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

AUTHORS:
Blessing Nemadziva[1]
Steven Sexton[2]
Catherine Cole[1]

AFFILIATIONS:
[1]Department of Science Communication, University of Otago, Dunedin, New Zealand
[2]College of Education, University of Otago, Dunedin, New Zealand

CORRESPONDENCE TO:
Blessing Nemadziva

EMAIL:
blessing.nemadziva@postgrad.otago.ac.nz

DATES:
Received: 18 Nov. 2021
Revised: 15 July 2022
Accepted: 15 Aug. 2022
Published: 31 Jan. 2023

HOW TO CITE:
Nemadziva B, Sexton S, Cole C. Science communication: The link to enable enquiry-based learning in under-resourced schools. S Afr J Sci. 2023;119(1/2), Art. #12819. https://doi.org/10.17159/sajs.2023/12819

ARTICLE INCLUDES:
☒ Peer review
☐ Supplementary material

DATA AVAILABILITY:
☐ Open data set
☐ All data included
☐ On request from author(s)
☐ Not available
☒ Not applicable

EDITORS:
Chrissie Boughey
Nkosinathi Madondo

KEYWORDS:
science communication, science education, enquiry-based learning, science models, STEM skills

FUNDING:
University of Otago

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[1], and is regarded as a key obstacle to the targeted 6% economic growth rate per annum[2]. 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'[3]. 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.[3] In 2018, approximately 54% of the OIHD listed occupations belonged to the STEM disciplines.

Erasmus and Breier[2] 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[4] (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.[5] 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[6] – what Le Grange[7] describes as 'change without difference'.

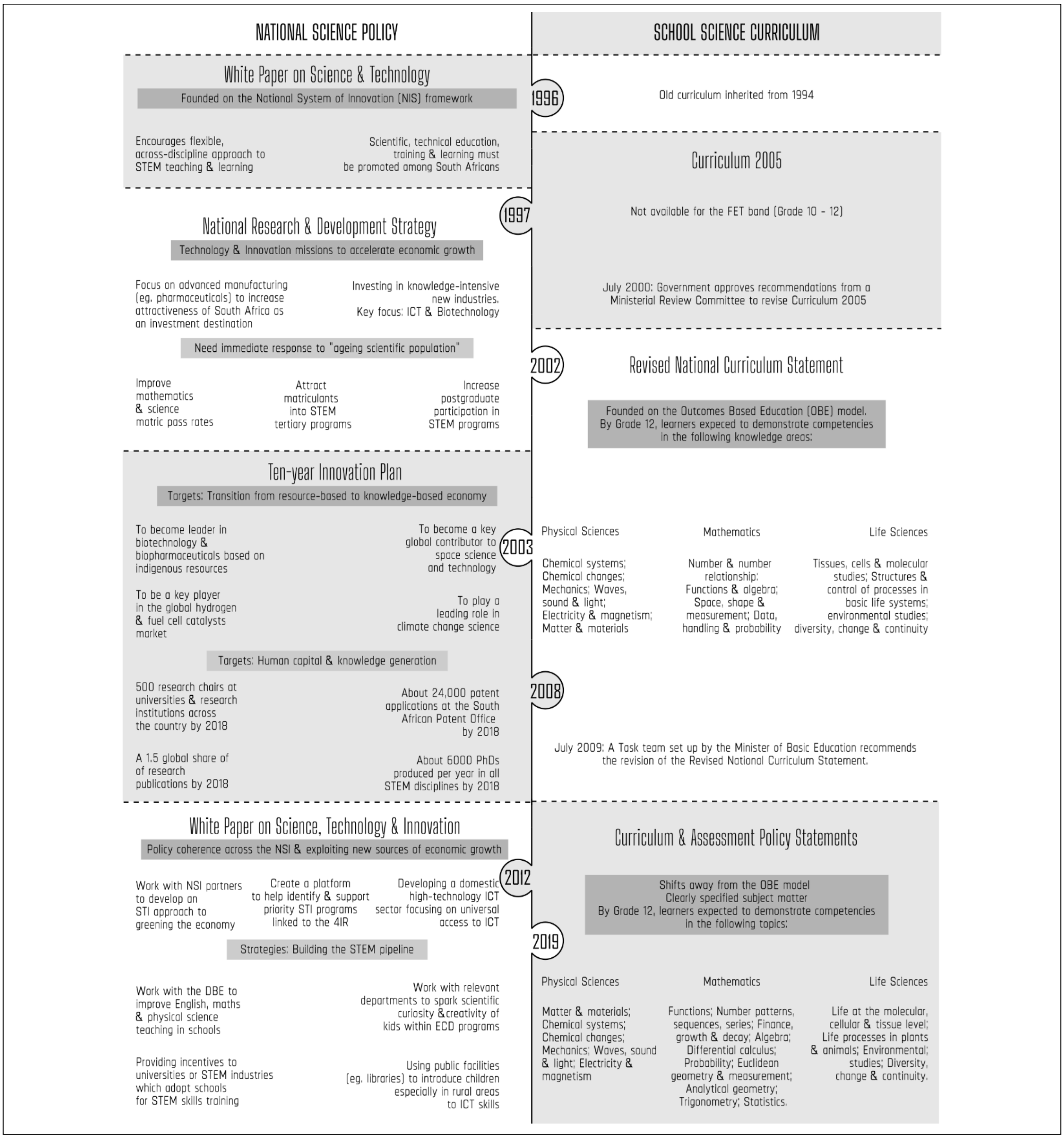

Figure 1: The response of the national science curriculum to changes in national science policy.

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.[4,8-11] 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[6] (as cited by Le Grange[7]) 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.[12] 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'[13]. In highlighting some of the key changes observed in the CAPS curriculum, Ramnarain[14] 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.[15] 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[16] 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

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

Source: Statistics on Post-School Education and Training in South Africa: 2015–2019.[16]

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.[17] Therefore, in Table 2 we present the

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Gr 1	O	5	5	5	5	5	5	R	R	R	R	R	R	R	R
Gr 2	O	O	5*	5	5	5	5	5R*	R	R	R	R	R	R	R
Gr 3	O	O	O	5*	5	5	5	5R*	5R*	R	R	R	R	R	R
Gr 4	O	O	O	O	5*	5	5	5	5R*	5R*	R	R	R	R	R
Gr 5	O	O	O	O	O	5*	5	5	5R*	5R*	5R*	R	R	R	R
Gr 6	O	O	O	O	O	O	5*	5	5R*	5R*	5R*	5R*	R	R	R
Gr 7	O	O	O	O5*	O5	O5	O5	5*	5	5R*	5R*	5R*	5R*	R	R
Gr 8	O	O	O	O	O5*	O5	O5	O5	5*	5	5R*	5R*	5R*	5R*	R
Gr 9	O	O	O	O	O	O5*	O5	O5	O5	5*	5R*	5R*	5R*	5R*	5R*
Gr 10	O	O	O	O	O	O	O5*O	O5O	O5O	O5R*	5*R	5R*	5R*	5R*	5R*
Gr 11	O	O	O	O	O	O	O	O5*O	O5O	O5O	O5R*	5*R	5R*	5R*	5R*
Gr 12	O	O	O	O	O	O	O	O	O5*O	O5O	O5O	O5R*	5*R	5R*	5R*

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Gr 1	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Gr 2	RC*	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Gr 3	RC*	RC*	C	C	C	C	C	C	C	C	C	C	C	C	C
Gr 4	R	RC*	RC*	C	C	C	C	C	C	C	C	C	C	C	C
Gr 5	R	RC*	RC*	RC*	C	C	C	C	C	C	C	C	C	C	C
Gr 6	R	RC*	RC*	RC*	RC*	C	C	C	C	C	C	C	C	C	C
Gr 7	R	R	RC*	RC*	RC*	RC*	C	C	C	C	C	C	C	C	C
Gr 8	R	R	RC*	RC*	RC*	RC*	RC*	C	C	C	C	C	C	C	C
Gr 9	R	R	RC*	RC*	RC*	RC*	RC*	RC*	C	C	C	C	C	C	C
Gr 10	5R*C	RC	RC	RC*	RC*	RC*	RC*	RC*	RC*	C	C	C	C	C	C
Gr 11	5R*	5R*C*	RC	RC	RC*	RC*	RC*	RC*	RC*	RC*	C	C	C	C	C
Gr 12	5R*	5R*	5R*C*	RC	RC	RC*	RC*	RC*	RC*	RC*	RC*	C	C	C	C

*Note: The letters and asterisks in each cell indicate the history of each cohort at that stage in its schooling, assuming learners who do not repeat any grades. To take an example of a cohort with a complex history, the Grade 12 group in 2014 has '5R*C*'. This means that these learners experienced in their schooling lives a bit of Curriculum 2005 (5), some teaching under the Revised National Curriculum Statement (R) and some under the new Curriculum and Assessment Policy Statement (C). The asterisks indicate that this group experienced the RNCS when it had just been introduced (one can see in the table this occurred in Grade 2 in 2004) and that it also experienced the introduction of the CAPS (in Grade 10 in 2012). The colouring in this table has been inserted to facilitate the tracking of single cohorts of learners. Grade R has been left out of this table as this grade has not been made compulsory yet.*

Source: Gustafsson[15]

Figure 2: The curriculum experiences of different cohorts of learners from 1997. (O) Old curriculum inherited in 1994; (5) Curriculum 2005; (R) RNCS; (C) CAPS.

number of learners who scored at least 40% in the NSC mathematics exams during the 2015–2019 period[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

Year	Mathematics		Life science		Physical science	
	Wrote	Pass by at least 40%	Wrote	Pass by at least 40%	Wrote	Pass by at least 40%
2015	263 903	84 297	348 076	160 204	193 189	69 699
2016	265 810	89 084	347 662	157 177	192 618	76 044
2017	245 103	86 098	318 474	166 071	179 561	75 736
2018	233 858	86 874	310 041	160 208	172 319	84 002
2019	222 034	77 751	301 037	147 436	164 478	85 034

Source: National Senior Certificate Examination Report: 2015–2019.[18-22]

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.[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.[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'[26]. Table 3 shows the rankings of South Africa in the TIMMS 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]

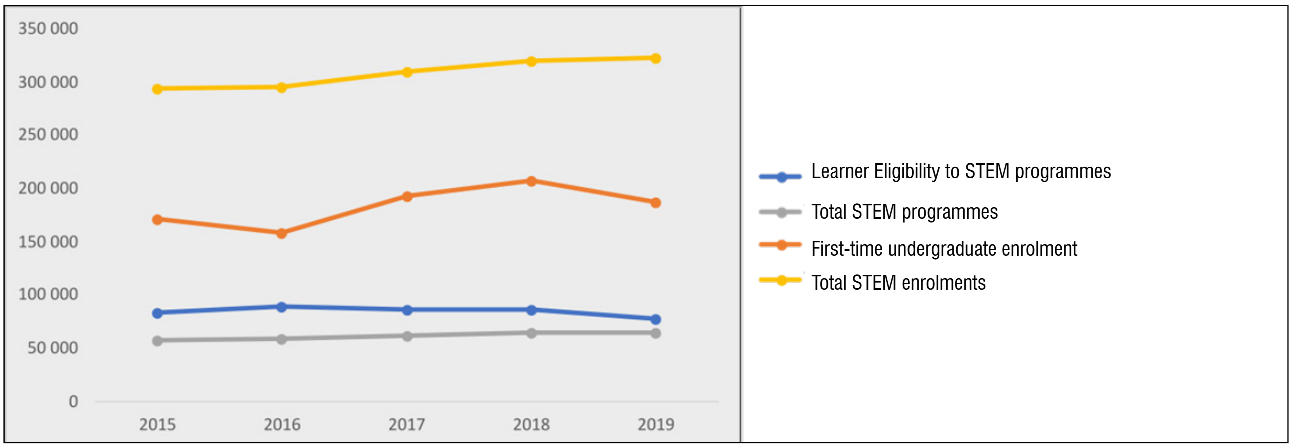

Figure 3: Trends of learner eligibility for STEM programmes, first-time undergraduate enrolment, and overall STEM enrolments for 2015–2019.

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

	Mathematics				Science			
Year	Ranking	Total participants	International mean	South African average score	Ranking	Total participants	International mean	South African average score
1995	41	41	513	354	41	41	516	326
1999	38	38	487	275	38	38	488	243
2003	45	45	466	264	45	45	473	244
2007[a]	–	–	–	–	–	–	–	–
2011[b]	43	45	–	352	44	45	–	332
2015	38	39	481	372	39	39	486	358
2019	45	46	490	389	46	46	490	370

[a]Did not participate

[b]From 2011, TIMMS assessments for South Africa were performed on Grade 9 learners.

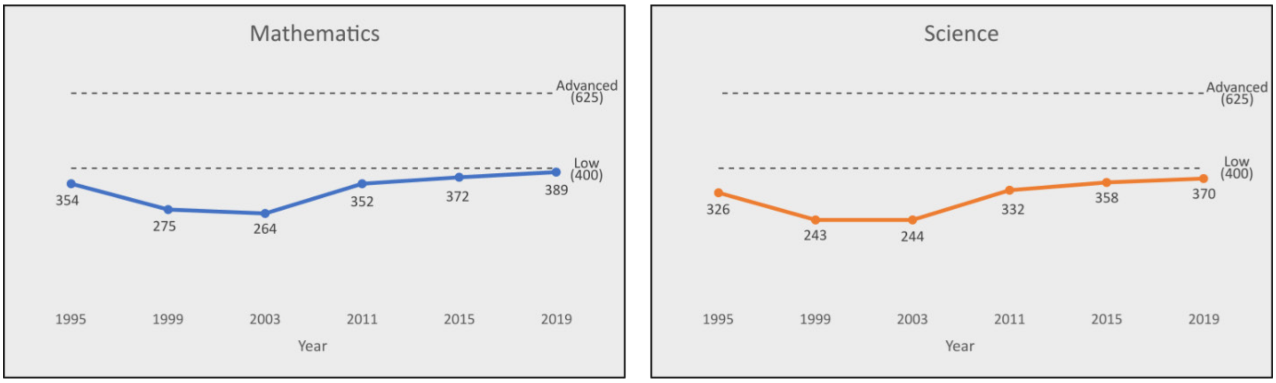

Figure 4: Trends in mathematics and science achievement for South African Grade 8/9 learners from 1995 to 2019. Data sourced from TIMMS reports.[27]

This report does not account for the dip in performance between the 1999 to 2003 assessment cycles[27] (Figure 4) 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'[9], 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.[28] 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.[29] 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.[28,30] Research strongly correlates background characteristics and learner performance; for example, van der Berg et al.[28] 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.[31] Laboratories are central to science education, particularly in facilitating enquiry-based learning.[32] 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.[33]

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.[34,35] 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 79% of Grade 6 mathematics teachers did not possess adequate knowledge to teach the subject at that level.[36] Some studies have also indicated a slight correlation between teacher content knowledge and student achievement.[37,38] 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.[36,39]

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 (LoLT) 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[40], researchers indicate that it is challenging and can take as long as 7 years for learners to master contextual proficiency in a second language[41]. 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.[42] 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.[17,43]

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.[44] 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.[45-47] Friedrichsen et al.[46] 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.[44] and Ramnarain and Schuster[48] 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.[44] use the terms 'didactic' and 'expository' interchangeably to describe what Ramnarain and Schuster[48] 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 science concepts.[47,48] It is teacher-centred and learning is predominately by memorisation of factual knowledge in preparation for examinations.[49]

A study by Ramnarain and Schuster[48] showed that didactic teaching practices were more prevalent in South African schools located in lower income areas (e.g. townships[48] or rural areas[50]) in comparison to suburban schools. According to their research, which was conducted with Grade 12 physical science teachers, 71% of their participating teachers in township schools employed direct instruction approaches compared to only 18% for suburban teachers.[48] Reasons cited for teaching orientation choices were mostly determined by class sizes and availability of resources. For their participating teachers, their class sizes were 45–50 and 26–30 for townships and suburbs, respectively (the officially recommended learner-to-teacher ratio in South Africa is 40:1 for primary schools, and 35:1 for secondary schools[51]). It is worth noting that 48% of the participating township schoolteachers who chose direct instruction still believed in student-centred teaching methods as encouraged by the CAPS curriculum. For example, a township teacher who was interviewed remarked that:

> *although I want to structure the activity for the students, I still want them to be actively involved in it. I do not want to stand in front and demonstrate it to them. This will be too teacher-centred, and the students will just be on the sidelines watching me.*[48]

Other studies focusing on overcrowded classes in rural South African schools have similarly shown how situational factors influence teachers to resort to didactic teaching practices despite willingness to adopt enquiry-based strategies.[50,52-54] There are reports however, which show that some teachers in under-resourced schools demonstrate teacher agency by using improvised materials to implement enquiry-based pedagogy. For example, one teacher used red cabbage juice as an improvised material to teach acid/base concepts.[54]

Enquiry-based orientation

Also referred to as the constructivist approach by Finson et al.[44], the enquiry-based orientation emphasises student autonomy[48]. 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.[47,48] In their study, Ramnarain and Schuster[48] found that only 29% of participating teachers in township schools could employ enquiry-based instruction compared to 82% for suburban teachers. Ramnarain[14,54] has 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.[14] Finson et al.[44] state that constructivist teaching approaches develop positive attitudes towards science in their participating learners. Emphasising enquiry-based practical learning in schools has proven effective in helping learners shift towards science careers[55,56], because by engaging in the experimental process – enquiry, planning, investigating, gathering data to relate evidence and explanations, and communicating findings – learners get to experience how scientists work. As such, it is now widely acknowledged that learner experiences from an enquiry-based learning pedagogy contribute to increased interest in science careers.[57,58]

Experience vs performance in the science classroom

A literature survey of South African education shows that most research has focused more on learner performance compared to learner experience. However, learner experience in the science classroom is a subject that requires equal attention as it also contributes towards learner performance. For instance, psychological studies have highlighted that physical experience improves learner performance and understanding of concepts.[59] Ideal learner experience is achieved through 'doing science' (i.e. enquiry-based).[60] However, in South Africa, this is not always achievable because of the lack of resources in a majority of schools. At the same time, an analysis of the TIMMS 2011 study by the HSRC showed that South African learners' enjoyment and value of science were higher than the international average.[61] This suggests that if resources to facilitate effective enquiry-based learning were sufficiently available, there could be significant improvement in the science education and training pipeline in South Africa. It is therefore vital to explore alternative strategies that can help improve the STEM learning experience in South African classrooms.

Integrating science communication practice into school learning

The academic field of science communication has grown rapidly in recent years, providing a better understanding of how to share knowledge effectively and engage diverse groups of society with science through different mediums (e.g. television, print media, Internet, exhibitions, and more).[62,63] A contemporary definition of science communication directs that its purpose is to produce in publics at least one of the following: awareness, enjoyment, interest, opinions, understanding of science (the vowel analogy).[64] This has clear relevance for STEM teaching and learning in schools, and the design of tools to enable students to experience science in engaging ways.[65]

Integrating science communication practice into school learning involves adopting tools and approaches that have proved effective in facilitating science learning in informal environments such as science museums, science centres, or planetariums. There is an increasing number of studies seeking to understand ways of integrating informal learning tools to formal science learning.[66-70] Studies have also shown that informal learning tools not only result in increased appeal for science[65,70], but also contribute to increased conceptual knowledge[71]. A common feature in most informal learning settings is interaction with phenomena, whether technological, natural, or designed exhibits. Museum exhibits are specifically designed to present challenges to visitors who will require further interaction to solve[72], and through this process of enquiry, knowledge appropriation occurs[73]. Allen[72] states that a typical enquiry cycle stimulated by an exhibit includes the following stages: (1) surprising phenomenon, which arouses visitor's initial curiosity; (2) exploration, where the visitor further interacts with the exhibit; (3) explanation, in which the label explains the science; (4) relevance, where the label relates the phenomenon to everyday experiences. This cycle bears similarities to enquiry-based learning in formal learning environments where the learner, like the visitor, has the freedom to explore, and the teacher, like the label, guides the learner to understand and appreciate the science.

Integrate science communication strategies into school science

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.[55,74-76] A good example are the BioBits educational kits which were designed by a group of synthetic biologists in the USA to help high-school learners conduct biological activities in classroom settings. Evaluations showed that the kits were effective in improving learner confidence in topics under study such as antibiotic resistance and CRISPR-Cas9 gene editing, as well as in increasing learner self-identification as scientists.[75] Another strategy is improvisation. Ramnarain and Mamutse[77] tested the efficiency of improvised materials as teaching tools in under-resourced South African schools in research that involved using red cabbage juice as an indicator to test the pH of various household products. Results showed that the improvised cabbage juice indicator was effective in helping learners understand acid/base concepts better, relating the science to daily experiences, and sparking scientific curiosity.[77] Other strategies applicable for classroom settings include role-playing, storytelling, games, and do-it-yourself (DIY) sessions.[78,79] 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 Asheela et al.[80] 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 model[81,82]). Similar programmes in the USA[82,83] and Taiwan[84] 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.[82-84] 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 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.[85] 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/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.[86] However, Zuze et al.[17] report that a lot of learners attending poor public schools do not get help from parents in science and mathematics homework due to issues with language and complexity of assignments. Obviously, what usually attracts much attention in such statistics is the staggering illiteracy rates in the wider South African population (12% as of 2019[87]). But this also points to the fact that public understanding of science campaigns have yet to make significant inroads in South Africa. There is therefore a need to increase support for public engagement initiatives using different media to make science accessible and attractive as a career route for high-school learners. With increased accessibility to information through TV, mobile phones and the Internet, one promising public engagement initiative is increasing support for story-based science video programmes. In reflection of the 2018 conference of the Public Communication of Science and Technology Network, Joubert et al.[88] note the renewed interest among science communicators to use storytelling in science engagement initiatives as 'it [stories] is about making people care…creating emotional connections between scientists and publics'. Such public engagement initiatives will not only help improve the appeal of science careers to learners, but also help improve social support from parents/guardians.

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.

Acknowledgements

We thank Ms Alison Chisholm (Education Library, University of the Witwatersrand, South Africa) for assisting us to access copies of the Curriculum 2005 and the Revised National Curriculum Statements. B.N. is supported by the University of Otago Doctoral Scholarship.

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.

References

1. Reddy V, Bhorat H, Powell M, Visser M, Arends F. Skills supply and demand in South Africa. Pretoria: HSRC Press; 2016.
2. Erasmus J, Breier M. Skills shortage in South Africa: Case studies of key professions. Cape Town: HSRC Press; 2009.
3. South African Department of Higher Education and Training (DHET). National list of occupations in high demand: 2018. Pretoria: DHET; 2018.
4. Jansen J, Taylor N. Educational change in South Africa 1994-2003: Case studies in large-scale education reform. Washington DC: The World Bank; 2003. Available from: https://www.jet.org.za/resources/jansen-and-taylor-world-bank-report.pdf/view
5. Ogbonnaya U, Awuah F. Quintile ranking of schools in South Africa and learners' achievement in probability. Stat Educ Res J. 2019;18:106–119.
6. Allais SM. Education service delivery: The disastrous case of outcomes-based qualifications frameworks. Prog Dev Stud. 2007;7:65–78. https://doi.org/10.1177%2F146499340600700106
7. Le Grange L. Curriculum research in South Africa. In: Pinar WF, editor. International handbook of curriculum research. 2nd ed. New York: Routledge; 2013. p. 478–487.
8. Erduran S, Msimanga A. Science curriculum reform in South Africa: Lessons for professional development from research on argumentation in science education. Educ Change. 2014;18:S33–S46. https://doi.org/10.1080/16823206.2014.882266
9. Cross M, Mungadi R, Rouhani S. From policy to practice: Curriculum reform in South African education. Comp Educ. 2002;38:171–187. https://doi.org/10.1080/03050060220140566
10. Chisholm L, Volmink J, Ndhlovu T, Potenza E, Mahomed H, Muller J, et al. A South African curriculum for the twenty first century: Report of the review committee on Curriculum 2005. Pretoria: Department of Basic Education; 2000.
11. Dada F, Dipholo T, Hoadley U, Khembo E, Muller S, Volmink J. Report of the task team for the review of the implementation of the National Curriculum Statement. Pretoria: Department of Basic Education; 2009.
12. Motshekga A. We've signed OBE's death certificate – Motshekga. Politicsweb. 06 November 2009 [cited 2021 Nov 01]. Available from: https://www.politicsweb.co.za/documents/weve-signed-obes-death-certificate--motshekga
13. South African Department of Basic Education (DBE). National Senior Certificate 2015: Technical report. Pretoria: DBE; 2015.

14. Ramnarain U. Inquiry-based learning in South African schools. In: Ramnarain U, editor. School science practical work in Africa. London: Routledge; 2020. p. 1–13. https://doi.org/10.4324/9780429260650

15. Gustafsson M. The introduction of the three waves of curriculum change in South Africa [document on the Internet]. c2012 [cited 2021 Nov 01]. Available from: https://www.education.gov.za/Portals/0/Documents/Reports/Research%20Repository/Curriculum/Introduction%20of%20three%20waves%20on%20curriculum%20change%20in%20SA.pdf?ver=2019-09-09-104816-753

16. South African Department of Higher Education and Training (DHET). Statistics on post-school education and training in South Africa: 2019. Pretoria: DHET; 2021.

17. Zuze L, Reddy V, Visser M, Winnaar L, Govender A. TIMSS 2015 Grade 9 national report: Understanding mathematics and science achievement amongst Grade 9 learners in South Africa. Cape Town: HSRC Press; 2017.

18. South African Department of Basic Education (DBE). National Senior Certificate examination report 2015. Pretoria: DBE; 2015.

19. South African Department of Basic Education (DBE). National Senior Certificate examination report 2016. Pretoria: DBE; 2016.

20. South African Department of Basic Education (DBE). National Senior Certificate examination report 2017. Pretoria: DBE; 2017.

21. South African Department of Basic Education (DBE). National Senior Certificate examination report 2018. Pretoria: DBE; 2018.

22. South African Department of Basic Education (DBE). National Senior Certificate examination report 2019. Pretoria: DBE; 2019.

23. Letseka M, Maile S. High university drop-out rates: A threat to South Africa's future. Pretoria: HSRC Press; 2008.

24. South African Council on Higher Education (CHE). A proposal for undergraduate curriculum reform in South Africa: The case for a flexible curriculum structure. Pretoria: CHE; 2013.

25. South African Department of Higher Education and Training (DHET). 2000 to 2017 First time entering undergraduate cohort studies for public higher education institutions. Pretoria: DHET; 2020.

26. Provasnik S, Kastberg D, Ferraro D, Lemanski N, Roey S, Jenkins F. Highlights from TIMSS 2011: Mathematics and science achievement of U.S. fourth- and eighth-grade students in an international context. Washington DC: US Department of Education; 2012.

27. US National Center for Education Statistics. Trends in International Mathematics and Science Study (TIMSS) [webpage on the Internet]. c2020 [cited 2021 Nov 01]. Available from: https://nces.ed.gov/timss/

28. Van der Berg S, Burger C, Burger R, de Vos M, du Rand G, Gustafsson M, et al. Low quality education as a poverty trap [working paper]. Stellenbosch: Stellenbosch University; 2011.

29. Louw W, Bayat A, Eigelaar-Meets I. A report of underperforming secondary schools in the Western Cape. Cape Town: University of the Western Cape; 2011.

30. Bayat A, Louw W, Rena R. The impact of socio-economic factors on the performance of selected high school learners in the Western Cape Province, South Africa. J Hum Ecol. 2014;45:183–196. https://doi.org/10.1080/09709274.2014.11906692

31. South African Department of Basic Education (DBE). National Education Infrastructure Management System Standard report. Pretoria: DBE; 2020.

32. Hofstein A, Lunetta VN. The laboratory in science education: Foundations for the twenty-first century. Sci Educ. 2003;88:28–54. https://doi.org/10.1002/sce.10106

33. Skelton A. Leveraging funds for school infrastructure: The South African 'mud schools' case study. Int J Educ Dev. 2014;39:59–63. https://doi.org/10.1016/j.ijedudev.2014.07.008

34. Van der Berg S, Spaull N, Wills G, Gustafsson M, Kotzé J. Identifying binding constraints in education (2016 May 24). SSRN. Available from: https://dx.doi.org/10.2139/ssrn.2906945

35. Hungi N. Accounting for variations in the quality of primary school education. Gaborone: Southern and Eastern Africa Consortium for Monitoring Educational Quality; 2011.

36. Venkat H, Spaull N. What do we know about primary teachers' mathematical content knowledge in South Africa? An analysis of SACMEQ 2007. Int J Educ Dev. 2015;41:121–130. https://doi.org/10.1016/j.ijedudev.2015.02.002

37. Spaull N. A preliminary analysis of SACMEQ III South Africa [working paper]. Stellenbosch: Stellenbosch University; 2011.

38. Bold T, Filmer D, Molina E, Svensson J. The lost human capital: Teacher knowledge and student achievement in Africa [working paper]. Washington DC: The World Bank; 2019. https://doi.org/10.1596/1813-9450-8849

39. Spaull N. South Africa's education crisis: The quality of education in South Africa 1994-2011. Johannesburg: Centre for Development and Enterprise; 2013.

40. Tibane E. Official guide to South Africa 2018/19. Pretoria: GCIS; 2019.

41. De Wet C. Factors influencing the choice of English as language of learning and teaching (LoLT) – a South African perspective. S Afr J Educ. 2002;22:119–124.

42. Probyn M. Language and learning science in South Africa. Lang Educ. 2006;20:391–414. https://doi.org/10.2167/le554.0

43. Le Grange L. Rethinking learner-centred education: Bridging knowledge cultures. Afr Educ Rev. 2019;16:229–245. https://doi.org/10.1080/18146627.2018.1464642

44. Finson KD, Pedersen J, Thomas J. Comparing science teaching styles to students' perceptions of scientists. Sch Sci Math. 2006;106:8–15. https://doi.org/10.1111/j.1949-8594.2006.tb18066.x

45. Gess-Newsome J. A model of teacher professional knowledge and skill including PCK: Results of the thinking from the PCK Summit. In: Berry A, Friedrichsen P, Loughran J, editors. Re-examining pedagogical content knowledge in science education: New York: Routledge; 2015. p. 38–52. https://doi.org/10.4324/9781315735665

46. Friedrichsen P, Driel JHV, Abell SK. Taking a closer look at science teaching orientations. Sci Educ. 2010;95:358–376. https://doi.org/10.1002/sce.20428

47. Kind V. Preservice science teachers' science teaching orientations and beliefs about science. Sci Educ. 2016;100:122–152. https://doi.org/10.1002/sce.21194

48. Ramnarain U, Schuster D. The pedagogical orientations of South African physical sciences teachers towards inquiry or direct instructional approaches. Res Sci Educ. 2014;44:627–650. https://doi.org/10.1007/s11165-013-9395-5

49. Koopman O. Science education and curriculum in South Africa. Cham: Palgrave Macmillan; 2017. https://doi.org/10.1007/978-3-319-40766-1

50. Ramnarain U, Hlatswayo M. Teacher beliefs and attitudes about inquiry-based learning in a rural school district in South Africa. S Afr J Educ. 2018;38(1), Art. #1431. https://doi.org/10.15700/saje.v38n1a1431

51. Marais P. "We can't believe what we see": Overcrowded classrooms through the eyes of student teachers. S Afr J Educ. 2016;36(2), Art. #1201. https://dx.doi.org/10.15700/saje.v36n2a1201

52. Onwu G, Stoffels N. Instructional functions in large, under-resourced science classes: Perspectives of South African teachers. Perspect Educ. 2005;23:79–91. https://hdl.handle.net/10520/EJC87330

53. Ramnarain UD. Teachers' perceptions of inquiry-based learning in urban, suburban, township and rural high schools: The context-specificity of science curriculum implementation in South Africa. Teach Teach Educ. 2014;38:65–75. https://doi.org/10.1016/j.tate.2013.11.003

54. Ramnarain U. Understanding the influence of intrinsic and extrinsic factors on inquiry-based science education at township schools in South Africa. J Res Sci Teach. 2016;53:598–619. https://doi.org/10.1002/tea.21315

55. Stark JC, Huang A, Nguyen PQ, Dubner RS, Hsu KJ, Ferrante TC, et al. BioBits™ Bright: A fluorescent synthetic biology education kit. Sci Adv. 2018;4:1–10. https://doi.org/10.1126/sciadv.aat5107

56. Mitchell R, Dori YJ, Kuldell NH. Experiential engineering through iGEM – An undergraduate summer competition in synthetic biology. J Sci Educ Technol. 2011;20:156–160. https://doi.org/10.1007/s10956-010-9242-7

57. Russell SH, Hancock MP, McCullough J. Benefits of undergraduate research experiences. Science. 2007;316:548–549. https://doi.org/10.1126/science.1140384

58. Kang J, Keinonen T. The effect of inquiry-based learning experiences on adolescents' science-related career aspiration in the Finnish context. Int J Sci Educ. 2017;39:1669–1689. https://doi.org/10.1080/09500693.2017.1350790

59. Kontra C, Lyons DJ, Fischer SM, Beilock SL. Physical experience enhances science learning. Psychol Sci. 2015;26:737–749. https://doi.org/10.1177%2F0956797615569355

60. Hodson D. Learning science, learning about science, doing science: Different goals demand different learning methods. Int J Sci Educ. 2014;36:2534–2553. https://doi.org/10.1080/09500693.2014.899722

61. Juan A, Reddy V, Zuze T, Wokadala C, Hannan S. Does it matter whether students enjoy learning science? Exploring student attitudes towards science in South Africa [policy brief]. Pretoria: Human Sciences Research Council; 2016. http://hdl.handle.net/20.500.11910/9543

62. Bubela T, Nisbet MC, Borchelt R, Brunger F, Critchley C, Einsiedel E, et al. Science communication reconsidered. Nat Biotechnol. 2009;27:514–518. https://doi.org/10.1038/nbt0609-514

63. Dawson E. Reimagining publics and (non) participation: Exploring exclusion from science communication through the experiences of low-income, minority ethnic groups. Public Underst Sci. 2018;27:772–786. https://doi.org/10.1177%2F0963662517750072

64. Burns TW, O'Connor DJ, Stocklmayer SM. Science communication: A contemporary definition. Public Underst Sci. 2003;12:183–202. https://doi.org/10.1177%2F09636625030122004

65. Martin K, Davis L, Sandretto S. Students as storytellers: Mobile-filmmaking to improve student engagement in school science. J Sci Commun. 2019;18:1–19. https://doi.org/10.22323/2.18050204

66. Zimmerman HT, Bell P. Everyday expertise: Learning within and across formal and informal settings. In: Land SM, Jonassen D, editors. Theoretical foundations of learning environments. 2nd ed. New York: Routledge; 2012. p. 224–241.

67. Zimmerman HT, Kanter DE, Ellenbogen K, Lyons L, Zuiker SJ, Satwicz T, et al. Technologies and tools to support informal science learning. In: Proceedings of the 9th International Conference of the Learning Sciences; 2010 June 29 – July 2; Chicago, IL, USA. Chicago, IL: International Society of the Learning Sciences; 2010.

68. Barab S, Zuiker S, Warren S, Hickey D, Ingram□Goble A, Kwon EJ, et al. Situationally embodied curriculum: Relating formalisms and contexts. Sci Educ. 2007;91:750–782. https://doi.org/10.1002/sce.20217

69. Barab SA, Sadler TD, Heiselt C, Hickey D, Zuiker S. Relating narrative, inquiry, and inscriptions: Supporting consequential play. J Sci Educ Technol. 2007;16:59–82. https://doi.org/10.1007/s10956-006-9033-3

70. US National Research Council. Learning science in informal environments: People, places, and pursuits. Washington DC: The National Academies Press; 2009.

71. Yoon SA, Elinich K, Wang J, Steinmeier C, Tucker S. Using augmented reality and knowledge-building scaffolds to improve learning in a science museum. Int J Comput-Support Collab Learn. 2012;7:519–541. https://doi.org/10.1007/s11412-012-9156-x

72. Allen S. Designs for learning: Studying science museum exhibits that do more than entertain. Sci Educ. 2004;88:S17–S33. https://doi.org/10.1002/sce.20016

73. Schiele B. Science museums and centres: Evolution and contemporary trends. In: Bucchi M, Trench B, editors. Routledge handbook of public communication of science and technology. 3rd ed. New York: Routledge; 2021. p. 53–76.

74. Huang A, Nguyen PQ, Stark JC, Takahashi MK, Donghia N, Ferrante T, et al. BioBits™ Explorer: A modular synthetic biology education kit. Sci Adv. 2018;4:1–10. https://doi.org/10.1126/sciadv.aat5105

75. Stark JC, Huang A, Hsu KJ, Dubner RS, Forbrook J, Marshalla S, et al. BioBits health: Classroom activities exploring engineering, biology, and human health with fluorescent readouts. ACS Synth Biol. 2019;8:1001–1009. https://doi.org/10.1021/acssynbio.8b00381

76. RADMASTE Microscience. RADMASTE Microscience Catalogue 2018 [catalogue]. Johannesburg: RADMASTE Microscience; 2018.

77. Ramnarain U, Mamutse K. The use of improvised resources in inquiry-based teaching in South Africa. In: Bungum B, Nilsson P, editors. Part 17 Strand 17: Science in the secondary school. 2016. p. 2795–2801.

78. Bray B, France B, Gilbert JK. Identifying the essential elements of effective science communication: What do the experts say? Int J Sci Educ B Commun Public Engagem. 2012;2:23–41. https://doi.org/10.1080/21548455.2011.611627

79. Rennie L, Howitt C, Evans R, Mayne F. Do-it-yourself astronomy: Getting the best out of a science kit. Teach Sci. 2010;56:13–17.

80. Asheela E, Ngcoza KM, Sewry J. The use of easily accessible resources during hands-on practical activities in rural under-resourced Namibian schools. In: Ramnarain U, editor. School science practical work in Africa. London: Routledge; 2020. p. 14–31. https://doi.org/10.4324/9780429260650

81. Glazer EM, Hannafin MJ. The collaborative apprenticeship model: Situated professional development within school settings. Teach Teach Educ. 2006;22:179–193. https://doi.org/10.1016/j.tate.2005.09.004

82. Ufnar JA, Lee C, Shepherd V. The Vanderbilt scientist in the classroom partnership: A novel collaborative apprenticeship model for situated professional development. JSO. 2018;1:78–92. https://doi.org/10.15695/jstem/v1i1.18

83. Abramowitz B, Ennes M, Killingsworth S, Antonenko PD, MacFadden B, Ivory A. Science in school: Transforming K-12 outreach through scientist teacher partnerships. JSO. 2021;4:1–14. https://doi.org/10.15695/jstem/v4i1.14

84. Shein PP, Tsai C-Y. Impact of a scientist–teacher collaborative model on students, teachers, and scientists. Int J Sci Educ. 2015;37:2147–2169. https://doi.org/10.1080/09500693.2015.1068465

85. South African Department of Science and Technology (DST). White Paper on Science, Technology and Innovation. Pretoria: DST; 2019.

86. Rice L, Barth JM, Guadagno RE, Smith GPA, McCallum DM, ASERT. The role of social support in students' perceived abilities and attitudes toward math and science. J Youth Adolesc. 2013;42:1028–1040. https://doi.org/10.1007/s10964-012-9801-8

87. Khuluvhe M. Adult illiteracy in South Africa. Pretoria: Department of Higher Education and Training; 2021.

88. Joubert M, Davis L, Metcalfe J. Storytelling: The soul of science communication. J Sci Comm. 2019;18:1–5. https://doi.org/10.22323/2.18050501