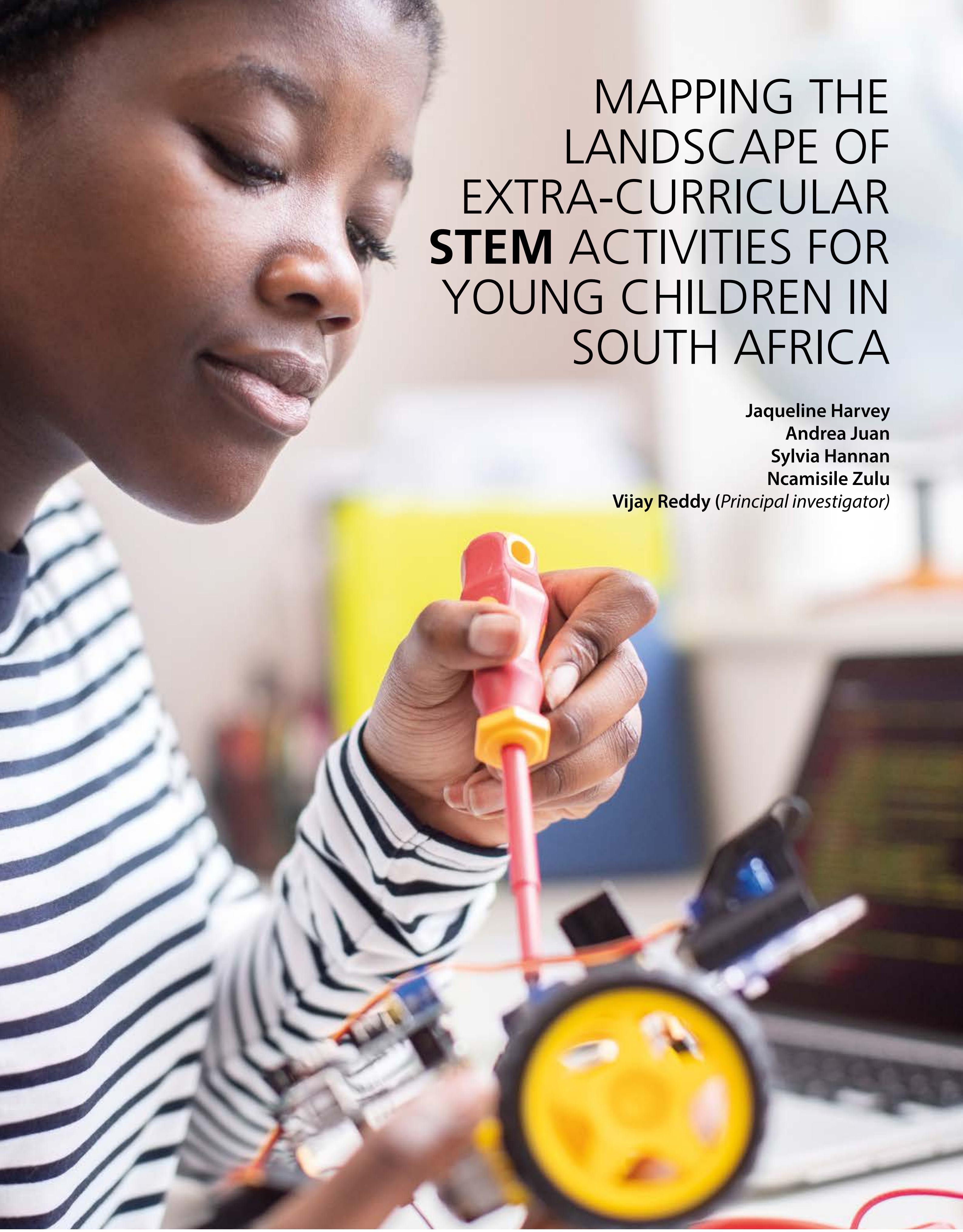

MAPPING THE LANDSCAPE OF EXTRA-CURRICULAR **STEM** ACTIVITIES FOR YOUNG CHILDREN IN SOUTH AFRICA

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ABBREVIATIONS AND ACRONYMS

DBE	Department of Basic Education
DSI	Department of Science and Innovation
DST	Department of Science and Technology
ECD	early childhood development
FEMSISSA	Foundation for English, Mathematics, Sciences, Sports and Innovation of South Africa
HSRC	Human Sciences Research Council
MIT	Massachusetts Institute of Technology
MLE	mediated learning experience
NCF	National Curriculum Framework
NRF	National Research Foundation
NSTF	National Science and Technology Forum
SAASTA	South African Agency for Science and Technology Advancement
SES	Science Engagement Strategy
STEM	Science, Technology, Engineering and Mathematics
TIMSS	Trends in International Mathematics and Science Study
UTK	United Technologies for Kids
WAAW	Working to Advance STEM Education for African Women
YiSS	Youth into Science Strategy

GLOSSARY

Activity
An activity is an interaction with STEM which involves both physical and mental engagement, as well as the presence of a mediator, which can include children themselves.

Catalyst
A catalyst is the organisation or person/group of people responsible for arranging and managing the activity.

Cognitive stages of development
Piaget identified four stages of cognitive development which delineate how knowledge is acquired from birth to adulthood.

Out-of-school activities
Out-of-school activities are those activities which occur outside school and are not connected to the school or the curriculum.

Psychosocial stages of development
Erikson formulated a theory of psychosocial development incorporating eight stages which emphasise the sociocultural determinants of development. These eight stages are presented as psychosocial conflicts that all individuals have to overcome or resolve successfully in order to adequately adjust to the environment. The first five stages cover the period from infancy to adolescence.

Science promotion
Science promotion encompasses creating awareness of science, its importance in society, and the benefits which it can provide.

Science/STEM engagement
'Science or STEM engagement' refers to a two-way interaction where individuals or groups engage with one another regarding STEM topics.

Young children/South Africans
The study focused on children from birth until approximately 15 years of age (Grade 9).

EXECUTIVE SUMMARY

The Department of Science and Innovation (DSI)[1] aims to advance science engagement and promotion within South Africa. To further this imperative, the current report explores and documents the existing landscape of extracurricular Science, Technology, Engineering and Mathematics (STEM) activities and initiatives for young children. The investigated landscape includes both South Africa and countries internationally so as to gain insight across diverse contexts.

Method

The report follows a systematic study methodology located within a quantitative design. The systematic study consolidated STEM activities, that is, those available until January 2018, into a typology. This instrument comprised a set of categories that provided a better understanding of each activity. Three researchers were involved in searching, reviewing and extracting data and, ultimately, populating the typology. A descriptive analysis of the typology was also performed.

Findings

The final number of activities included in the typology was 292, with 42 located within South Africa. Activities most often covered a combination of STEM areas (157), with the next most common focus being science (85). Although there was a wide range of strengths, the most common were interesting, modern and fun. This was considered crucial, as this may draw children towards the STEM fields. However, the main weakness of the identified activities was that resources (including high participation fees) were required, which precludes many children from STEM engagement. Recommendations therefore focused on ways of increasing access.

Recommendations

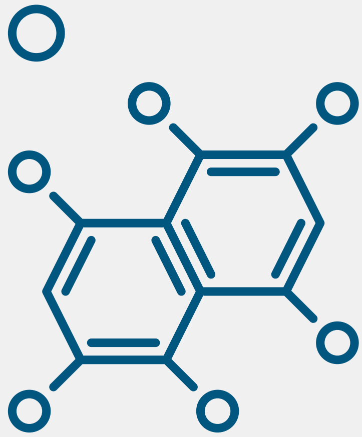
Recommendations centred on monitoring and evaluation with a view to determining best practices for young children in South Africa as well as the creation of an online portal. The latter is envisioned as acting as a virtual hub where STEM resources could be presented to children, parents and teachers. Other recommendations included the promotion of activities and partnerships across all areas so as to reach a wider audience. Finally, it was recommended that the DSI increase its communication with relevant role players. The ultimate goal of this report is therefore to assist the DSI in creating a culture of science engagement within South Africa. Each recommendation entailed the following:

1 Following the reconfiguration of government departments in June 2019, the Department of Science and Technology (DST) was renamed the Department of Science and Innovation (DSI).

1. Monitoring and evaluation, including a NEEDS analysis of South African communities with regard to extracurricular activities, with a view to developing application and accessible activities;
2. Development of an online STEM portal which is accessible via computers, tablets and smartphone devices;
3. Partnerships with existing South African science centres and the promotion of their activities;
4. Promotion of current organisations and their satellite activities, including visits to rural areas and teaching promising children to teach their peers;
5. Development of partnerships between organisations offering STEM activities and organisations delivering services to rural areas;
6. Development of STEM activities specific to the unique contexts of South African children; and
7. Increased communication by the DSI.

Conclusion

The purpose of this report is to assist the DSI with its aim of advancing science engagement and promotion among young South African children. Based on the identified extracurricular STEM activities and their strengths and weaknesses, recommendations focus on increasing accessibility to the wide range of activities already available in South Africa. The recommendations also include insights from those activities taking place internationally. It is envisioned that, through the development of innovations and partnerships, a culture of science engagement among young South Africans can be fostered.



1

ONE
INTRODUCTION

South Africa is currently undergoing transformation into a knowledge-based economy. The efficacy of this transformation lies in burgeoning knowledge-based industries as well as the use of technology in order to innovate. The labour market will therefore need an increase in high- and middle-skilled individuals, particularly in the Science, Technology, Engineering and Mathematics (STEM) fields. The promotion of STEM is thus a core focus in South Africa so as to support these needs. Furthermore, it is important to foster interest and knowledge in STEM from a young age. This will ensure an interested public as well as a competent and engaged workforce. In focusing on children from birth to 15 years old, the current study therefore provides a detailed but holistic view of STEM-related activities and initiatives that support engagement, education and progression through the STEM pipeline.

Graduates in STEM fields are a crucial requirement for South African economic transformation.

This study is situated within frameworks implemented in South Africa to promote STEM. The Department of Science and Innovation (DSI) has provided an overarching strategic framework to do so through the Science Engagement Strategy (SES) (DST, 2015). Spurred on by concerns about an inadequately sized STEM workforce, economic growth and individual well-being, this strategy identifies a wide range of targeted sectors of the public, which includes learners and their families. The SES is an overarching policy document which integrates a range of science engagement and promotion initiatives as a means of advancing science engagement and promotion in the country. The SES seeks to develop South African citizens who are knowledgeable about science, are scientifically literate, and are able to critically engage concerning processes and issues that impact their lives. Following this, the DSI produced a Science Engagement Strategy Implementation Plan (2017). The detail of the current report and its focus on children from birth to 15 years furthers the aims of these strategies.

The SES vision is to develop ‘a stimulated and engaged South African society that is inspired by and values scientific endeavour, critically engages with key science and technology issues, and participates in a fully representative innovative science and technology workforce’ (DST, 2015: 20).

It is also important to assess the feasibility of STEM activities in the South African context. South Africa continues to make strides in redressing injustices resulting from the apartheid legacy. Although access to education has greatly improved, challenges such as poverty continue to be obstacles to equal quality of education for all learners. Language currently constitutes a further challenge rather than providing support. The majority of learners complete some or all of their education in a second or even third language (Manyike, 2013; Pretorius & Spaull, 2016; Taylor & Von Fintel, 2016). This hampers their academic development, as they must simultaneously acquire additional language proficiency. The negative impact of these contextual factors on achievement was shown in both the Grade 5 and Grade 9 Trends in International Mathematics and Science Study (TIMSS) 2015 South African results. South Africa was one of the five lowest-performing countries in terms of both mathematics and science learners. In addition, it has been indicated that factors such as school climate, socio-economic status, school and home language equivalence, and bullying were highly influential as regards Grade 5 and 9 learner achievement. The Grade 5 results further showed the importance of the home and of caregivers in early learning (Isdale, Reddy, Juan & Arends, 2017; Zuze, Reddy, Visser, Winnaar & Govender, 2017). The TIMSS 2015 results therefore reveal that much improvement is still required in these subjects – which is crucial in any STEM field – and that contextual factors need to be taken into consideration.

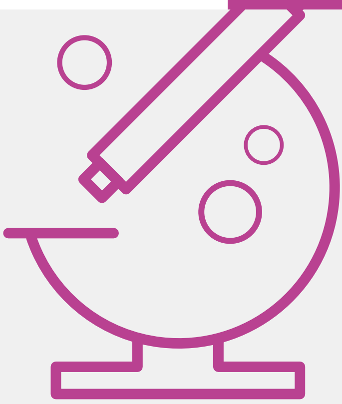
The main purpose of this study was to explore and document the current landscape of extracurricular STEM activities and initiatives for young children (from birth to 15 years) in South Africa. This report aims to provide a view of STEM-related activities and initiatives that supports children's engagement with STEM which, in turn, enhances skills development, STEM learning, positive attitudes to STEM and interest in STEM careers. The second purpose of this report is to explore what activities are undertaken internationally with a view to adapting these activities for the South African context.

1.1 KEY RESEARCH QUESTIONS

The broad research objective was to map the landscape of extracurricular STEM activities for young children internationally, and in South Africa specifically. The key research questions were:

1. What extracurricular STEM activities are offered to young children internationally?
2. What extracurricular STEM activities are offered to young children in South Africa?
3. How can activities offered internationally be adapted for, and adopted in, South Africa?
4. How can we expand access to extracurricular STEM activities that are offered?

The next section of the report presents a conceptual framework of how children learn and provides a brief overview of the relevant literature regarding learning and engagement in respect of STEM activities. Section 3 presents the methodology used in the study, and the key findings are discussed in Section 4 of the report. The report concludes, in Section 5, with a set of recommendations for expanding and enhancing extracurricular STEM activities for young children in South Africa.



2

TWO
LEARNING THROUGH ENGAGING IN ACTIVITIES

This section discusses learning and the role that extracurricular activities can play. It furthermore indicates children's developmental stages as well as what the ideal extracurricular activity would include. Learning is a process in which people engage throughout their lives in various contexts. Bjornavold (2000) suggests that learning is contextual in character. Knowledge and competences are acquired, as a result of individuals' participation in communities of practice, through an ongoing process of learning. A focus is therefore required on both the relational side, which refers to an individual's role within a social group, and as regards the engaging and communicative nature of learning (Bjornavold, 2000). Social constructivism therefore guides this study.

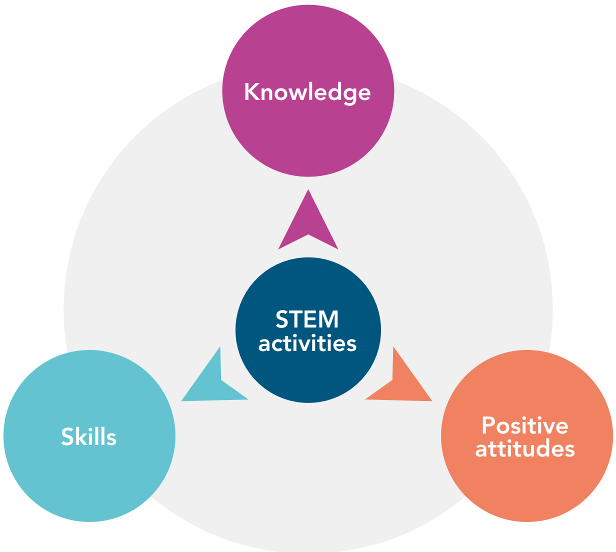
Social constructivism is a response to criticisms of cognitivism. With regard to similarities, both social constructivism and cognitivism state that knowledge is actively constructed in response to interactions with the environment. The theories furthermore agree that children do not respond to external stimuli but rather to their interpretation of the stimuli. However, they differ in that social constructivism rejects the separation of learning from its social context. Social constructivism notes that both language and culture play key roles, as they are the frameworks through which individuals experience the environment. Vygotsky furthermore argued that learning is collaborative and thus deeply impacted by language (Goswami, 2004). This is a crucial point for the current study, as South African children have widely diverse backgrounds. During extracurricular activities, children's backgrounds and previous experiences influence their co-construction of knowledge through interaction.

This theory was therefore appropriate for the current study, as many extracurricular activities seek to engage children through interactions and activities with others. It furthermore takes into account the relational and communicative nature of learning.

2.1 WHY SHOULD CHILDREN ENGAGE IN STEM ACTIVITIES?

The importance of cognitive and overall development before children even enter formal schooling is acknowledged by the South African government (DBE, 2015). As noted in the National Curriculum Framework (NCF), the first four years of life are the foundation for health, human capacity, and personal and social well-being (DBE, 2015). With regard to STEM, exposing children to these types of activities even before they are enrolled in formal education can promote the development of a wide range of cognitive and psychosocial knowledge and skills. This foundation is as important as engaging children at later ages, if not more so. Thus, beginning early and continuing to engage children in STEM activities can be a means of promoting enthusiasm and interest in these fields, as well as a desire to pursue them throughout secondary school and as a career thereafter (Figure 1). It is not only content knowledge that children need in order to achieve success and/or progress through the STEM pipeline, but also skills and positive attitudes that are fostered early on.

Figure 1: Intended outcomes of STEM activities



Engaging in STEM activities during childhood can influence attitudes and career aspirations. Aspirations tend to be formed before the age of 14 and changing children's attitudes becomes gradually more difficult after this age. In addition, this is an important period for identity formation, which can have implications for the type of career to which children aspire (Tytler, Osborne, Williams, Tytler & Clark, 2008). Importantly, children have identity beliefs that support or hinder future careers in the STEM areas (Dorsen, Carlson & Goodyear, 2006). Taking this into consideration, there are two important factors: early engagement and parental roles.

2.1.1 Engagement must start from an early age

It is important to engage children in STEM activities from an early age. Neural pathways established during the first years of life are essential for subsequent skill development, lifelong learning and long-term capabilities. Certain skills and abilities are acquired more effectively during early periods than during later life stages. Early childhood development (ECD) can thus be a primary component of children's later ability to cope and their acquisition of future skills (Cunha, Heckman, Lochner, & Masterov, 2006; DBE, 2015; Kotzé, 2015).

2.1.2 Parents play a vital role

The quality of a child's environment, the nurturing, and the responsiveness of adults are vitally important for shaping brain architecture (DBE, 2015; Eldering & Leseman, 1993). Learning is therefore influenced and facilitated by children's parents or caregivers. A lack of resources which limits parental investment and/or the absence of a stimulating home environment can have a negative impact on children's development and academic achievement. Activities are not, however, dependent on economic resources, as parents can be shown how to stimulate child development through informal learning. Parents can therefore be shown how to mediate learning (e.g. playing counting games while performing daily activities) which stimulates their child's development.

Extracurricular STEM learning can occur at home, through interaction with parents/caregivers, and at institutions which provide a range of activities which children can engage in. The role of the home is particularly important for young children who have yet to enter school, as parents bear the responsibility of encouraging STEM learning at this stage. Once children have entered school, parents still have a crucial role to play in supporting their children's STEM learning and in encouraging interest in STEM. Institutions also have an important role to play in promoting STEM learning, as they can create unique activities and provide children with a wealth of STEM information. STEM activities should not only enhance children's STEM knowledge and provide them with skills to tackle STEM, but should also promote positive attitudes to STEM.

2.2 APPROPRIATE ACTIVITIES THAT TARGET SPECIFIC STAGES OF COGNITIVE DEVELOPMENT

It is important to take into account the cognitive development of children, as this impacts the type of activity that is appropriate for them. Furthermore, as noted in the introduction, engagement in STEM activities can develop knowledge and skills which will form the foundation for later engagement in STEM fields. It is, therefore, important to ensure that activities are targeting the correct stage. According to Piaget, there are four stages of cognitive development:

1. Sensorimotor (0 to 2 years);
2. Pre-operational (3 to 6 years);
3. Concrete operational (7 to 11 years); and
4. Formal operational (12 years to adulthood).

Erikson's stages of psychosocial development are also used to demarcate age groups:[2]

1. Infancy (0 to 1.5 years);
2. Early childhood (1.6 to 2 years);
3. Pre-school (3 to 5 years);
4. School-going age (6 to 11 years); and
5. Adolescence (12 to 18 years).

Within each of these stages, individuals have different skills and interests and therefore require interventions which are relevant for that particular stage (see Appendix 1). However, it should be noted that some children develop at different rates; hence the above groupings are more properly guidelines than fixed stages of development.

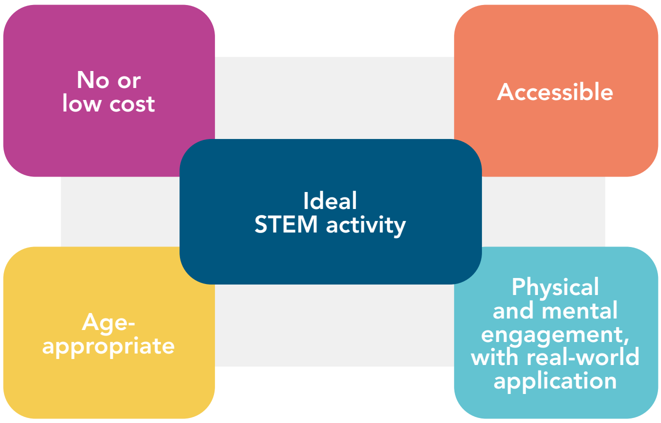
2.3 WHAT DOES AN 'IDEAL' EXTRACURRICULAR STEM ACTIVITY LOOK LIKE?

The authors consider an ideal extracurricular STEM activity (Figure 2) to incorporate certain aspects:

- A key criterion would be to provide the activity at no or a low cost.
- Secondly, and linked to the above, the activity should be appropriate to the aims and context of South Africa. It should, therefore, include features that increase accessibility to all children regardless of their home language, socio-economic status or geographic location.
- If the activity cannot easily be implemented for all children, the catalyst should act as a facilitator. The catalyst would thus be responsible for innovations to overcome challenges preventing children from taking part in such activity. This shifts responsibility from families, who may not have the resources, to the catalysts themselves.
- In addition, as indicated above, the activity should target specific developmental stages in order to ensure that it is appropriate.
- The activity should involve both physical and mental engagement. Passive activities, such as listening to the radio, television programmes, vlogs or applications, were therefore not considered.
- Finally, it is expected that the activity have real-world application and that these links be highlighted for children. Not only would this increase their ability to visualise themselves as working within that role, but it would also increase interest in STEM itself.

2 For the sake of space, only those stages relevant to children of school-going age are shown.

Figure 2: Characteristics of the ideal extracurricular STEM activity



The next section discusses the methodology employed when compiling this report and answering the research questions.

3

THREE
METHODOLOGY

3.1 RESEARCH STRATEGY

To answer the research questions about current STEM activities in South Africa and internationally, and to make recommendations with a view to creating a culture of science engagement among young children, this study employed a systematic study methodology located within a quantitative design. A systematic approach encompasses a critical and methodical analysis of all relevant and available research evidence. A systematic study was appropriate for this project, as it allowed a more structured and organised search approach to a wide range of learning-activity types. Both high-income and low-income countries were researched. High-income countries were included as they typically have more advanced and established activities, while low-income countries were included as they have contexts which are more similar to those of South Africa, therefore making them more suitable for South Africa to learn and adapt activities from. This systematic study consolidated the STEM activities that were available until January 2018.

3.2 DATA-COLLECTION INSTRUMENT

A typology of activities was used as a data-collection tool. This typology was developed in order to categorise the range of extracurricular activities and initiatives that are undertaken internationally, and those that are undertaken in South Africa. This instrument comprised a set of categories that provided a better understanding of the STEM activities. These categories were discussed and agreed on by the research team and are presented in Table 1. The definitions for each of the categories – continent/country, level of access, activity area, activity name, catalyst, mediator, age range, resource requirements, monitoring and evaluation, and strengths and weaknesses of the activity – were included in the typology to allow the research team to collect as much data as possible, and to ensure consistency across the categorisations made by the different researchers. The website in respect of each activity was also included, as well as a section for any additional comments.

3.3 DATA-COLLECTION PROCESS

Three researchers were involved in searching, reviewing and extracting data related to STEM activities. The Internet search engine, Google Search, was used. The search terms which were used were continent or country, combined with the following: *STEM activities, extracurricular activities, out-of-school activities, afterschool activities, activities for children, science activities, technology activities, engineering activities, and mathematics activities*. The typology was then populated with the extracted data. Lastly, a descriptive analysis of the typology was conducted.

The final number of activities included in the typology was 292, with 42 located within South Africa. Each activity was evaluated based on the categories listed in Table 1.

Table 1: STEM activities typology

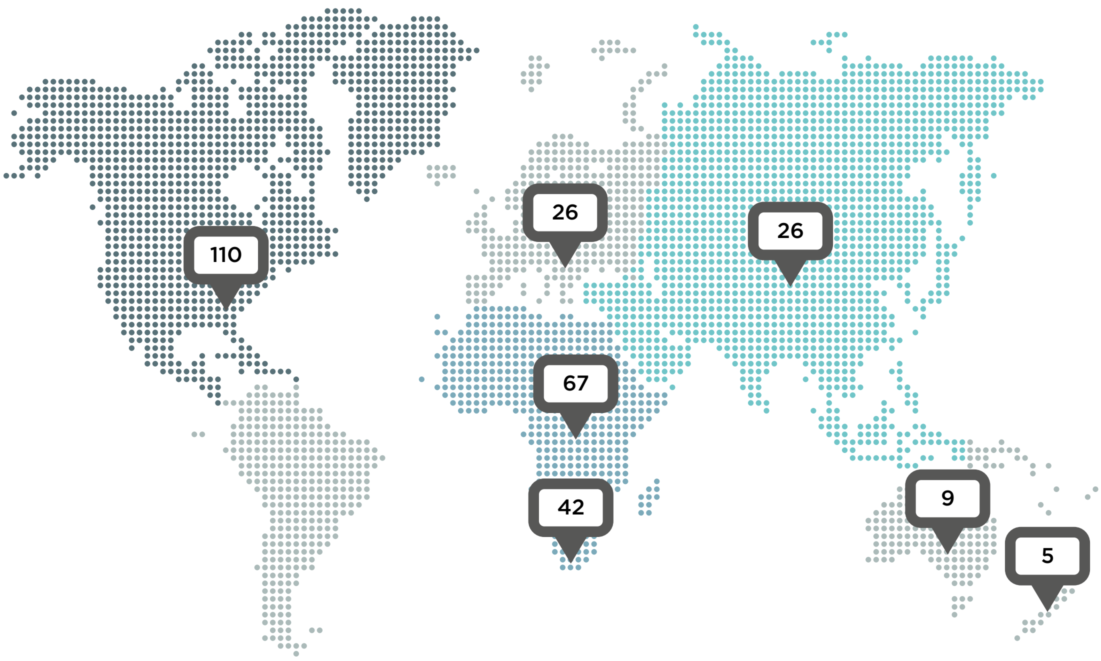
	Activity
Continent or country	1. Africa 2. America 3. Asia 4. Europe 5. South Africa 6. Australia 7. New Zealand 8. Multiple countries, including South Africa 9. Multiple countries, excluding South Africa 10. Unknown
Access	1. Low 2. Medium 3. High Low-access activities are those with selective intake criteria, such as high fees or accommodation costs, specialised resources such as laboratories, or entrance examinations. 'Medium access' refers to those activities with 'opportunity' intake criteria. This includes situations where a specific community is chosen to take part and the learner happens to live within that community. 'Medium access' also refers to activities where an Internet connection is required. Activities are labelled as high-access if they have no intake criteria, for example where activities can be done at home.
Activity area	1. Science 2. Technology 3. Engineering 4. Mathematics 5. Any combination of these
Activity name	The name of the activity
Organisation name	The name of the organisation or institution
Mediator	1. Organisation 2. School/teacher 3. Parent 4. Child 5. Multiple mediators This identified how children gained awareness of, or access to, the activity.
Age range	Minimum and maximum age
Resource requirements	1. Low 2. Medium 3. High Although similar to access, this category is based on the resources needed to undertake the actual activity once access has been gained. Activities which require low resources are coded as those activities which require household items such as paper, two-litre bottles or plastic packets. Those requiring medium resources refer to activities that have to be printed – this could require a computer, an Internet connection and a printer – or activities where particular items have to be purchased, such as elastic bands, paper clips or tape. Activities are labelled as requiring high resources if children have to have their own computer, laptop or tablet. Activities needing laboratory facilities or camps are also categorised as requiring high resources. Lastly, activities which require specialised toys for all ages, such as playdough or robotic mechanisms, are listed as requiring high resources.

Table 1: STEM activities typology	
	Activity
Monitoring and evaluation	1. No 2. Yes
Strengths	1. Interesting 2. Modern 3. Free 4. Resources provided 5. Targets girls 6. Targets at-risk children 7. Targets psychosocial skills 8. Includes mentoring or role-modelling 9. Directly related to labour market 10. Wide age range 11. Accessible 12. Creative/innovative 13. Fun
Weaknesses	1. Resources required 2. Limited locations 3. Limited explanation of STEM concepts

FOUR
FINDINGS

The identified STEM activities were organised into a typology. Two hundred and ninety-two activities[3] were identified. These were categorised according to continents: Africa (67), America (108), Asia (26), Europe (26), and Australasia (14). Two activities, run by iD Tech and ProjectCSGirls, are active across multiple continents but originated within the United States of America. They were therefore combined with activities in America during analysis. The typology also lists activities which occur in South Africa (42). Of note, the Working to Advance STEM Education for African Women (WAAW) Foundation was included in 'Africa' but is active in multiple countries, including South Africa. The originating countries in respect of seven activities could not be sourced but were largely websites containing information and activities for download and thus accessible online. Figure 3 indicates the number of activities identified across the continents.

Figure 3: STEM activities



3 The list of activities is not exhaustive but provides a comprehensive overview of STEM activities which are undertaken internationally, and in South Africa specifically.

As noted in the typology, activities were categorised as focusing on science (87), technology (30), engineering (11), mathematics (9), or a combination of these (155), and covered all ages from birth to adulthood.

Activities were also rated according to specific strengths and weaknesses which could contribute to, or detract from, developing a culture of STEM engagement. Figure 4 and Figure 5 indicate the number of times each strength or weakness was noted in respect of the activities by the research team. Activities which were free, accessible, targeted girls and targeted children considered to be at risk or which provided mentorship and/or role-modelling, were scarce. The most common strength was that the activities were interesting, while the most common weakness was that the activities required resources. Another weakness was that many of the activities took place in limited locations. When cultivating STEM activities in South Africa, it must be considered that some provinces are primarily rural and therefore activities need to be mobile in order for them to be able to be accessed by the majority of children in those provinces. A final weakness was that an explanation of how the activities are linked to STEM was not included, for example how they contribute to understanding a theoretical concept.[4] This is imperative, as it underlines the importance of the activity, improves learning when the links between what is being done and the concept are explicit, and promotes the development of activities which relate well to STEM engagement and learning.

Figure 4: Strengths of all identified activities

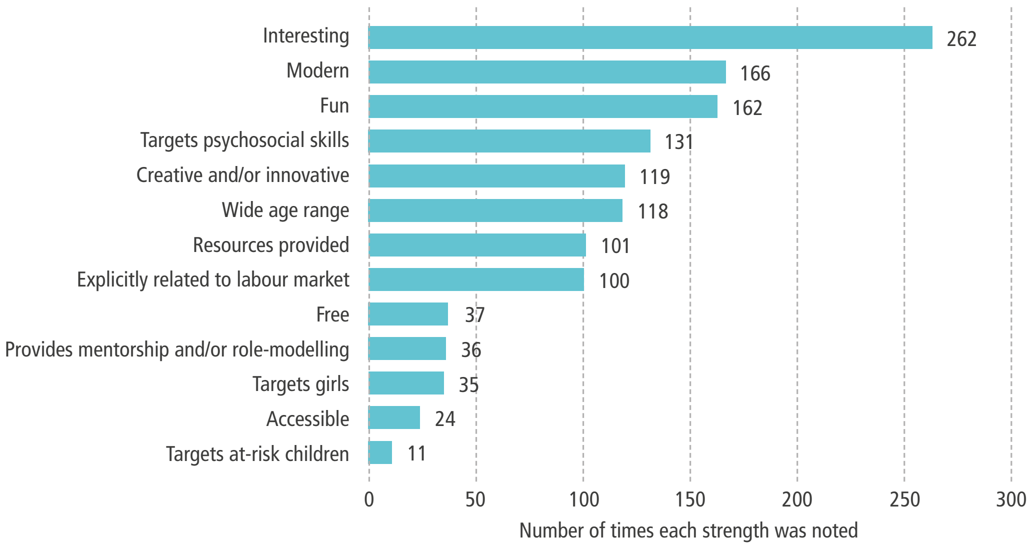
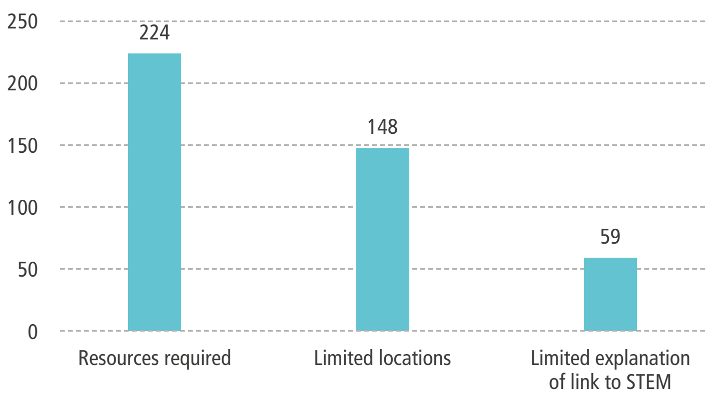


Figure 5: Weaknesses of the identified activities



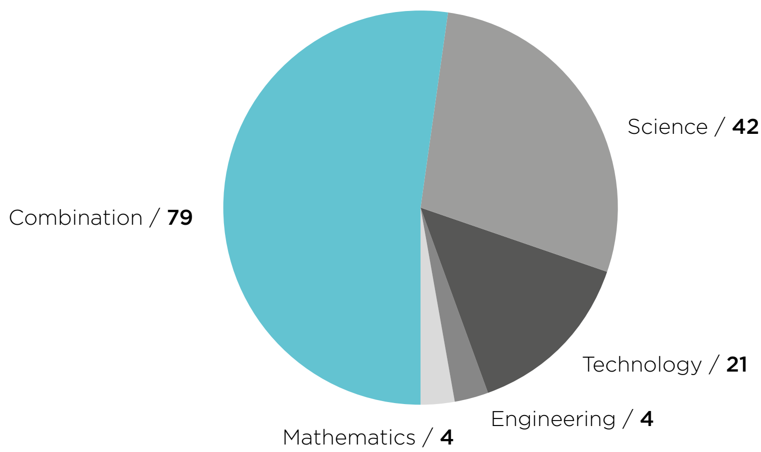
4 This weakness was difficult to classify because, for example, a website may not include this information but the purchased activity may in fact include it.

The following section seeks to answer the first and second research questions, that is: What activities are offered internationally and within South Africa? Since each activity is listed in detail within the typology, only the aggregated findings are presented in this section. The findings are divided into three subsections: (1) High-income countries; (2) Low-income countries; and (3) South Africa. Activities in the high-income countries are able to indicate the leading STEM activities. Furthermore, these activities are undertaken in countries that are further advanced in STEM fields. In contrast, activities in low-income countries highlight innovative approaches to different contexts that may be similar to the South African context. These are then contrasted with what is currently taking place in South Africa and with what activities could be undertaken to promote STEM engagement among South African children.

4.1 HIGH-INCOME COUNTRIES: NORTH (AND SOUTH) AMERICA,[5] EUROPE AND AUSTRALASIA

Activities crossed all STEM sectors as well as all ages (Figure 6). There were activities for children from as young as one year up until adulthood. For example, the Go Science Girls webpage has STEM activities aimed at the following age ranges: 1–2 years; 3–4 years; 5–6 years; and 7–9 years.

Figure 6: Activities organised by STEM sector

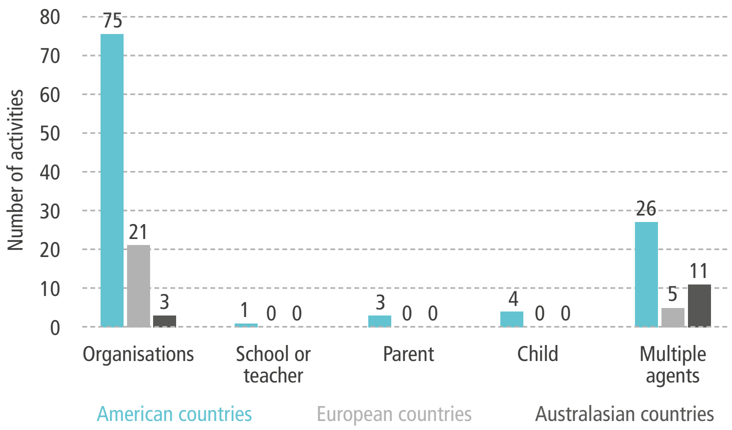


Activities were low- or medium-access (147) activities, with only three activities which could be rated as high-access. One of the latter activities was the STEM Labs initiative of United Technologies for Kids (UTK). This mediator is funded by student organisations from the University of California, Berkeley, the Massachusetts Institute of Technology (MIT), and the University of Michigan. UTK aims to promote STEM education in high schools through resourcing science and technology laboratories and by offering afterschool programmes. Examples of such programmes include: 3D printing and industrial design; electronics with Arduino; programming; robotics; biotechnology; and drone technology.

The lack of high-access activities could be related to the different contexts of high-income countries, such as the United States of America, and low-income countries, such as South Africa. This may also explain why activities were primarily catalysed and mediated through organisations rather than the government (Figure 7). Furthermore, the majority of activities required a medium (93) or high (51) level of resources, which reflects the dependence on organisations as well as on an Internet connection (Figure 8).

5 Although South America is not a high-income country (continent) context, only two activities were identified and these were therefore included here for simplicity.

Figure 7: Activities in high-income countries by mediator



The majority of activities identified had the following strengths: interesting (145), followed by fun (128), targeting psychosocial skills (114), and incorporating a wide age range (100) (Figure 8). The identified weaknesses of the activities are presented in Figure 9.

Figure 8: Strengths of the identified activities in high-income countries

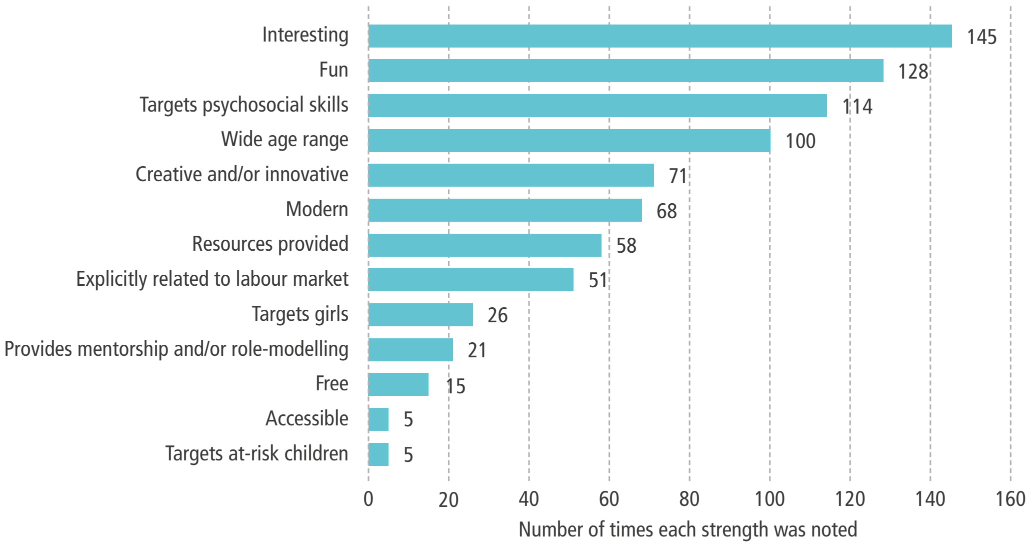
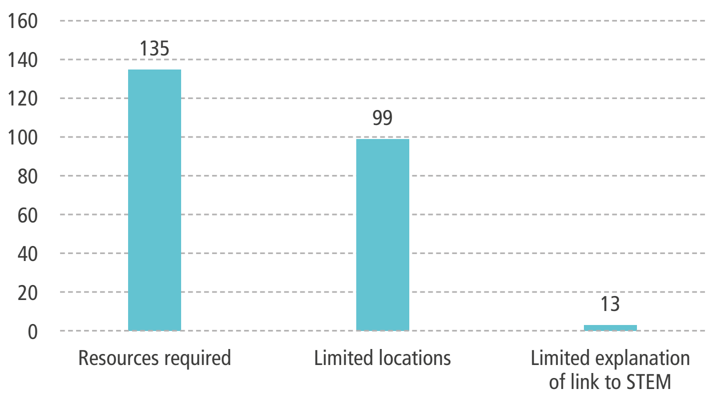


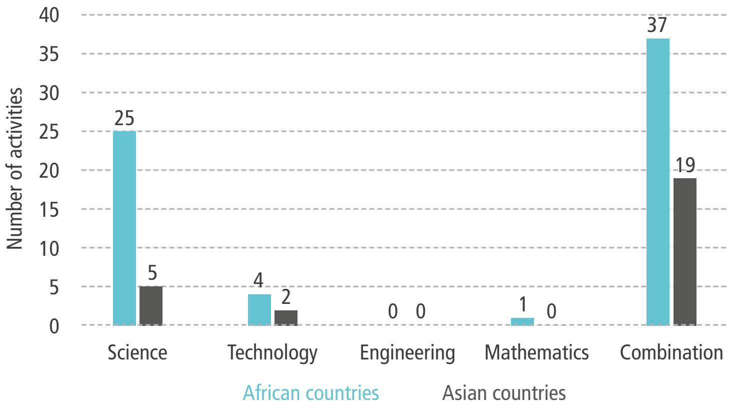
Figure 9: Weaknesses of the identified activities in high-income countries



4.2 LOW-INCOME COUNTRIES: AFRICA AND ASIA

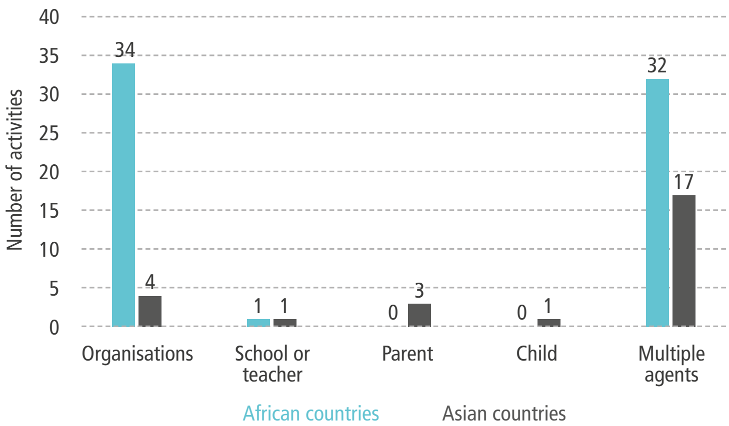
Ninety-three activities were identified in African (excluding South Africa) and Asian countries. Interestingly, across both continents, there were no activities where the sole focus was engineering (Figure 10), although activities targeted a diverse age range (3–18 years).

Figure 10: Activities in African and Asian countries by STEM sector



Activities were primarily low- or medium-access activities, with only seven being high-access activities. The former included activities which needed to be downloaded and therefore required Internet access and, at times, a personal computer or laptop. Activities which were high-access activities included community programmes run by organisations and which were free for targeted children. Activities, particularly in Asian countries, were most often mediated through multiple agents and/or avenues (Figure 11).

Figure 11: Activities in African and Asian countries by mediator



An excellent example of an organisation acting as a catalyst is the Agastya International Foundation (Table 2). This foundation is located in India, which is also a low-income country, and provides the following for teachers, parents, learners and communities:

Table 2: Activities offered by the Agastya International Foundation

	Activity
Main campus 172-acre creativity campus	**Teacher training:** A lab is used to refine effective teaching methods and teacher-training strategies as well as illustrate the science behind concepts often taught by rote. **Camps@campus:** Programmes are provided for children and young adults from affluent city schools as well as for children from rural areas. For learners, these programmes are able to supplement curriculum work, strengthen both academic understanding and real-world application, and foster interaction between urban and rural learners. Subjects covered by way of labs include physics, chemistry, biology, mathematics, astronomy, art and ecology. Through sport and other activities, skills such as teamwork and empathy are also developed. **Media Arts Lab:** Directs iCommunity (see below). **Art@Agastya:** Art instruction is included in order to complement traditional teaching, as it promotes balance, includes different types of learning styles, and teaches active observation crucial for scientific inquiry. Furthermore, engagement in art promotes creativity and curiosity, which later relate to innovation and invention. **Performing Arts Centre:** Through dance and music, children are able to: see lessons in physics, including force, mass, motion and sound waves; use rhythmic patterns to learn mathematical lessons such as counting, addition, fractions and exponentials; learn about symmetry, sound and spatial relationships, as well as concepts such as frequency and harmonics; and develop emotional intelligence. The performing arts are also able to connect children to their cultural heritage. **Young Instructor Leader:** This programme targets children with a special interest in, and aptitude for, science, mathematics and other key areas. Those selected attend courses specially designed to promote creativity, cooperative learning, leadership skills and self-confidence. Through this, these learners are able to become peer teachers at learning centres and science fairs.
Hubs A hub is defined as the centre point of a network.	**Science centres:** These act as hubs within both urban and semi-urban areas. Learners are bussed in to learn from hands-on models and experiments. The centres also offer teacher training, special training sessions and activities, as well as summer camps.
Satellites A satellite is a peripheral part of a network which is separate from but still dependent on and/or controlled by the centre (or hub).	**iCommunity:** Mobile labs outfitted with solar power and digital equipment are sent into rural villages where instructors demonstrate principles of science through integrating language, ancient folklore, rural art, community life and basic digital skills. **iMobile** (Figure 12)**:** The iMobile lab is outfitted with computers, cameras, audio-recording devices, a battery-operated Internet hub and a project. The lab visits each of the surrounding schools and community centres in a planned rotation of ten to 12 lessons each year, reaching approximately 500 learners and achieving 6 000 exposures. **Lab-in-a-Box:** As it is not always possible to visit all schools regularly, each school can receive a box with equipment to perform hands-on science experiments. Each of 12 boxes has a theme and relates to key concepts in physics, chemistry, biology and mathematics. For example, the chemistry kit provides lab apparatus to perform experiments using household chemicals. Teachers using the box are trained by the Agastya International Foundation, making them agents of change for improving instruction in schools.

Table 2: Activities offered by the Agastya International Foundation

	Activity
Satellites (continues)	**Lab-on-a-Bike:** This programme extends the reach of the mobile labs by using motorbikes and the lab-in-a-box to visit remote village schools. The instructor (rider) delivers science education and digital literacy using a computer and a portable Internet connection. Learners are able to play simple science games, watch language-neutral videos, participate in multimedia conferencing, and do quizzes. Teachers are provided with instructional videos on using the lab-in-a-box, and are also able to access an online community in local languages where they can learn together. **Operation Visantha:** This programme trains young volunteers, especially college students, to go back to their home villages and tutor learners who are not in school for various reasons. The volunteers receive training two to three times a month to sharpen their teaching skills and learn remedial-education strategies. They receive a modest monthly honorarium. The tutoring sessions are two-hour classes presented six days a week. **Maja Box:** The Maja Box, which is intended for the home (and children from 7 to 11 years), contains games, puzzles, scientific toys and do-it-yourself activities which stimulate scientific inquiry. The instructions for each activity are included as pictographs. This could be greatly beneficial in South Africa where literacy rates are low for both children and adults. In addition, it could assist with any language challenges that may occur. The Maja Box further includes a Think Box at the end of each activity which poses questions in order to promote reflection and deeper understanding.
Innovation fairs	Beginning in 2012, these fairs ask teams – two engineering students paired with two high school students – to solve a problem relating to a selected topic.
Science fairs	Agastya hosts more than 100 science fairs a year which draw more than 45 000 teachers, parents and learners. During the fairs, instructors demonstrate low-cost experiments and elaborate models in order to encourage curiosity and creativity.

Figure 12: Mobile Lab offered by the Agastya International Foundation

Figure 13: Vehicle used for the Mobile Lab offered by the Agastya International Foundation

As is evident from the list in Table 2, the Agastya International Foundation has made great strides in improving the access of all children to STEM education as well as in promoting a culture of science. South Africa faces many challenges which are both similar to, and vastly different from, those of India, but there is much that can be learnt from this foundation and others like it. STEM Synergy, for example, is active in African countries and has innovative developments for this context.

Digital literacy is becoming fundamental to success in the workplace and it is therefore necessary to cultivate this in children from a young age. STEM Synergy has developed an innovative solution through its 75 virtual computing labs (in addition to 18 STEM centres, four shared-science high schools, national science competitions, and national science museums in Ethiopia, Israel, Kenya, South Sudan, Rwanda, Uganda, Burundi and Kurdistan). The virtual computing labs overcome several challenges regarding the introduction of technology in schools, such as expense, breakages, disabling viruses, hardware failures, obsolete operating systems, inconsistent software, and poor access to electricity. Each learner workstation has a display monitor, keyboard and mouse but no computer. Instead, these elements are connected to a device linked to the teacher's computer. This high-capacity computer requires one power source, prevents classroom overheating, and limits infection by computer viruses. This could be an effective means of introducing technology in South Africa, and it could also be implemented in STEM centres offering extracurricular STEM activities for children.

No activities were identified in African countries that focused particularly on mediation through parents or children. However, it should be noted that websites such as Little Einstein's East Africa include activities for children aged three to eight which can be mediated both through parents and children themselves, depending on the activity. Therefore, parents and children can be included through these types of activities. (To avoid duplication, these types of activities were marked as 'mediated through multiple avenues'). The required resources were also in line with the access and mediator aspects of the identified activities. For instance, ten activities in total required low resources (Figure 14).

The most common strengths of activities in African and Asian countries were: interesting (76), followed by modern (65) (Figure 15). The most common weakness was that resources were required (Figure 16).

Figure 14: Resources required by activities in African and Asian countries

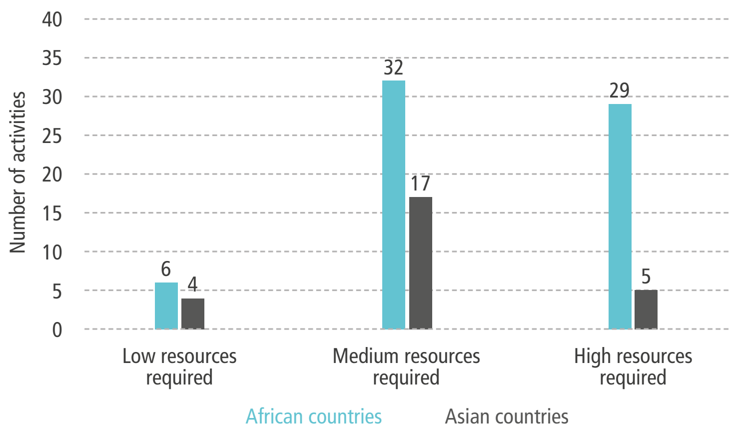


Figure 15: Strengths of the identified activities in low-income countries

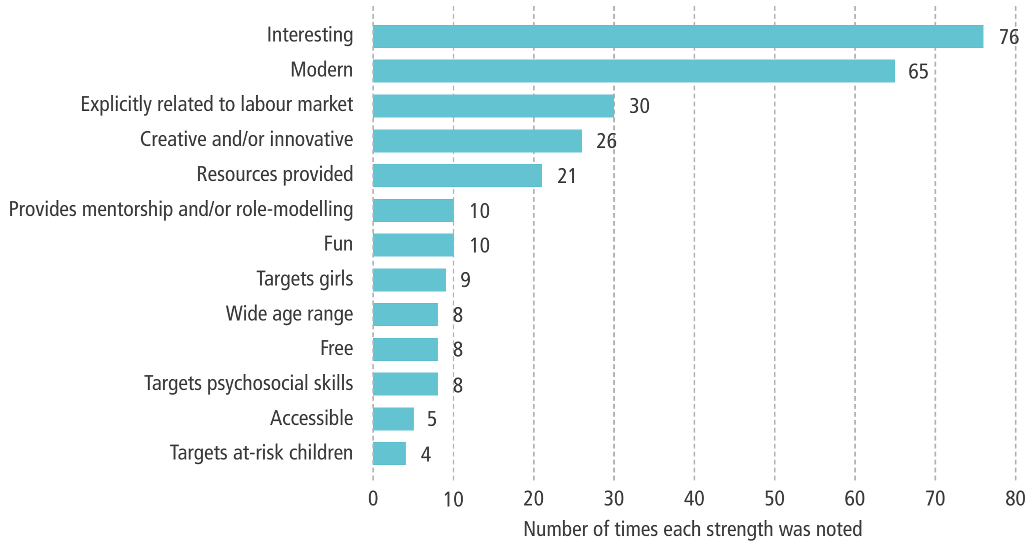
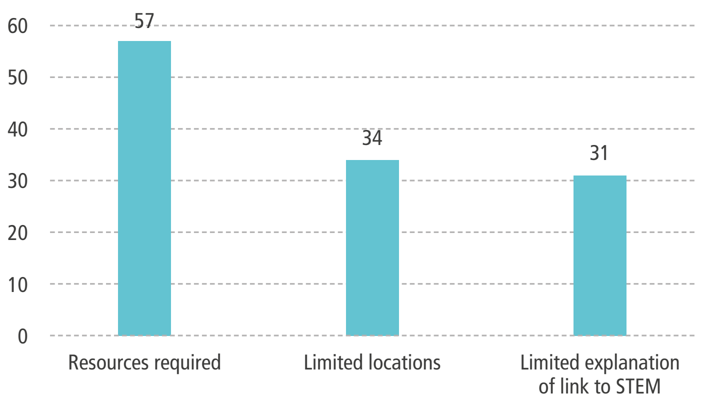


Figure 16: Weaknesses of the identified activities in low-income countries



4.3 SOUTH AFRICA

Forty-two activities were identified that take place in South Africa across multiple provinces. A summary of the activities identified[6] is presented in Table 3. As can be seen from Figure 17, the majority of activities focused on a combination of STEM topics (14), with three activities being related to technology only.

Figure 17: Activities organised by STEM sector

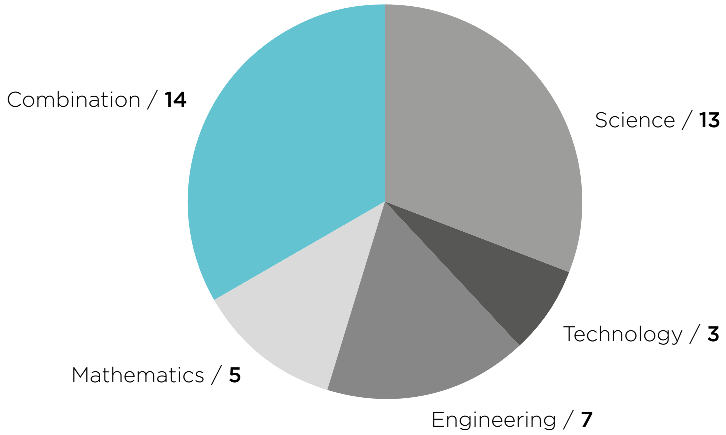


Table 3: A summary of activities (42) offered in South Africa

Activity name	Catalyst	Cost	Age range
Annual Olympiads	Conquesta Olympiad http://www.conquestaolympiads.com/	R16.00 +R16.00/ subject	6–13
Big Builders Education Programme Bricks Challenge Education Programme Galileo Technic Education Programme Robo Bricks Education Programme Robotics and Software Engineering Education Programme Young Engineers Birthday Young Engineers Holiday Club	Young Engineers (South Africa) http://www.young-engineers.com.au/big-builders-knex/	Unspecified	4–6 7–11 10–13 10–13 10–13 Unspecified Unspecified
Brilliants Programme Share and Dare Programme Bursary database for SET-related studies Details of 50 SET career paths proSET	National Science and Technology Forum (NSTF) http://www.nstf.org.za/youth/	Unspecified	Unspecified
FIRST LEGO League	FIRST Lego League South Africa http://www.fllsa.org/	R500.00/ team	9–13
Flying and falconry displays Interactions with birds	Eagle Encounters http://www.spier.co.za/visit/eagle-encounters	R65.00	Unspecified
Mobile Laboratories (aka BMW Centres of Excellence)	BMW MST Excellence Project https://www.bmw.co.za/en/topics/fascination-bmw/corporate-social-investment/education.html	Free	9–18

6 It should be noted that this is not an exhaustive list but is instead aimed at providing a comprehensive list of the types of activity that are available. Also, see Zulu, Juan & Luescher (2018) for a full discussion of South African Olympiads.

Table 3: A summary of activities (42) offered in South Africa			
Activity name	**Catalyst**	**Cost**	**Age range**
National Science Olympiads	National Science Olympiad http://www.saasta.ac.za/competitions/natural-science-olympiad/	R10.00–R30.00	10–18
Natural Science Olympiad National Science Olympiad National Schools Debates Competition 2018 AstroQuiz	South African Agency for Science and Technology Advancement (SAASTA)/National Research Foundation (NRF) http://www.saasta.ac.za/	R20.00–R25.00 R20.00–R25.00 Unspecified Unspecified	15–18 15–18 15–17 13
Olympiad Birthday parties Living Maths sleepovers Imagination Chapter of Cape Town (Kindergarten)	Living Maths http://www.livingmaths.com/	R5.00 R15.00/hour R330.00 Free	Unspecified
Olympiads Maths game kits	Foundation for English, Mathematics, Sciences, Sports and Innovation of South Africa (FEMSISSA) http://femssisa.org.za/	R5.00 R30.00–R55.00	6–18 7–18
Programming Olympiad Applications Olympiad	Institute of IT Professionals South Africa http://olympiad.org.za/	Free	Unspecified
Robot Design and Building	World Robot Olympiad http://www.wrosa.co.za/	R250.00	10–18
Science shows Workshops Industry visits Science camps	Osizweni Education and Development Science Centre https://ridgetimes.co.za/43501/osizweni-education-and-development-centre-excelled-in-the-previous-financial-year/	Free	6–18 13–18 13–18 13–18
South African Mathematics Challenge	South African Mathematics Foundation http://www.amesa.org.za/Challenge/Index.htm	R8.00/ R10.00/ R12.00	10–18
STEM Holiday Clubs & Robotics After-School Classes Robotics After-School Club	Live Kaizen https://livekaizen.co.za/	R220.00/day R180.00/lesson	5–10 6–15
Tenikwa Wildlife Awareness Centre	Tenikwa Wildlife Awareness Centre http://tenikwa.com/	Free for children under 6 years; R150.00 for children 6–12 years	Unspecified
UCT Mathematics Competition	University of Cape Town http://www.math.uct.ac.za/mam/outreach/competition/about/	Free	13–18
Visits to the Tswalu Kalahari Reserve, Northern Cape	Tswalu Junior Ranger https://www.tswalu.com/experiences/family	Unspecified	Unspecified

The activities covered the ages from four years to adulthood, with three catalysts focusing on children aged five years and younger, namely: (1) Young Engineers (South Africa); (2) Living Maths; and (3) STEM & Robotics for Kids. This latter period (five years and younger) is an important one (as discussed previously). The identified activities for this age group, that is, children before they enter Grade 1, are briefly presented in Table 4.

Table 4: Examples of activities for South African children aged five years and younger	
	Activity
Young Engineers	These programmes are recognised and have adopted an 'edutainment' approach. LEGO® brick kits are used which have been specially designed for the Young Engineers community and lesson plans. Young Engineers programmes were evaluated by the Center for Cooperation and Advancement and its website states that 'statistical tests show a clear connection between participation in our e² Young Engineers programs and success at school as well as the development of an arc of skills'. However, the two-page report from 2012 does not provide clarity regarding either the sample (including age, size and country) or the method – children were interviewed about their experiences but limited information is provided. The Big Builders Education Programme targets children aged four to six years. **Big Builders Education Programme:** Subjects include: • Physics principles: Basic principles such as balance and buoyancy; • The animal kingdom; • Biology: Natural pest control, pollination and symbiosis; • The universe; • Geometry; and • Transportation and traffic safety. **Big Builders Education Programme Values:** Development of the following skills: • Motor skills; • Social-interaction skills; • Self-expression ability; • Creative thinking; and • Broad knowledge.
Living Maths	Living Maths organises an annual Mathematics Olympiad for learners from Grade R to Grade 9. Participating learners receive a certificate and a Sharp calculator. The results are released each year as well as descriptive statistics, e.g. 171 529 learners took part in 2017 compared with 184 923 in 2016. This was one of only two catalysts, the other being the South African Mathematics Foundation, which focuses on mathematics.
Live Kaizen	Live Kaizen states that it includes activities for children from the age of five years. The STEM Holiday Clubs and Robotics After-School Classes seek to support and guide the innate curiosity of children. Live Kaizen also provides interactive learning sessions termed 'Hands-on Activities and Experiments' which were developed in collaboration with a psychologist, engineers and scientists. The sessions explore STEM topics while including experimentation, song and play.

Of the activities in South Africa, 28 were classified as low-access, with 14 being identified as medium-access and high-access. The vast majority of activities were mediated through an organisation (33), with a further nine being mediated through multiple agents. For example, the organisation Live Kaizen requires parents to pay fees and thus has low access. However, as shown by the Agastya International Foundation, organisations are also able to provide many activities that are freely available to assist at-risk children. There are 35 STEM centres within South Africa[7] which act as a hub that any member of the public can visit. Using central hubs in this way may also allow for activities that require fewer resources.

In addition, corporates such as BMW are able to provide much-needed funding. The BMW MST Excellence Project was initiated more than 20 years ago and deploys mobile laboratories to participating schools in South Africa. This project has been implemented in 37 schools that serve historically disadvantaged communities and thus targets at-risk children. The project impacts more than 40 000 learners and 148 teachers. Furthermore, the project follows up on children taking part and is able to show that such children perform better than the national average in both mathematics (13.5% better) and science (16.8% better), as well as achieve a higher pass rate (23.5% higher). Not

7 The science centres in South Africa offer a range of activities. However, these were not included in the typology, as they are already well known for their science-engagement activities which are supported by the DSI.

only is this project a worthwhile endeavour, but it also showcases the key role that monitoring and evaluation play in assessing the efficacy of the extracurricular STEM activities.

The most commonly identified strengths of the activities offered in South Africa were that they were interesting (33) and modern (30), followed by being explicitly related to the labour market (19) (Figure 18). An example of the latter is an online resource offered by the National Science and Technology Forum (NSTF) where careers in the STEM fields are listed. However, the information provided is limited. Careers are listed in categories (biological sciences, built environment, earth sciences, engineering, medical and health sciences, and natural sciences), with a brief description of each category. Once a category is selected, only the names of professions are listed, without any further description or information. This could, for instance, be substantially supplemented with information and requirements regarding entry into higher education. The Working to Advance STEM Education for African Women Foundation (WAAWF) is a good example. The WAAWF organises a variety of STEM activities and projects, including scholarships, teacher training, camps, outreach, code schools, and afterschool clubs and workshops. In addition, the WAAWF acknowledges that the people children have in their lives can make a significant impact on whether children enrol for STEM courses as a result of role-modelling or the encouragement of self-efficacy beliefs. The College to Secondary Outreach and Mentoring Programme includes a STEM Chapter Project: the organisation recruits, trains and equips university students to provide STEM tutoring, computer science training and mentoring for public schools in their communities. There are currently 19 STEM chapters in 11 African countries, including South Africa through the University of Pretoria and the University of KwaZulu-Natal.

Figure 18: Strengths of the identified activities in South Africa

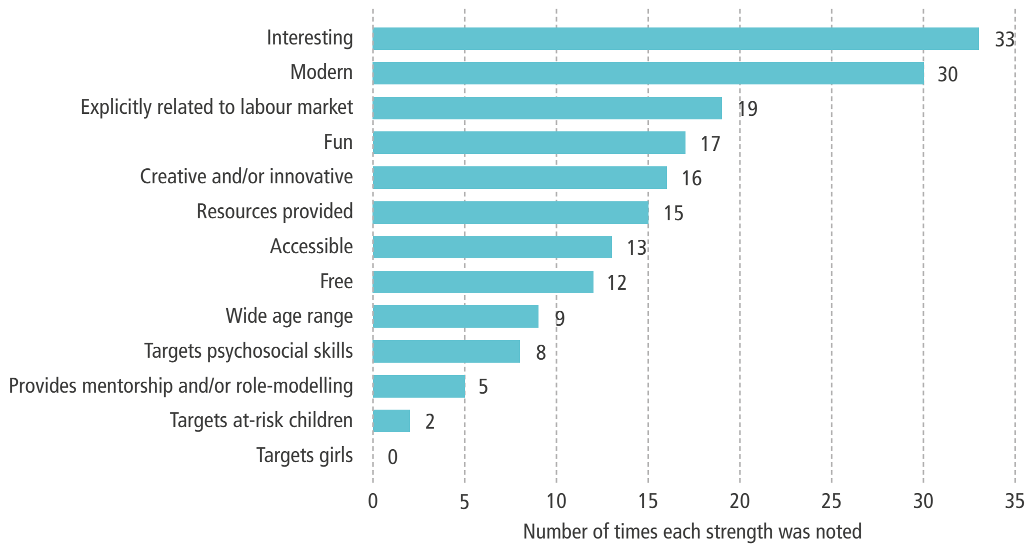
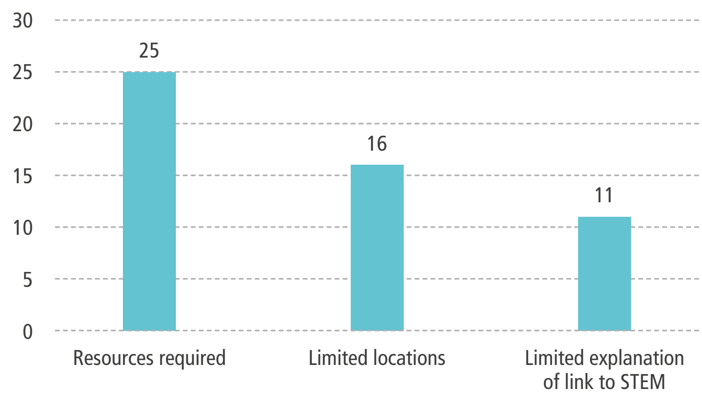


Figure 19 shows the most commonly noted weaknesses of activities in South Africa. These were similar to the weaknesses of the international activities which were explored.

Figure 19: Weaknesses of the identified activities in South Africa



Identified activities which listed ages were analysed according to the cognitive and psychosocial stages that they cover (Table 5). Many activities covered multiple ages and are noted more than once. The majority of activities targeted the higher developmental stages, that is, the formal-operational cognitive stage (23) and the adult psychosocial stage (23). This is not surprising, as these are the teenage years when the majority of children are expected to express an interest in a certain field of study. Many organisations and other mediators may therefore assumed that this is the most important stage at which to intervene. However, the earlier foundations are equally, if not more, important. Fewer activities focused on these stages, with no activities specifically looking at the sensorimotor cognitive stage or the infancy and early-childhood psychosocial stages. It should be noted that these may be covered through activities found online but which were not listed in the typology.

Table 5: Coverage of the cognitive and psychosocial stages

Cognitive development stages	Number of activities
Sensorimotor (0 to 2 years)	0
Pre-operational (3 to 6 years)	7
Concrete operational (7 to 11 years)	17
Formal operational (12 years up to adulthood)	23
Cognitive development stages	**Number of activities**
Infancy (1 to 1.5 years)	0
Early childhood (1.6 to 2 years)	0
Preschool (3 to 5 years)	3
School age (6 to 11 years)	9
Adolescence (12 to 18 years)	23

4.3.1 What can South Africa learn from international practices?

In countries considered high-income, there are few activities which could be deemed highly accessible. Nevertheless, an important takeaway from the activities offered by them is that universities have a crucial role to play in engaging children in STEM fields. Not only are universities able to fund initiatives, but they also have a vast student body that can engage with, inspire and tutor young children from many communities. For example, since many students are required to fulfil community-service obligations, a minor tutoring role could also be included. South Africa should therefore carefully consider activities which are implemented through universities and their students, such as those of the WAAWF. Universities are a valuable resource for children of all ages and one which is not being used to its full potential.

Low-income countries showcased the key roles played by Internet availability as well as by non-profit and similar organisations. The most influential theme, however, was the power of a united hub with far-reaching spokes. Having centralised access enables a wide-range of extracurricular STEM activities to be offered. In addition, it allows for incorporation of other supportive subjects such as the creative arts. Together with the 'hard sciences', such as mathematics, this provides holistic development that helps children succeed. Miller and White (2013) address this in their article for *The Conversation*:

> *Combining arts and science in the curriculum could be the answer. From science, students learn about sound methods for testing hypotheses, and about interpreting and drawing valid conclusions from data. From arts, they will also learn about developing arguments, and about understanding, moving, and changing the minds of diverse audiences.* (Miller & White, 2013)

This quote summarily indicates that both the sciences and the arts can be useful in assisting South African children in their development in STEM fields. As an example, the psychosocial skill of being able to see something from another perspective and then use this to shape your own argument is invaluable in many fields, including research, science teaching, and the health sciences. Furthermore, many future careers are becoming increasingly transdisciplinary and thus these skills are highly sought after by employers (Miller & White, 2013). Becoming an architect, for instance, requires technological, engineering and mathematical knowledge as well as a certain degree of artistry.

4.3.2 How can South Africa work with existing activities to foster a culture of STEM engagement?

This section has presented the wide range of activities which are currently available both within and outside South Africa. All extracurricular STEM activities which are available are beneficial to the development of a STEM culture, although in different ways. For example, a robotics course would have a direct impact on content knowledge and skills in that area, whereas a mentorship programme would have greater psychosocial influences. The authors note, however, that it is important that children are stimulated from as early an age as possible. The need for a well-built foundation cannot be overstated. Extracurricular STEM activities which provide opportunities for children even before they enter school should therefore be a key focus. Caregivers are therefore crucial in implementing extracurricular STEM activities and should receive assistance in mediating activities.

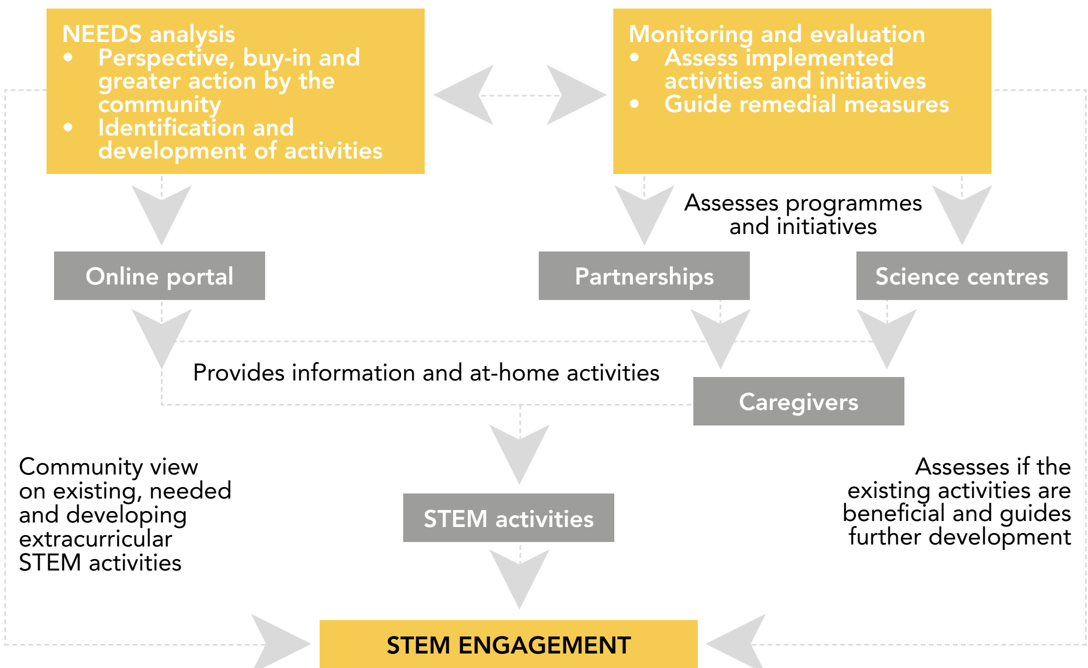
The strengths and weaknesses of the activities indicate that, while activities are indeed being implemented, they are not easily accessible for the most part. In other words, exciting and useful extracurricular STEM activities are not benefitting the children who most need them. The discussion and recommendations in the next section thus focus on ways to improve accessibility.

5

FIVE
DISCUSSION AND RECOMMENDATIONS

The previous section provided a descriptive analysis of extracurricular STEM activities implemented across the world. Given the positives and negatives associated with the various types of activity, the present report now considers what can best be adapted for and within South Africa. Therefore, this section discusses the above findings and makes recommendations for the South African context. The first recommendation relates to the need to first understand the status quo within South Africa. As this has yet to be done, the recommendations thereafter are guided by: (1) international best practice, and (2) the above findings, including the model cases. In doing so, the section answers the third and fourth research questions by proposing ways to adapt internationally offered STEM extracurricular activities to this context, as well as increase access to them. While reading this section, it is important to bear in mind that the recommendations should not be considered in isolation. Each recommendation builds upon, or supports, the others so as to create a coherent plan for moving forward. Therefore, based on the findings, the recommendations together indicate how to create a culture of science engagement within South Africa (Figure 20).

Figure 20: How each recommendation works together to facilitate a culture of STEM engagement



5.1 THERE SHOULD BE MONITORING AND EVALUATION OF STEM ACTIVITIES

Monitoring and evaluation are a crucial part of ensuring that an activity is beneficial for children, that is, evaluating its reach and assessing whether the activity is cost-effective. Limited information was found, both nationally and internationally, on the monitoring and evaluation of the identified activities. Evidence of monitoring and evaluation was limited to annual reports. Several activities were also monitored in terms of how many children had taken part in the activity and how many exposures had taken place. Activities involving competitions, such as the Olympiads, were also monitored and evaluated in terms of achievement and other factors such as demographics. However, it is difficult to monitor and evaluate activities which are available online or which are not subject to a specific time, place or number of children.

5.1.1 Recommendation 1

It is recommended that systematic monitoring and evaluation take place, including a NEEDS analysis of South African communities in relation to extracurricular STEM activities. It is crucial to understand the community's perspective on what would assist in terms of access and quality of extracurricular activities. Not only would this promote the development of activities that are most likely to be beneficial, but it would also gain buy-in from the community and engender greater action by its members. The authors do realise, however, that each context is unique, but a diverse sample would be able to identify key needs in order to guide later initiatives.

A NEEDS analysis as well as monitoring and evaluation are also important for other reasons. Firstly, not all extracurricular STEM activities are advertised or well known and a NEEDS analysis would assist in identification, as it would utilise information from the community. Linked to this, a NEEDS analysis would also allow for the development and promotion of diverse activities which are relevant and accessible to children in various contexts. Finally, monitoring and evaluation would provide an indication of whether implemented activities are targeting the correct age group in terms of cognitive and psychosocial stage (Appendix 1). Owing to the contextual challenges of South Africa, some children may not have the foundational knowledge and skills necessary to critically engage with STEM content. Activities for South African children may therefore have to include remedial measures as well as the introduction of new concepts. The use of monitoring and evaluation thus relates to the third recommendation, namely that ongoing activities should take place at hubs such as science centres. A centralised location would allow for pre- and post-assessments to determine the efficacy and appropriateness of a given activity as well as what remedial measures are necessary.

5.2 CENTRALISED FACILITATION SUPPORTS AWARENESS AND ACCESS

A central facilitating organisation would be able to alert children, parents and teachers to the appropriate types of resources for STEM activities so that they can find and use them. An organising body acting in this way would then be the *catalyst* between children and STEM activities. For example, organisations would be able to centralise resources, funding and activities so that more is available to a wider audience. The Department of Science and Innovation (DSI) has already undertaken such initiatives through its Science and Engagement Strategy (SES) and is therefore an example of such an organisation. However, a catalyst can also be a person, school or science centre and have a broader reach on the ground.

As highlighted in the findings section, the Agastya International Foundation is also an excellent example of such an organisation. This organisation has effectively created a centralised location that provides a wide variety of activities which allow children and other role players to engage with STEM fields. What is important, here, is that it not only makes resources available for all ages (e.g. individuals can visit its centres), but also takes STEM extracurricular activities to all areas within India. Its diverse ways of entering communities furthermore capitalise on the principles of social constructivism. By providing children with the means to interact with the content, their peers, mentors, teachers and parents, the foundation is allowing them to learn effectively and in a way that takes into account language and culture. Through this, it acts as a catalyst to inspire STEM engagement where, previously, there were only gaps. It is recommended that this type of central organisation together with its activities be initiated within South Africa. Although this would be a long-term undertaking, the following two recommendations can be a starting point, together with those regarding location.

5.2.1 Recommendation 2

It is recommended that an online STEM portal be developed. This would act as a virtual hub where STEM resources could be presented to children, parents and teachers in an easy-to-understand and accessible format. Such a portal would provide unique opportunities for South African children, as resources could be provided in the different languages and so inspire interaction with a wider community. This platform should be made accessible through smartphone devices. Examples of the information which should be included are: STEM activities – both those which are available online and those which are undertaken by organisations within South Africa; STEM information; STEM academic and career opportunities; as well as ways for volunteers to become involved. Activities could be tailored to different contexts so that children can apply what they are learning to what is around them. It is important that these resources be printable or be distributed in hard-copy format so that mediators who do not have Internet access are able to use them as well.

This portal would also act as a means to promote DSI–organisation and organisation–organisation interactions. Although a wide variety of activities is already available within South Africa, such activities are largely independent in nature. By unifying key extracurricular STEM organisations and activities it may be possible to ensure that all children at least have the opportunity to participate in certain activities in order to support STEM engagement. This would be possible through aspects of unification, including funding, monitoring and evaluation activities. Ultimately, together with the third recommendation regarding links with the science centres, this would serve to move towards building an organisation such as the Agastya International Foundation.

5.2.2 Recommendation 3

The third recommendation is that the science centres be considered a key partner and be organised as a unit. The available extracurricular STEM activities at the centres should be aligned with the online STEM portal so that if children want to recap or extend an activity they were involved in at the centre, they will be able to do so at a later stage. This enables monitoring and evaluation of a broad sample group (see the first recommendation) and creates a physically central place where schools, parents and children can access STEM information and hands-on activities.

Use of the science centres as a cohesive unit would also allow extracurricular STEM activities to incorporate remedial measures. Using language as an example, information and activities could be translated into multiple languages and used within all centres. In addition, science-centre employees could be trained to simultaneously facilitate language development while delivering STEM content information and mediating project-based inquiry. Although the studies were performed with teachers, research by, for example, Buxton, Lee and Santau (2008) as well as by Moje, Collazo, Carrillo and Marx (2001), illustrate how this can be done. These studies indicate that the diverse linguistic and cultural backgrounds of children can be incorporated in the learning environment in order to link their own experiences to what they are learning and so enhance their knowledge. This is dealt with further in the sixth recommendation.

5.3 LOCATION IS AN IMPORTANT CONSIDERATION

South Africa has a landscape comprising urban, semi-urban and rural areas. Living in a sparsely populated area can limit children's access to STEM activities. Some of the South African science centres and museums, such as the Durban Natural Science Museum, have mobile facilities which are able to reach more children, and particularly those in more remote locations who are unable to visit these institutions.

5.3.1 Recommendation 4

It is recommended that the current organisations and their satellite activities be promoted, as they play a vital role in reaching all South African children. This would link to the first and second recommendations where an online portal and increased interaction between organisations would allow for coordinated efforts. In addition, although there are already activities taking place in science centres, museums, universities and other organisations, there are further innovations which could be implemented to improve access and STEM engagement. For example, teaching promising children how to illustrate scientific principles to their peers, as has been done by the Agastya International Foundation, can be an effective strategy. To enhance their success, these organisations should therefore be supported through the provision of resources and the marketing of their current activities. Moreover, they should be supported in promoting innovation and expanding their activities.

5.3.2 Recommendation 5

It is important to note that there are also initiatives being undertaken which are unrelated to education. Partnerships can therefore also be formed between organisations offering STEM activities for children and organisations which aim to reach rural areas for other purposes. For example, a partnership with mobile clinics may allow for providing a combination of health-care and hands-on STEM activities in one visit to rural areas where children are not often exposed to extracurricular STEM. Another example would be a partnership with the science centres to provide STEM camps for South African children. STEM camps are widely available internationally; they cover different ages and involve activities allowing for both physical and mental engagement. Linked to the sixth recommendation, these types of camps can be supported by the DSI and could even be taken to South Africa children living in rural areas. Another possibility is that of using community centres. Resources and trained mediators could be used to engage children in activities such as games, quizzes or competitions after school or on weekends. Mediators and resources could, for example, be provided by universities or the DSI. These types of partnership may also be assisted through interaction on the online portal.

5.3.3 Recommendation 6

As the social constructivism theory emphasises, being able to relate new information to background knowledge and experiences enables learning. It is thus recommended that the DSI and organisations develop STEM activities that are specially intended for different locations within South Africa. For example, learning about medicinal plants or technological advances within their area would have value for children. Not only would this promote learning and STEM engagement through participation, but children would also be able to see how such knowledge is applicable and how they can be involved. This changes perceptions about the type of person that can work in STEM fields. Children who are able to visualise themselves as working within STEM will be more likely to aspire to these types of careers.

5.4 COMMUNICATION AND PROMOTION BY THE DSI IS NECESSARY

There are many excellent initiatives and activities currently available in South Africa. However, without promotion, many individuals remain unaware of their existence and this precludes their children from participation. Even if they are knowledgeable about the activities available, a lack of communication about how to become involved or what is required might equally bar many children from participating. Through a variety of avenues, such as school notices or local newspaper advertisements, the DSI can create awareness of the available extracurricular activities. The online portal could assist by ensuring that the DSI has an up-to-date inventory of all available activities across the country.

Communication by the DSI can also be instrumental in making caregivers aware of their role. As noted throughout this report, the early ages are crucial in developing the foundational knowledge and skills that later lead to STEM engagement. If caregivers underestimate their role in their child's development, this can have detrimental results. Sensory play, as an example, can be performed with minimal resources. Caregivers can also assist development in a myriad of other ways which, though they may seem small, can have a huge benefit. These include conversing with their children in order to stimulate language development or encouraging curiosity about the world around them.

5.4.1 Recommendation 7

It is recommended that the DSI use various means of engaging with schools, organisations and parents in order to provide further information beneficial to children. Not only can this be through the online portal, but also through existing channels such as television, radio, newspapers or notices sent directly to schools. The science centres can also create specific programmes for caregivers in order to educate and create interest in STEM fields. Although the National Curriculum Framework (NCF) already notes that caregivers are crucial (DBE, 2015), the DSI can initiate a campaign that specifically develops scientific literacy among caregivers. This will enable caregivers to enter into STEM-related dialogue with their children, assist them with their homework, and foster interest.

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CONCLUSION

Science, Technology, Engineering and Mathematics (STEM) are key areas for a country's development, and therefore promoting knowledge, interest and involvement in these areas is crucial. This is particularly important in South Africa as the country transforms into a knowledge-based economy concomitant with different workforce requirements. The use of extracurricular STEM activities is one way of promoting a culture of STEM engagement, and therefore this report provided a detailed analysis of activities offered both nationally and internationally for children from birth to 15 years of age. The report also explored how access to these activities can be improved for South African children.

The report identified a wide range of activities which covered all ages, with 42 activities available within South Africa. It is a positive finding that there are activities for all ages, as progression through the STEM pipeline is just that – a progression. Knowledge and skills build on each other and it should therefore be ensured that children have adequate foundations on which to build. Children who are precluded from participation may not see themselves as 'scientists' or may struggle later on in their academic journey, thus preventing them from gaining valuable skills and/or pursuing a STEM career. Recommendations related to this aspect of inclusion focused on increased communication by the DSI regarding the key role played by caregivers and on the effect of early-age activities.

Also related to accessibility issues was the fact that there were few activities which could be evaluated as being broadly accessible, which is concerning. South Africa continues to deal with the social injustices of the past and it is therefore important that children are provided with equal opportunities to develop their skills and pursue their interests. Several recommendations thus related to making these existing activities accessible, including: a centralised hub for organising activities and interaction between organisations in order to make participation a reality for all children; taking activities to rural areas; and communication by the DSI promoting available activities. It was also recommended that regular monitoring and evaluation be included in all STEM initiatives and activities, as this would ensure that (1) the activities themselves are beneficial for South African children, (2) the activities provided are appropriate for, and tailored to, the unique South African contexts, and (3) the needs of South African children are being met, which may require the inclusion of remedial measures.

This report, it is submitted, therefore makes a substantial contribution to the implementation of strategies and plans by the DSI to promote public knowledge about STEM subjects, scientific literacy, and engagement with policymakers.

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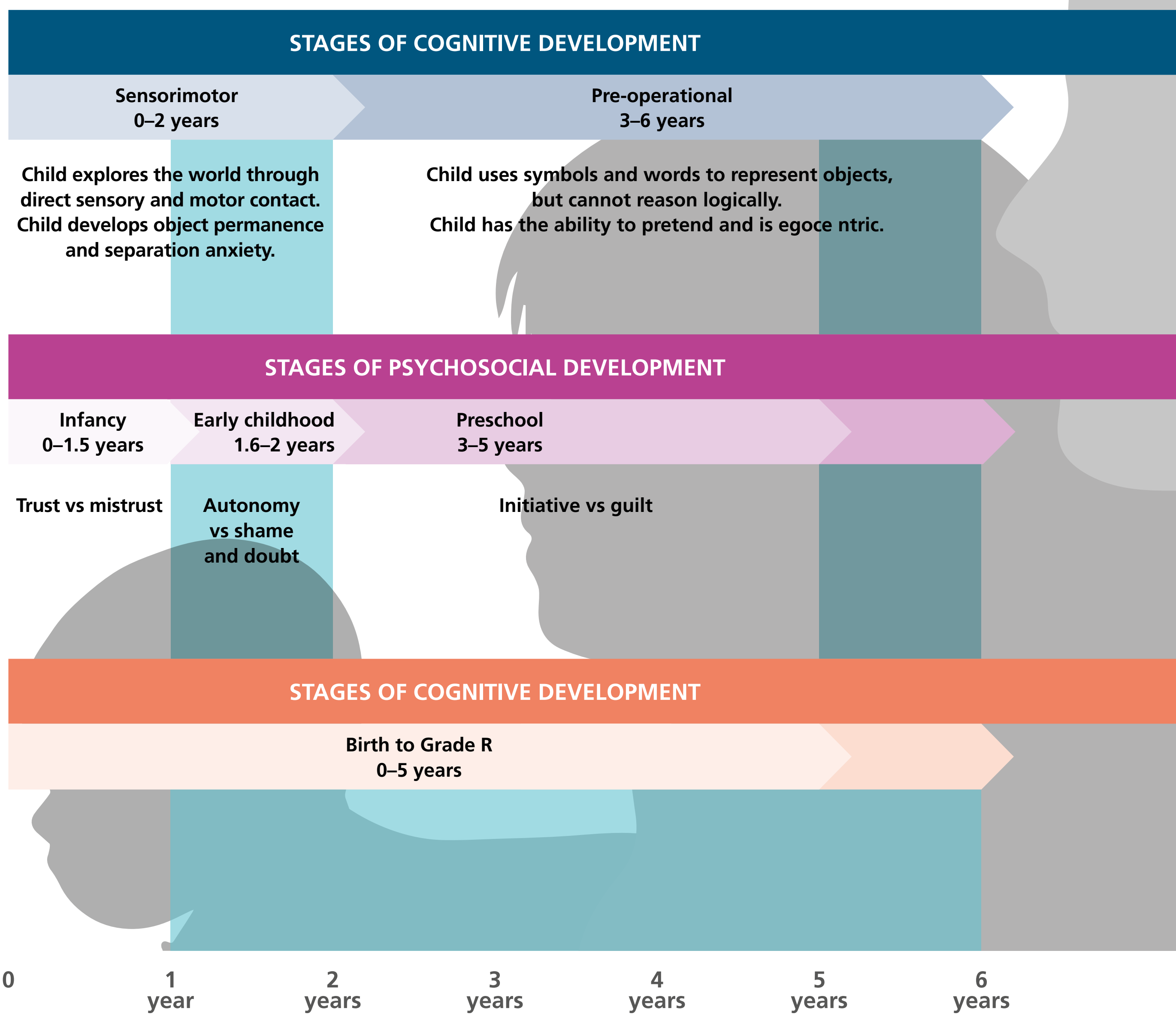
APPENDIX 1
STAGES OF CHILD DEVELOPMENT



STAGES OF COGNITIVE DEVELOPMENT

Concrete operational
7–11 years

Learner can think logically about concrete objects, which enables them to add and subtract. The child also understands conv ersations.

Formal operational
12–adult

Learner can reason abstractly and think in abstract terms.

STAGES OF PSYCHOSOCIAL DEVELOPMENT

School age
6–11 years

Industry vs inferiority

Formal operational
12–adult

Adolescence
12–15 (18) years

STAGES OF COGNITIVE DEVELOPMENT

Grades 1 to 3
6–9 years

Grades 4 to 6
10–12 years

Grades 7 to 9
13–15 years

7 years | 8 years | 9 years | 10 years | 11 years | 12 years | 13 years | 14 years | 15 years

APPENDIX 2
AUTHOR BIOGRAPHIES

MS JAQUELINE HARVEY

Harvey's work focuses on neuroeducation and psycholinguistics. Research in this area will assist in attaining transformation of the South African education system where inclusion remains an overarching goal. Her PhD project aims to explore the relationships between working memory, academic reading, and academic achievement in first-year online distance e-learning tertiary students. Harvey is the co-author of several journal publications related to the impact of language on learner achievement. She is a member of the Health Professions Council of South Africa (HPCSA) as an intern psychologist.

DR ANDREA JUAN

Juan is a Research Specialist with research interests in analysis of policymaking and implementation within the South African education sector. Beyond this, she is extensively involved in the evaluation of South African learner achievement in the Trends in International Mathematics and Science Study (TIMSS). She is particularly interested in the contextual and non-cognitive factors, such as attitude and self-efficacy beliefs, which impact academic achievement. Juan's publication record illustrates her commitment to communicating the results of her research to a wide range of stakeholders.

MS SYLVIA HANNAN

Hannan is a Senior Researcher interested in the public relationship with science, as well as Science, Technology, Engineering and Mathematics (STEM) capacity building, and the promotion of STEM for learners. She also focuses on basic education, predominantly on non-cognitive and contextual aspects. Her publications relate to issues of school climate, such as bullying, and learner attitudes, science achievement, and the relationship between early learning activities and later achievement. In addition, she has worked on two articles related to her Masters dissertation, focusing on the dominant agendas of sustainability and urban regeneration, through the development of mega-projects.

MS NCAMISILE ZULU

Zulu's research focuses on Black women, identities, resilience, empowerment and agency within the South African context. Zulu writes on father absence and academic performance among Black women. She also writes on Black women within the academia and young children and youth into Science, Technology, Engineering and Mathematics (STEM) subjects and careers. She is currently completing her PhD, which focuses on the discourses of Black women professors from a South African context at the University of KwaZulu-Natal.

DR VIJAY REDDY

Reddy is a Distinguished Research Specialist at the Human Sciences Research Council (HSRC). She coordinated the South African component of the Trends in International Mathematics and Science Study (TIMSS) in 2003, 2011, 2015 and 2019, and has published extensively on TIMSS. She led the multi-year research project Labour Market Intelligence Partnership (LMIP) to support the Department of Higher Education and Training in building the Skills Planning Mechanism. She has conducted research and published in the area of Public Understanding of Science.

This research report explores and documents the existing landscape of extracurricular Science, Technology, Engineering and Mathematics (STEM) activities and initiatives for young children. The investigation included both South Africa and international countries so as to gain insight across diverse contexts.

We categorised 292 STEM activities, both within South Africa and around the world, into a typology which included the country where the activity takes place, who can access it, STEM subject area, mediator of the activity, its cost, and its strengths and weaknesses.

We found that the activities most often covered a combination of STEM activities. The most common strength of these activities is that they are interesting, modern and fun. The main weakness is the high participation fee which precludes many children from accessing these activities. Our recommendations focused on ways to increase access.

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