Science communication: The link to enable enquiry-based learning in under-resourced schools

Improving skills in STEM disciplines has been identified as essential in meeting South Africa’s economic growth targets. Despite this, learner uptake and completion rates within these subjects is currently well below international standards. We therefore examined key stages within the science education system to identify factors contributing to the low throughput in science education. We reviewed how national science policy changes have impacted the curriculum and teaching practices across different education establishments and socio-economic groups. We highlight that 80% of public schools have a lack of resources for practical learning, making it difficult for teachers to implement enquiry-based teaching methods. We explored strategies for effective engagement with science from the science communication literature and present recommendations to improve learner engagement with science in under-resourced school settings. Whilst education reform is needed at a national scale, we make a case for using science communication practices in science classes as a more immediate solution to generate greater interest and understanding, and encourage learners to pursue careers in science.

Significance:

- We examined key challenges in the science education and training pipeline in South Africa and recommend the use of science communication practices to design resources to enhance science teaching and learning in under-resourced schools.
- Exploring ways of integrating informal learning tools into schools could be a simple approach to improve science teaching and learning in developing countries such as South Africa where infrastructural deficit poses a longer-term barrier to learning.

Introduction

The shortage of qualified human resources in the science, technology, engineering, and mathematics (STEM) disciplines has been a recurring challenge in South Africa, and is regarded as a key obstacle to the targeted 6% economic growth rate per annum. In 2018, the South African government published a list of Occupations in High Demand (OIHD) in the Government Gazette. The gazette defines OIHD as occupations that have shown ‘relatively strong employment growth, and/or are experiencing shortages in the labour market or which are expected to be in demand in the future’. The purpose of the OIHD gazette is to provide insightful information about the skill needs of the nation, thereby influencing informed prioritisation in resource allocation, particularly in education and training. In 2018, approximately 54% of the OIHD listed occupations belonged to the STEM disciplines.

Erasmus and Breier indicated that skills shortages in STEM could be traced to the inefficiencies in the current education and training pipeline which was characterised by low maths and science output. Realising the importance of STEM skills in economic development, we attempted to identify key factors causing low throughput within the science education and training pipeline in South Africa, and to recommend strategies for addressing these. Along the way, we address such important questions as:

1. How have the national policies on science changed since the first democratic government of South Africa was elected in 1994?
2. How have the science policies influenced curriculum design and teaching practice over the years?
3. What is the current status of STEM education in South Africa?
4. What resources are currently available for science education, and are these effective?
5. Can science communication approaches help improve STEM teaching and learning in schools, as well as improve the appeal of STEM careers among learners?

Brief history of South African education

When the first democratic government of South Africa was elected in 1994, some of its immediate priorities were to redress the complex socio-economic challenges in the country such as poverty, inequality, and high levels of unemployment. Education was viewed as a key transformative tool to achieve an egalitarian society, and as a result, a raft of reforms were implemented within the education sector. The initial changes were intended to unify the 19 racially, ethnically, and geographically separated departments of education which existed pre-1994, thus paving the way to the formation of a single national core syllabus (curriculum changes will be further discussed in detail).

### The South African education and training pipeline

At the national level, education is governed by two ministries: the Department of Basic Education (DBE) and the Department of Higher Education and Training (DHET). The DBE is responsible for setting national policy for all school learning which is then implemented in schools through the nine provincial departments of education. South Africa uses the quintile ranking system to classify public schools based on the socio-economic status...
of the communities in which they are located. There are five quintiles: Quintile 1 (Q1) describes schools located in impoverished communities and serves the poorest 20% of learners while Quintile 5 (Q5) describes schools located in wealthy communities and serves the 20% least poor learners. This system is mostly used to aid equitable resource allocation among public schools. The South African Schools Act (Act 84 of 1996) makes it compulsory for children between 7 and 15 years of age to attend school and complete Grade 9. Based on a learner’s career choice and performance in Grade 9, they can specialise at Grade 10 in humanities, commerce, or science. At Grade 12, learners sit for the national examination which is commonly referred to as ‘matric’ in South Africa. With the National Senior Certificate (NSC/matric certificate), learners can access tertiary education. The DHET is responsible for setting policy which governs tertiary learning at all Technical and Vocational Education and Training (TVET) colleges, private colleges, and universities in South Africa.

### National science policy and its influence on science curriculum

Figure 1 provides a timeline of changes in the STEM curriculum alongside the changes in national science policies and strategies since 1994. The South African school curriculum has been revised three times in 15 years. The changes to national science policies and strategies were in response to factors such as STEM skill needs of the economy (e.g., the need to address the ‘ageing scientific population’ in the National Research & Development Strategy) and global competitiveness (e.g., identifying and supporting priority Science Technology and Innovation (STI) programmes linked to the Fourth Industrial Revolution in the White Paper on STI). Over this period, changes to the school curriculum primarily reflect policy flaws but there is little evidence to suggest improvement of individual subject content – what Le Grange describes as ‘change without difference’.

![Figure 1: The response of the national science curriculum to changes in national science policy.](https://example.com/figure1.png)
The first national curriculum, Curriculum 2005, was introduced in 1997 and framed after the Outcomes-Based Education (OBE) model. The Revised National Curriculum Statement (RNCS), also founded on the OBE model, replaced Curriculum 2005 in 2003 only to be revised again after 9 years. Both curricula were revised upon recommendation from review committees which highlighted a wide range of issues including vagueness on subject matter and assessment guidelines as well as complicated language leading to implementation challenges for teachers. In terms of subject matter design, both curricula broke away from the traditional subject demarcations and prescribed a blurred, integrated learning approach. For instance, science subjects for the Further Education and Training band (Grades 10–12) were blurred across a ‘learning field’ consisting of physical, mathematical, computer, life, and agricultural sciences. In critique of OBE, Allais (as cited by Le Grange) argues that disciplinary knowledge is vital as it facilitates the sequencing of learning in the classroom. The consistent underperformance of South African learners in both national and international assessments in a way summed up the challenges with OBE in South Africa. The Curriculum and Assessment Policy Statements (CAPS) was introduced in 2012 to replace the RNCS. This marked a shift away from the OBE model and towards a ‘high knowledge curriculum that emphasises subject content and assessment as the centre-piece of curriculum implementation’. In highlighting some of the key changes observed in the CAPS curriculum, Ramnarain notes that: "Inquiry-based science education is posited as the means by which the challenges of the previous curriculum related to inaccessibility, irrelevance and incompatibility with the nature of science can be negotiated."

A detailed discussion on enquiry-based learning is presented in sections below.

Figure 2 illustrates the complicated history of curriculum experiences that learners were exposed to as a result of the drastic curriculum changes. For instance, learners who were in Grade 1 in 2003 were exposed to Curriculum 2005 (2003), RNCS (2004–2011) and CAPS (2012–2014) during their schooling years. These changes would obviously affect both learner experience and performance as well as teacher teaching practice.

### The current state of science education and training in South Africa

The Statistics on Post-School Education and Training in South Africa reports provide official annual records of enrolments and graduations from South African higher education institutions (HEIs). Over the period 2015–2019, the South African STEM education and training pipeline seemingly reflected an improving system. The number of students who enrolled for STEM programmes at public HEIs increased by 9.6% (Table 1). Similarly, the number of STEM graduates emerging during the same period increased by an overall 11.3%. However, it is not possible to resolve the proportion of international students contributing to this figure for STEM enrolments. International students contribute substantially to total HEI enrolments (Table 1), and may not be evenly distributed across the fields of study. Furthermore, the data do not say much about the throughput rate, that is, how long students take from first-time enrolment until completion of the programme.

### Table 1: Number of STEM student enrolments at South African higher education institutions

<table>
<thead>
<tr>
<th>Year</th>
<th>Total STEM enrolments</th>
<th>Total national enrolments</th>
<th>Total international student enrolments</th>
<th>Total graduates</th>
<th>STEM graduates</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>294 935</td>
<td>985 212</td>
<td>72 959 (7.4%)</td>
<td>191 524</td>
<td>58 090</td>
</tr>
<tr>
<td>2016</td>
<td>295 383</td>
<td>975 837</td>
<td>69 381 (7.1%)</td>
<td>203 076</td>
<td>59 125</td>
</tr>
<tr>
<td>2017</td>
<td>310 115</td>
<td>1 036 984</td>
<td>67 434 (6.5%)</td>
<td>210 931</td>
<td>61 581</td>
</tr>
<tr>
<td>2018</td>
<td>320 671</td>
<td>1 085 568</td>
<td>64 018 (5.9%)</td>
<td>227 188</td>
<td>65 211</td>
</tr>
<tr>
<td>2019</td>
<td>323 105</td>
<td>1 074 912</td>
<td>58 852 (5.5%)</td>
<td>221 942</td>
<td>64 636</td>
</tr>
</tbody>
</table>


Reviewing first-time enrolment (students registering for the first time at any HEI) figures may therefore provide a clearer picture of the transition from basic to tertiary education and the uptake rates of STEM programmes at HEIs. To investigate this further, we estimated the possible number of learners eligible for STEM programmes at HEIs. The general minimum requirements for admission into HEIs is that learners should score at least 40% in four NSC subjects for eligibility into a diploma programme, or at least 50% in four NSC subjects for eligibility into a bachelor programme. According to data from the Central Applications Office, mathematics is considered a gatekeeper subject for admission into most STEM programmes. Therefore, in Table 2 we present the

### Figure 2: The curriculum experiences of different cohorts of learners from 1997: (O) Old curriculum inherited in 1994; (S) Curriculum 2005; (R) RNCS; (C) CAPS.
number of learners who scored at least 40% in the NSC mathematics exams during the 2015–2019 period\textsuperscript{18-22} (estimations have been used because there are no disaggregated statistics of first-time undergraduate enrolments in STEM programmes).

Table 2: Learner performance in National Senior Certificate mathematics, life science, and physical science exams

<table>
<thead>
<tr>
<th>Year</th>
<th>Mathematics</th>
<th>Life science</th>
<th>Physical science</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wrote</td>
<td>Pass by at least 40%</td>
<td>Wrote</td>
</tr>
<tr>
<td>2015</td>
<td>263 903</td>
<td>84 297</td>
<td>348 076</td>
</tr>
<tr>
<td>2016</td>
<td>265 810</td>
<td>89 084</td>
<td>347 662</td>
</tr>
<tr>
<td>2017</td>
<td>245 103</td>
<td>86 096</td>
<td>318 474</td>
</tr>
<tr>
<td>2018</td>
<td>233 858</td>
<td>86 874</td>
<td>310 041</td>
</tr>
<tr>
<td>2019</td>
<td>222 034</td>
<td>77 751</td>
<td>301 037</td>
</tr>
</tbody>
</table>


By using NSC mathematics exam results as estimates for STEM programme eligibility, we can assess how well the South African education system has prepared students for tertiary study in these subjects. While STEM enrolments and STEM graduation rates have reportedly increased by 9.6% and 11.3%, respectively, Figure 3 shows that learner eligibility to STEM programmes and first-time enrolment numbers have been fluctuating and relatively flat over this same period (2015–2019). A possible explanation for this mismatch could be that a significant number of students were failing to complete programmes within stipulated timeframes and therefore remained in the system for longer. Poor graduation rates among South African students are well documented.\textsuperscript{23,24} For example, as of 2015, only 31.9% of contact students doing 3-year degree programmes at public HEIs successfully graduated within the stipulated timeframe.\textsuperscript{25}

In addition to this, learner performance has been consistently below international standards. South Africa has been participating in the Trends in International Mathematics and Science Study (TIMSS) since 1995. TIMSS compares the performance of learners from different countries in mathematics and science at Grades 4 and 8. As of 2011, South African assessments were performed on Grade 9 learners since ‘the TIMSS eighth grade assessment was too difficult for eighth grade students’\textsuperscript{26}. Table 3 shows the rankings of South Africa in the TIMSS assessments, focusing on Grade 8/9 which is the last grade of compulsory schooling.

The improvement in performance in the past six cycles has been insignificant for both science (44-point improvement) and mathematics (35-point improvement) as the average learner achievement is still below TIMMS’ minimum competency levels (Figure 4). However, the TIMMS 2015 Grade 9 National Report prepared by the South African Human Sciences Research Council (HSRC) declares that:

‘from 2003 to 2015 the country [South Africa] has shown the biggest positive improvement of all participating countries in both mathematics (by 90 points) and science (by 87 points), which is equivalent to an improvement in achievement by two grade levels.’ 17

Table 3: The rankings of South African Grade 8/9 learners in the TIMMS assessments for mathematics and science

<table>
<thead>
<tr>
<th>Year</th>
<th>Mathematics</th>
<th>Science</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ranking</td>
<td>Total participants</td>
</tr>
<tr>
<td></td>
<td>1995</td>
<td>41</td>
</tr>
<tr>
<td>1999</td>
<td>38</td>
<td>38</td>
</tr>
<tr>
<td>2003</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>2007*</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>2011a</td>
<td>43</td>
<td>45</td>
</tr>
<tr>
<td>2015</td>
<td>38</td>
<td>39</td>
</tr>
<tr>
<td>2019</td>
<td>45</td>
<td>46</td>
</tr>
</tbody>
</table>

\*Did not participate
\*From 2011, TIMMS assessments for South Africa were performed on Grade 9 learners.
This report does not account for the dip in performance between the 1999 to 2003 assessment cycles which coincides with the period when Curriculum 2005 was introduced in 1997. According to scholars, this was ‘poorly planned and hastily introduced in schools with teachers being insufficiently prepared, with inadequate resources’, leading to discussions which eventually led to its replacement by the RNCS in 2004. Whilst the TIMMS score recovered, it has plateaued and remains well below the lowest international benchmark. It is, however, acknowledged that there are other factors that contribute to this low performance in STEM subjects.

Barriers to effective teaching and learning in South Africa

In this section we discuss four barriers to learning and how they impact South Africa. These include socio-economic, infrastructural, pedagogical, and language challenges.

Socio-economic challenges

The socio-economic background of learners is a major determinant of school access as it is generally easier for learners to attend schools closer to home. Those from poor communities usually have access to Q1–Q3 schools while learners from wealthy communities can access Q4 and Q5 schools. As a result, learners tend to get education of variable quality depending on socio-economic background. A majority of underperforming secondary schools – those failing to achieve a pass rate of at least 60% in the NCS examination – are located in townships, informal settlements or rural areas. Indiscipline, lack of study motivation and parental support, poor school administration, and lack of qualified or experienced teachers generally characterise the learning environment at underperforming schools. Research strongly correlates background characteristics and learner performance; for example, van der Berg et al. state that ‘from an early age there are already stark distinctions between the prospects of children from poorer communities and those from more affluent communities’.

Infrastructural challenges

A significant number of schools in South Africa still lack adequate infrastructure required to create a conducive learning environment. As of 2020, of the 23 267 schools inspected, 24% used pit latrines, 25% had no reliable water source, and 16% were without or with unreliable electricity supply. Laboritories are central to science education, particularly in facilitating enquiry-based learning. However, it seems laboratories and library facilities are a very rare luxury for most public schools; 80% had no laboratory facilities, and 74% had no libraries. The famous ‘mud schools’ lawsuit which pitted Centre for Child Law and Others vs Government of the Eastern Cape Province and Others just exposed the extreme state of infrastructure deficit at most schools, especially those in rural areas.

Pedagogical challenges

The quality of an education system is generally reliant on availability of competent teachers. According to research, the key issues affecting expected outputs in the South African schooling system include teacher absenteeism, insufficient teacher content knowledge, and pedagogical skill. Several studies have shown that a significant number of teachers do not have adequate knowledge for the classes they teach. For example, results from the SACMEQ III (Southern and Eastern Africa Consortium for Monitoring Educational Quality) study showed that about 75% of Grade 6 mathematics teachers did not possess adequate knowledge to teach the subject at that level. Some studies have also indicated a slight correlation between teacher content knowledge and student achievement. In South Africa, there are indications that there is an uneven teacher distribution with Q5 schools having a high concentration of teachers with better subject matter knowledge when compared to Q1 schools.

Language challenges

Language is a delicate subject as it has political, socio-cultural, and historical significance. In South Africa, there are 11 official languages. The South African Language in Education policy does not clarify the official language of learning and teaching (LoL T) as it merely states that ‘the language(s) of learning and teaching in a public school must be (an) official language(s)’. Schools are left to determine their own language policies. Except for language subjects, all NSC examination papers are set in English, which is generally the LoLT of choice in most schools. With only 8.1% of the South African population identifying English as a mother tongue, researchers indicate that it is challenging and can take as long as 7 years for learners to master contextual proficiency in a second language. It is common, in instances where both teachers and learners share a common language, for the teacher to codeswitch from the LoLT to the common language for clarity. However, reports show that learners who are assessed in a language other than their mother tongue are significantly disadvantaged compared to those who are assessed in the same language they speak at home.

STEM teaching practices in South Africa

Teaching practices can have an impact on learner performance in STEM subjects as well as influence a learner’s general perception about science careers. In this section, we examine the science teaching orientations in South Africa as reported in the literature. ‘Teacher orientation’ is a term that has been debated among curriculum studies scholars. Friedrichsen et al. warned that the term has not been properly defined and as a result, has been used variably in different contexts. In this article, we discuss teacher orientation in reference to the teaching practices used in science classrooms following the classifications by Finson et al. and Ramnarain and Schuster. These authors stipulated two distinct categories: (1) didactic/direct instruction (ready-made science) and (2) enquiry-based instruction (science-in-the-making).

Didactic orientation

Finson et al. use the terms ‘didactic’ and ‘expository’ interchangeably to describe what Ramnarain and Schuster refer to as ready-made science or direct instruction. Didactic orientation is considered a traditional teaching practice characterised by directly telling, showing, or explaining the
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Science communication literature presents opportunities for ‘simple fixes’ which can be incorporated into formal STEM teaching in places where there are inadequate resources. The strategies can enhance the learning experience of learners in the 80% of South African public schools which lack adequate facilities for STEM learning. One simple fix is the development of inexpensive science models that can be easily used in non-laboratory settings. Over the years, a variety of science models of varying sophistication have been developed to aid enquiry-based learning in schools, and the design of tools to enable students to learn by exploring ideas while the role of the teacher is to guide/facilitate towards the understanding of underlying scientific principles of the topic under study. In their study, Ramnarain and Schuster found that only 29% of participating teachers in township schools could employ enquiry-based instruction compared to 82% for suburban teachers. Ramnarain and Schuster have researched extensively about enquiry-based learning in South Africa and concluded that its implementation was influenced by two major factors: (1) intrinsic teacher factors such as professional knowledge competency and teacher confidence in using enquiry-based methods and (2) extrinsic school factors such as availability of resources, class sizes, availability of time and differences in culture with which teachers operate.

Enquiry-based practices are the recommended science teaching orientation. Also referred to as the constructivist approach by Finson et al., the enquiry-based orientation emphasises student autonomy. Learners learn by exploring ideas while the role of the teacher is to guide/facilitate towards the understanding of underlying scientific principles of the topic under study. In their study, Ramnarain and Schuster found that only 29% of participating teachers in township schools could employ enquiry-based instruction compared to 82% for suburban teachers. Ramnarain and Schuster have researched extensively about enquiry-based learning in South Africa and concluded that its implementation was influenced by two major factors: (1) intrinsic teacher factors such as professional knowledge competency and teacher confidence in using enquiry-based methods and (2) extrinsic school factors such as availability of resources, class sizes, availability of time and differences in culture with which teachers operate.

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sparking scientific curiosity.8 Other strategies applicable for classroom settings include role-playing, storytelling, games, and do-it-yourself (DIY) sessions.19,20 The advantage with science communication is its flexibility which allows strategies to be customised to suit specific contexts (e.g. social contexts and education level of target audience, making use of available resources, relatability with target audience). However, using these strategies in a science classroom could be a challenge to most teachers who might lack the necessary skills. For example, a study by Ashlea et al.21 on the use of everyday resources in hands-on classroom activities showed that teachers would require training for effective use of such resources in their teaching.

Include science communication in teacher training programmes

Integrating science communication strategies into school science can be easier when introduced through teacher professional training programmes. Here we cite two examples through which this can be implemented. The first approach may involve formation of school–university partnerships where teachers are paired with STEM postgraduate students to co-teach science classes (the collaborative apprenticeship model22,23). Similar programmes in the USA24,25 and Taiwan26 have proven effective both in helping improve learner cognition in science as well as improving teacher science content knowledge and confidence in using enquiry-based pedagogy.27,28 In addition, the presence of the graduate scientist in the classroom benefits the science teacher who can observe and learn new strategies of communicating science to their professional training programme. Already, the 2019 White Paper on Science, Technology & Innovation has provisions to encourage such partnerships through providing incentives to universities which adopt schools for STEM skills training.47 The second approach can be including science communication coursework in teacher tertiary training programmes. A similar trend is being observed in most STEM degree programmes where science communication (sometimes packaged as ‘science in/and/or for society’) is becoming a compulsory subject in STEM degree programmes with the idea that each graduate should be able to communicate science as much as they can do science. Essentially, it is expected that teachers would be more comfortable using science communication strategies in their classrooms if they had been part of their professional training programmes.

Expand public engagement with science initiatives to improve social support

Positive attitudes towards science from parents/guardians, and their active involvement in learners’ homework exercises, is a key factor in learner engagement with science.48 However, Zuze et al.49 report that a lot of learners attending poor public schools do not get help from parents in science for their own professional development. Already, the 2019 White Paper on Science, Technology & Innovation has provisions to encourage such partnerships through providing incentives to universities which adopt schools for STEM skills training.47 The second approach can be including science communication coursework in teacher tertiary training programmes. A similar trend is being observed in most STEM degree programmes where science communication (sometimes packaged as ‘science in/and/or for society’) is becoming a compulsory subject in STEM degree programmes with the idea that each graduate should be able to communicate science as much as they can do science. Essentially, it is expected that teachers would be more comfortable using science communication strategies in their classrooms if they had been part of their professional training programmes.

Conclusions

In this article, we traced factors responsible for the low throughput observed within the South African science education and training pipeline. We have identified that the challenges with STEM education in South Africa are multi-layered: flawed education policies which were difficult for teachers to implement in the classroom; historical socio-economic challenges mean the majority of learners only receive low-quality education; and the lack of resources in 80% of public schools makes it difficult for teachers to implement enquiry-based teaching methods. Despite the complexity of the challenges, studies which have identified that South African learners enjoy and value science more than their international peers give cause for optimism. We recommend the adoption of science communication practices into science classes as an approach to help improve STEM education as well as improving the appeal of STEM careers among high-school learners. We also recommend the increase in public engagement of science initiatives through either media or outreaches as a means to attract high-school learners into STEM careers.

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Competing interests

We have no competing interests to declare.

Authors’ contributions

B.N.: Conceptualisation; writing — the initial draft; writing — revisions. S.S.: Conceptualisation; student supervision; writing — review and editing; validation. C.C.: Conceptualisation; student supervision; writing — review and editing; validation; project leadership.

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