- The Dinaledi program nearly doubled the number of students who entered and wrote HG physical sciences. By 2007, 35 students entered HG physical sciences in Dinaledi schools on average, compared to 18 students in similar non-Dinaledi schools. In addition, 60% more students passed the HG physical sciences exam. The program affected different schools differently.

Formerly disadvantaged Bantustan schools and schools in KwaZulu Natal and Limpopo were able to take full advantage of the program and deliver huge improvements in the observed indicators.

- By contrast, effects are small and statistically insignificant in Free State, Gauteng, Mpumalanga, North West and Western Cape. These preliminary findings deserve a more in-depth analysis. The founding rationale of the Dinaledi or 'star' schools was to enable a nucleus of well-functioning schools that had previously offered Mathematics and School Science at standard grade to introduce higher grade classes, and to act as mentor-trainers of neighbouring schools to allow them to follow suit.

- The above finding suggests that the first objective was achieved, especially in schools in rural areas, and this despite sever resource constraints. The original design called for the provision of mathematics and physical science teachers additional to establishment. This did not happen, and in the words of one Superintendent -General, 'we had to make do with what we had.'

The 2014 Review (§5.2.1.) then noted that;
The Dinaledi Project initiative has achieved several important gains, but has not achieved the level of positive impact that was intended. The gains include:

- A major improvement in MST infrastructure in Dinaledi schools;
- A consistent higher pass rate in Dinaledi schools than in other schools. Dinaledi schools have been responsible for a significant percentage of the annual national passes in maths and science.
- While some Dinaledi schools have not risen to the challenge, most Dinaledi schools have made and continue to make a major contribution to MST achievement.

It would appear that the Dinaledi programme continues to hold valuable potential to contribute to MST improvement but a review is necessary if the potential is to be exploited to optimal effect. In this regard, the following is proposed:

1

The list of schools designated as Dinaledi schools should be reviewed and strengthened by:

- Removing non-performing schools from the project;
- Restructuring the programme to provide for differentiated levels of support for different categories of schools in Dinaledi. This will include providing more support for non-fee paying Dinaledi schools than for fee paying schools;
- Increasing the number of non-fee paying Dinaledi schools with high levels of potential

2

A stronger system of curriculum support, planning, management and monitoring should be put in place alongside infrastructural and resource provision. Provincial education departments should convene transversal Dinaledi committees that include representation from curriculum, HRD and teacher training, institutional development and other relevant directorates.

3

MST content, instructional management, assessment and other training should be strengthened for classroom teachers and management training provided for SMTs in Dinaledi schools.

4

Local private and public sector partnerships should be sought to support MST curriculum activity at schools and to strengthen links to the world of work.

5

A strategic investment to expand the role of selected Dinaledi Schools to include Boarding Facilities for Learners and Teachers should be considered in the short-term These recommendations appear to be unhelpful, in that a similar culling exercise took place in the early 2000s. What really went wrong with Dinaledi? This story remains to be told. It now appears that the Dinaledi School project has been terminated. The Shooting Star has fallen to earth.

3.4 ANTICIPATING THE FUTURE

Anticipation sets out to provide a glimpse of possible futures, and to use this insight better to understand the present. This is a somewhat different approach to forecasting, an example of which is the 1999 expectation of US futurist Ray Kurzweil that by 2019, avatars would have replaced flesh and blood teachers.

Not so. Kurzweil was far out of the box. Yet, in contrast is the Bill Gates remark of 1995 that 'People often overestimate what will happen in the next two years and underestimate what will happen in ten. I'm guilty of this myself.' But, thanks to Moore's Law, the roadmap of the ICT revolution has shown remarkably forecast accuracy regarding computing power and the associated possibilities.

In fact, Kurzweil's predictions on the advent of artificial intelligence were conservative. Artificial intelligence, data analytics and surveillance are here. We are living the Fourth Industrial Revolution.

Historically, pandemics have forced humans to break with the past and imagine their world anew. This one is no different. It is a portal, a gateway between one world and the next. Arundhati Roy, Financial Times, 3 April 2020

ICTs provide the illusion of personal empowerment to the connected, who can access information, anywhere, anytime. They promote the 'gig' economy of individuals, who like lone consultants, are employed to fill a short-term gap.

In opposition to this 'freedom' is the surveillance state, now further advanced by the COVID-19 pandemic and the need for track and trace. Education systems, with their origins in the 1st and 2nd industrial revolutions, have been slow to change. The mode of education production, of cultural reproduction as 'teacher-in-classroom' based remains dominant. Education systems, designed to free up parents to 'go to work' may become redundant.

COVID 19

FOLLOWING IN THE WAKE OF THE UNRESOLVED 2008 FINANCIAL CRISES

highlighted the question of the resilience of the global economic order.

Applying anticipation, one therefore tests each sector with the question 'has this mode of doing outlived its purpose?' Specifically, is the education system fit for purpose? Has it reached the end of it shelf-life? What then some possibilities? Anticipation is the capacity to incorporate the future into relevant ways of functioning in the present.

We are living in a unique moment, a period in which centralized production has contracted, travel is curtailed, and leisure industries have shut down. The collapse in economic activity, and collateral pollution, is unprecedented.

- For the connected, maintaining contact from home base, be this suburban house, a lean-to, or apartment, is essential and possible, provided electricity supply is maintained. School is out; universities are on long leave. Life goes on. Will it be an attempt to return to 'normal,' or shall we strive for a new normal?

Classroom schooling, even in the hands of a brilliant teacher, is not the most effective way to transmit the 'selection from culture.' Learning the three R's does not require attendance in a room with thirty others. Studying accounting or quantum physics is open to anyone who is enrolled in a MOOC. The cognitive side is open to substitution; the social and socialization is another matter.

Above all, is the concern that the 4IR, like its predecessors may exacerbate inequalities. It is hardly necessary to remind of the concerns with the 'digital divide; that were aired over the last three decades. Perhaps the most positive recommendation that can be tendered is to introduce coding into classroom activities as soon as possible. Coding is a low-cost activity, closely linked with language development, and online in and itself relies on basic arithmetic operations.

3.5 SWOT ANALYSIS OF STEM EDUCATION

The SWOT analysis is based on the above considerations. It serves to summarize what works, what doesn't, and suggest why this may be so.

3.5.1 STRENGTHS

- Pockets of world class research
- Tradition of NGO intervention
- Multimedia delivery skills
- Software development cadre
- Well-managed examination systems
- Postgraduate hub for Sub-Saharan Africa
- Progression toward gender equity in the research system
- Progression toward employment equity in the government research sector

3.5.2 WEAKNESSES

- Leveling of the goalposts (NSC pass level of 30%)
- Institutional capture (excess pay awards; cash for posts)
- Under-prepared subject teachers
- Sub-optimal allocation of subject teachers
- Illiteracy – written and spoken
- Grade 4 switch to English or Afrikaans
- Immigration regulations block foreign graduate and staff employment
- Constrained research system
- TVET Colleges as parking lots for youth
- TVET staff underqualified
- High cost of broadband
- VAT on books
- Low expenditure on school buildings and infrastructure
- Limited policy learning
- Impact of COVID-19 pandemic

3.5.3 OPPORTUNITIES

- Seize the pandemic moment to develop new solutions
- Build the capable state based on meritocratic appointments
- Professionalize teaching
- Meritocratic appointment to the public service
- Language literacy for all
- Introduction of coding into schooling
- Application of social media
- Strengthen management information systems
- Futures thinking and Anticipation
- Arm's length monitoring and evaluation
- Implementation of free nationwide wi-fi

3.5.4 THREATS

- Weak or unwilling state intervention
- Violence
- Social exclusion
- Economic exclusion
- Unsustainable public wage bill
- Nativism
- Obstruction by interest groups

4.0 RECOMMENDATIONS

Fundamentally, SME capability can only be built in the context of a capable state. The two attributes march together. That being noted, two major recommendations are tendered.

4.1 ADDRESS THE PROBLEM OF THE MEDIUM OF INSTRUCTION.

Learners fail at mathematics (and science) since they struggle with the medium of instruction, and many of their teachers hardly fare better.

Whence the solution? Not apparently from the research community, and not from the teacher unions. Neither has offered a solution. It falls to the Department of Basic Education (DBE), working with the Department of Arts and Culture, and Communications, to recognize this reality. A radical change to language teaching is recommended.

4.1.1 English (or Afrikaans!) should be offered as a foreign language of communication anchored in social, scientific and cultural realities. Tuition will require re-training of teachers and the development of new instructional materials. This may be achieved face-to-face, through radio, TV and social media. Such an intervention would call for united action of all concerned, especially the unions, and needs to commence at grade 4 at the latest.

4.1.2 Disseminate free wi-fi to all schools, colleges, universities and municipal offices

4.2 RE-IMAGINE AND CONSTRUCT STEM AS AN ESSENTIAL RESOURCE

Reimagine 'schooling,' technical and vocational, and higher education, in the light of expected changes in social organization, the nature of work, and the 'with COVID-19' scenario. A review of mathematics offerings is needed, with careful appraisal of calls for early streaming. Teachers and instructors are essential to this effort.

Accordingly

4.2.1 Work with all parties to build a capable education workforce. This implies a new social compact between government, organized labour and civil society. Adversarial relationships do not benefit the community at large.

4.2.2 All teacher educators should be professionally qualified for competence, and demonstrate recent relevant experience in the setting for which they teach. So, for example, a mathematics teacher educator giving pre-service instruction to secondary level teachers must have recent experience teaching mathematics at that very level.

4.2.3 Teachers should be deployed according to their pedagogic content knowledge. Teachers who teach a senior level mathematics or science class must have attained a pass in the subject at first year university level.

4.2.4 Experiment with new learning models for STEM. This may include problem and project-based learning, group learning, and online methods.

4.2.5 Coding should be introduced as early as possible. This is a more credible investment than the attempt to deploy robotic technologies.

4.2.6 Review the Dinaledi Schools project as the means for building and sharing excellence in SME, and as knowledge transfer agents for SME in-service education and training. In particular, determine the appropriate level of resources needed for success, and ensure that commitment to this is provided from Treasury, and organized labour.

4.2.7 Raise the goal posts – consider increasing the pass level to 50% in all NSC subjects.

4.2.8 Build public-private partnerships to support SME, at all levels, and in all communities

4.2.9 In order to ensure system learning, require formative and impact evaluation as a component of all large-scale education projects

REFERENCES

- Blum J, Krishnan N, and Legovini A 2010. Doing the math on a math & science program: South Africa's Dinaledi. Washington, World Bank.
- Cosser M, Kraak A and Winnaar L 2011. Further Education and Training (FET) colleges at a Glance in 2010. FET Colleges Audit May - July 2010. Pretoria, HSRC Department of Education 2014. Investigation into the Implementation of Maths, Science and Technology. Pretoria, Department of Basic Education
- Department of Social Development (2015). **National Integrated Early Childhood Development Policy**. Pretoria: DSD.
- DBE and DHET 2011. Integrated Strategic Planning Framework for Teacher Education and Development in South Africa 2011–2025 Technical Report. Pretoria, Department of Basic Education and Department of Higher Education and Training
- DHET 2019. Statistics on Post-School Education and Training in South Africa 2017. Pretoria, Department of Higher Education and Training of Cape Town.

- Mlachila M and T Moeletsi, 2019 Struggling to Make the Grade: A Review of the Causes and Consequences of the Weak Outcomes of South Africa's Education System. IMF Working Paper WP/19/47. Washington DC, International Monetary Fund

- Kahn M 2018. Co-authorship as a proxy for collaboration: a cautionary tale. Science and Public Policy 45 (1): 117–123. https://doi.org/10.1093/scipol/scx052

Mouton J 2015. The State of SA journals project. Presentation to the National Editors Forum meeting, Academy of Sciences of South Africa, 9 September 2015 OECD 2018.
https://www.oecd-ilibrary.org/education/teachers-salaries/indicator/english_f689fb91-en

- Simkins C 2015. Technical report. Teacher supply and demand in South Africa: 2013 to 2025. Johannesburg, Centre for Development and Enterprise

- Spaull N 2013. Poverty and privilege: Primary school inequality in South Africa. Int J Ed Dev 33 (5): 436-447

- Spaull N and Kotze J 2015. Starting behind and staying behind in South Africa. The case of insurmountable learning deficits in mathematics. Int J Ed Dev 41 Special Issue S1: 13-24.

World Economic Forum 2018. Global Competitiveness Report 2018. Geneva, World Economic Forum.

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