NATIONAL SCIENCE AND TECHNOLOGY FORUM
pro*SET*/NSTF DISCUSSION FORUM: STEM EDUCATION AND MATHS REFORM

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SUMMARY OF POLICY ISSUES THAT EMERGED FROM THE pro*SET*/NSTF DISCUSSION FORUM ON STEM EDUCATION AND MATHS REFORM

In the drive for quantity in the field of STEM education, it is tragic that in the school system as a whole only 30% of students reach grade 12. There is only 30% participation in physical science at matric level, and the pass rate is only 40%. In the university system, only 30% of students complete their degree in the prescribed time. Universities are failing their stakeholders, and this disappointing throughput cannot be allowed to continue.

No nation is better than the quality of its education.

Both quality and quantity are national needs, and both are essential. However, national resources are very limited and it is therefore essential to prioritise. It does not make sense to keep making small corrections; we need to go to the source of the problem.

South Africa needs to promote a culture that good quality mathematics and science teachers are wanted, have a future and will be supported and cherished.

Department of Basic Education

- The overall aim, objectives and proposed activities for the revised MST Education Strategy (2019–2030) are endorsed.
- The Department of Basic Education's Ministerial Task Team (MTT) on MST needs to identify the priorities for enhancing quality and quantity in STEM education, and then stick to them.
- It is difficult to attract high-performing students to the teaching profession, and there is a need to look at incentives for MST teachers. The remuneration packages of MST teachers need to be revisited.
- Provinces are at different levels, and a separate strategy is required for each province.
- The disparity between urban and rural schools requires differentiated interventions for rural schools.
- Subject advisers have a role to play in improving the depth of knowledge.
- The development of meaningful teacher guides is critical.

Teachers

- The quality of the system cannot exceed the quality of its teachers. The teacher is at the centre of the delivery of quality STEM education.
- All other problems with STEM education are secondary to the problem of teacher quality and quantity.

Teacher education

- In order to ensure more and better MST teachers, initial teacher education must be improved. Increased funding to universities for BEd courses in MST education, attractive student bursaries, university-based short courses and special courses for subject advisers are all initiatives that could be beneficial.

Teaching approach

- In the drive for high marks, learners and students tend to be taught to pass examinations rather than to understand concepts.
- Space needs to be established in classrooms to allow learners to become autonomous and to learn to think.

Mathematics

- We need to look at ways to make mathematics fun, attract students to the subject, and build a nation that loves mathematics. The fun of learning mathematics has been lost and needs to be retrieved.
- The basics of learning mathematics should be laid down early in life through development of the recognition of numbers and sequences.
- South Africa needs to reflect on the reform movement in mathematics education.

Physical science

- Physical science must be taught by those who have been educated and trained in the discipline.

Engineering and technical science

- A re-conceptualised technical science curriculum could serve many who do not want to do technology subjects but have an interest in this domain.
- There is an opportunity to introduce more engineering education. Engineering can unify both STEM and STEAM (science, technology, engineering, art and mathematics) subjects without the addition of large volumes of content. The engineering design process places emphasis on the process and design of solutions.

Interventions

- It is essential to prioritise and to avoid spending on ill-conceived or poorly prepared brief interventions.

Role of the NSTF

- pro*SET* should discuss how they could help to lift the low ceiling of STEM education.
- The NSTF should consider awarding Oscars to MST educators.

OPENING AND WELCOME

Ms Jansie Niehaus (Executive Director, NSTF) welcomed everyone to the Discussion Forum. The NSTF is a member organisation representing more than 100 organisations with a mandate to engage with government policy. The NSTF plays a powerful role in consultation and lobbying on policy matters. In partnership with South32, the NSTF also makes awards to recognise teams, organisations and individuals for outstanding contributions to science, engineering, technology and innovation.

This Discussion Forum is aimed at collecting feedback from both experts and non-experts and is organised under the auspices of pro*SET*, a sector of the NSTF representing professional bodies and learned societies. Whilst it is impossible in one day to identify all the issues, it was hoped that it would be possible to flag the key issues, which would be fed back to government, particularly to the Department of Basic Education.

The Discussion Forum would be followed by a two-day intensive workshop, led by the Ukuqonda Institute, on what is wrong with science, technology, engineering and mathematics (STEM) education.

Mr Dawie Botha (chairperson of pro*SET* and representative of the South African Academy of Engineering) suggested the view that the fun of learning mathematics has been lost and needs to be retrieved. Mathematics is everywhere and numbers are everything, and it is important to lighten up and show the fun in mathematics. Some examples of everyday exposure to mathematics include that eggs come in 12s or 6s, gloves have five fingers, shoes are sold in pairs, people weigh themselves in kilograms, blood pressure is shown as a number, traffic lights come in threes, tables have four legs but milking stools have three

Many studies have shown that learning mathematics is good for the brain and that the basics should be laid down early in life through development of the recognition of numbers and sequences. The Fibonacci sequence, a numerical sequence of spirals, and the golden ratio found in buildings and artwork are mathematical concepts that occur in many everyday places such as the centre of the sunflower.

Let us look at ways to make mathematics fun, attract students to the subject, and build a nation that loves mathematics.

Prof Piet Human (Ukuqonda Institute) explained that the schooling system in South Africa is different from many other countries. South Africa has 12 years of schooling prior to university, whereas learners in most other countries one more year of schooling. This means that first-year students at South African universities are at a disadvantage. The Ukuqonda Institute was established in the early 1990s to provide a bridging facility for students from rural areas and disadvantaged schools. Several thousand students have passed through the institute, and several hundred are now qualified scientists and engineers.

The intention of the Discussion Forum was to look for solutions rather than problems and to reflect on the reform movement in mathematics education. This ambitious movement started some 40 years ago. It considerable challenges to implementing, but works very well where it has been implemented. International experts have been invited to assist with the challenges that South Africa faces in reforming mathematics education and to advice on possible remedies.

SCIENCE OSCARS AND MATRIC PASS RATES: QUALITY AND QUANTITY IN STEM EDUCATION

Prof John Bradley, Honorary Professor, Department of Education, University of the Witwatersrand

The focus of this meeting is quantity and quality in STEM education, which is a challenge across all the mathematics, science and technology (MST) subjects and affects most professions and indeed the nation.

In stock of the current state of STEM education, it is important not to overlook that there are quality outputs. This quality is evident in the public recognition of excellence, for example, through the Science Oscars coordinated by the NSTF and the awards made by professional societies. The Department of Science and Technology published a book entitled *What a Great Idea* thathighlights inventions that originated in South Africa. The publication is inspiring to both students and teachers.

In the drive for quantity in the field of STEM education, it is tragic that in the school system as a whole only 30% of students reach grade 12. There is only 30% participation in physical science at matric level, and the pass rate is only 40%. In the university system, only 30% of students complete their degree in the prescribed time. Universities are failing their stakeholders, and this disappointing throughput cannot be allowed to continue.

Many people at all levels are trying to reduce the wastage in the MST education system. There are numerous activities aimed at reducing the matric failure rate, including in-service teacher training and support, winter schools, matric crash courses and teacher compliance initiatives. The effort to improve participation rates in SET includes science fairs, science centres and achievement awards.

Why is the participation rate in physical science so low? There is a need to focus on teachers. Learners are very aware of the importance of physical science for careers in SET and are also aware of the employment possibilities in this domain. However, learners are also aware that the pass rates in these subjects are low and that the teachers might not be very inspiring. They therefore tend to choose life sciences instead. Physical science teachers in many schools are qualified to teach life sciences but are often persuaded by desperate school principals to teach physical science. Furthermore, learners are warned against doing mathematics where the pass rate is low and are advised to take mathematics literacy instead, despite mathematics being a requirement for admission to engineering or science courses at tertiary level.

Good quality physical science teachers are critical to addressing both the pass and participation rates. It is essential to recruit teachers who understand physical science and are passionate about both the learners and the subject. Loving the subject depends upon content knowledge.

Initial teacher education in physical sciences is mainly via a BEd (Bachelor of Education) degree, which is a four-year professional degree that includes teaching experience. Entry requirements for this degree are lower than for other professional degrees, and entrants are often not as well prepared in science. New graduates specialising in physical science tend to have modest subject knowledge, and mediocre new teachers will not improve the pass and participation rates. In order to improve physical science teaching at schools, improvements have to be made at university level.

Whom does the physical sciences curriculum serve? The Council for Quality Assurance in General and Further Education and Training (Umalusi) has expressed the view that the curriculum is traditional, prescriptive, teacher-centred and content-based, all of which are damning words from the perspective of educators. It is a very old-style curriculum, which is unsatisfactory in terms of both quality and quantity and neglects recent topics that could inspire. This deserves serious debate, particularly regarding what the overarching goals should be. Consideration should also be given to world trends towards science for all, as exemplified in the proposals of the US National Academy of Sciences and the UK Association for Science Education.

A further area that requires attention is the 'T' in MST education. There is very little understanding at the official level that the 'T' stands for technology education and not information and communications technology (ICT). Technology is offered to all learners in grades 4–6 as natural sciences and technology, and in grades 7–9 technology is separated from natural sciences. In the grades beyond that, there is hardly any technology in the school curriculum.

Specialised technology subjects such as electrical technology are offered to a small minority in the Further Education and Training (FET) band and restricted to those who are able to pass technical sciences. Technical science is based on physical science but is not well conceived. A re-conceptualised technical science curriculum could serve many who do not want to do technology subjects but have an interest in this domain.

Both quality and quantity are national needs, and both are essential – it is not an either/or situation. However, national resources are very limited and it is therefore essential to prioritise. The Department of Basic Education's Ministerial Task Team (MTT) on MST needs to identify the priorities for enhancing quality and quantity, and then stick to them.

Some quotes from the literature that are relevant to the situation in South Africa include:

- 'Teachers cannot effectively teach what they do not know themselves.'
- 'No education system can out-perform the quality of its teachers.'

- 'Weak teacher knowledge creates a low ceiling which South Africa cannot circumvent.'

The message is clear. All other problems are secondary to the problem of teacher quality and quantity.

In order to ensure that we have more and better MST teachers, we must improve initial teacher education. Increased funding to universities for BEd courses in MST education, attractive student bursaries, university-based short courses and special courses for subject advisers are all initiatives that could be beneficial.

It is essential to prioritise and to avoid spending on ill-conceived or poorly prepared brief interventions. The development of meaningful teacher guides is critical. pro*SET* should discuss how they could help to lift the low ceiling, and the NSTF should consider awarding Oscars to MST educators.

Discussion
Question (Prof Hamsa , University of the Witwatersrand): Does the education system nationally have the capacity to impact on the ceiling created by teacher knowledge?

Response: I do not have a national overview of university capacity and am therefore not equipped to answer that question.

Question (Dr Mampone Seopa, Limpopo Department of Education): What is your opinion of the quality of training at the former teacher training colleges compared with the current university system?

Response: It is not easy to compare, but quality does depend on which college was attended. Even now, some university graduates are better than others. However, it does not make sense to keep making small corrections; we need to go to the source of the problem. It is true that even a bad curriculum can be improved by a good teacher, so the focus should be on producing good teachers. We need to use all available capacity, wherever it may be, to raise the quality of new teachers.

Question (Dr Gerda Botha, SA Council for Natural Scientific Professions): Can South Africa hope to improve the STEM education system alone, or should we draw on the experience of other countries? Have any other countries dealt with this problem, and are there any other models?

Response: Everything should be explored including the role that subject advisers can play in improving the depth of knowledge. Foreign intervention can play only a minor role. South Africa has to build its own capacity throughout the system and promote a culture that good quality mathematics and science teachers are wanted, have a future and will be supported and cherished.

Comment (Angela James, University of KwaZulu-Natal): We need to look at the whole system. We prepare teachers for the classroom, but when they take up posts at schools they are told not to try to change the system. We need to question the role of subject advisers, the Department of Basic Education and get right what happen in schools.

Comment (Waldo Viljoen, SA Institute of Industrial Engineers): Being married to a mathematics teacher, I am able to observe the struggles in schools. From my work in industry, it is clear that increasing numbers of teachers are leaving and moving to other professions. It would seem that this is mainly because of remuneration. In other countries emphasis is put on teachers' packages.

Response: There is certainly much that is wrong in the system. Addressing the issues will not be easy, and we will have to prioritise.

THE REVIEWED NATIONAL STRATEGY FOR MATHEMATICS, SCIENCE AND TECHNOLOGY EDUCATION IN GENERAL EDUCATION AND TRAINING (GET) AND FURTHER EDUCATION AND TRAINING (FET) (2019–2030)

Ms Elspeth Mmatladi Khembo, Project Manager, MST Conditional Grant, Department of Basic Education

In 2001 the revised National Strategy for Mathematics, Science and Technology Education in GET and FET was developed but did not include an implementation plan. In 2005 an implementation plan

was developed, and in 2011 the National Development Plan (NDP) was published which set ambitious targets with regard to MST. In 2012 the Curriculum Assessment Policy Statement (CAPS) was developed, followed in 2013 by the report of the MST Ministerial Task Team (MTT). In 2014 the MST Integrated Framework, based on the recommendations of the MTT, was initiated and included inputs from the departments of Science and Technology, Basic Education, and Higher Education and Training. The MTT highlighted the differences between the provinces. Any strategies have to take into account that progress and needs vary between provinces. In effect, given the significant differences between the provinces, we have nine countries in one country to deal with. This provides the background to the present situation of education in South Africa.

It is important to know where we have come from. Former President Mbeki highlighted the need for mathematics and science education in order to boost the economy of the country, with a particular focus on girl learners and on attracting learners to become teachers. When the implementation plan was developed in 2005, the four pillars identified for attention were the shortcomings of dedicated schools, teacher support, teacher development and resource provision.

The NDP of 2011 set ambitious targets. It called for an increase in the number of students eligible to study mathematics and sciences at university to 450 000 by 2030. The NDP also called for mathematics achievement to be at 50% or above. In 2017 only 22.2% of learners achieved this target in mathematics, and only 26.9% in the physical sciences.

The NDP target for literacy, numeracy, mathematics and science outcomes was that 90% of learners in grades 3, 6 and 9 should achieve 50% or more, as measured by the Annual National Assessments (ANA). The 2014 results showed that for grade 3 the average was 55.5%, with 64.5% of learners achieving over 50%; for grade 6 the average was 43.1%, with 35.4% of learners achieving over 50%; and for grade 9 the average was 10.9%, with only 2.9% of learners achieving over 50%. It is recognised that ANA is not a suitable measurement system and a new assessment method is being developed that will replace the current ANA method. It will be challenging to meet the NDP targets.

The NDP also calls for improved performance in international comparative studies, and in this respect the Department of Basic Education aims to improve South Africa's average results for Southern and East African Consortium for Monitoring Educational Quality (SEACMEQ) tests for grade 6 languages and mathematics from 495 to 600 points by 2022. There will also be a focus on improving average grade 8 scores in the Trends in Mathematics and Science Study (TIMSS) from 264 to 420 points by 2023. It is proposed that grade 8 scores in the TIMSS round closest to 2030 should reach 500 points.

There have been small gains in the 2014 TIMSS achievements, and some good work is being done, but the differences in performance levels between provinces are still cause for concern. There have also been some small gains in SEACMEQ scores, but there is a need to raise the quality of teachers. Provinces are at different levels, and a separate strategy is required for each province. It is also clear that the disparity between urban and rural schools requires differentiated interventions for rural schools.

In 2013 a Ministerial Task Team was appointed to conduct an investigation into the implementation of the National Strategy for Mathematics, Science and Technology Education in GET and FET (2001). The recommendations, which were presented in June 2013, included a review of the national strategy to align with the sector plan and the NDP goals; the establishment of a dedicated MST office in the Department of Basic Education; a focused teacher development and support programme; the establishment of norms and standards for resource provisioning and management; and strengthening and realigning of the Dinaledi Schools Project .

The NDP is critical to the revision of the MST strategy. A model has been developed that places the outer and encompassing ring at the highest level of the NDP, prioritising issues of unemployment and the eradication of poverty, and the classroom in the centre. The vision of the revised strategy is to achieve inspired learners equipped with MST competencies to meet the growing demands of a changing world. The mission for the revised strategy is to increase learner participation and improve the performance of learners in MST from birth to grade 12. The mission is based on four key activities: updating curriculum content, developing teacher support, provision of educational material and training, and mobilising partnerships to enhance learning outcomes.

Strategic aims, each with goals and output targets, have been developed based on the premise that the classroom is at the centre, with a relevant curriculum taught by competent teachers:

- Strategic Aim 1:To provide quality learning for all learners through relevant MST curricula and interventions
- Strategic Aim 2:To improve teacher demand, supply, utilisation, development and support
- Strategic Aim 3:To improve provision, management and effective utilisation of resources
- Strategic Aim 4:To improve partnerships to enhance quality MST education.

The revised MST Education Strategy (2019–2030) is informed by the MTT and other departmental issues. All interventions and teacher guides are research based. The focus is on the classroom and the competency of teachers. The process of implementing the strategy has short, medium and long term goals.

The key activities for the short term (2018–2021) include: the establishment of an MST directorate, national and provincial implementation plans, field testing of the strategy in selected districts, development of a framework for strengthening the curriculum, a conceptual framework for a comprehensive teacher development programme, relevant provincial intervention programmes, guidelines and norms for MST infrastructure and resources, and the establishment of an accord with key stakeholders.

The activities for the medium term (2022–2025) include: full-scale implementation of a teacher development programme, review of the MST curriculum in line with the framework, review of the targets against the plan, full-scale implementation of the MST education strategy, mechanisms to attract and retain quality MST teachers, and fully equipping all schools with the necessary resources and capacity.

The activities for long term (2026–2030) include: competent and qualified MST teachers in every classroom, monitoring and evaluation of MST strategic actions against outputs, continuous review of the curriculum, and a review of the MST education strategy in terms of findings and recommendations.

High-impact activities and interventions are being carried out at the Department of Basic Education aimed at achieving the NDP targets and the continuous review of the MST curriculum. National and international assessments are being reviewed, and intervention programmes are being prioritised in various groups and across provinces.

IMPROVING STEM EDUCATION THROUGH TEACHER DEVELOPMENT AND SUPPORT
Dr Mampone Seopa, Limpopo Department of Education

The Limpopo Department of Education has been proactive in implementing further teacher education and was also among the first provinces to heed the call of the Department of Basic Education for the establishment of an MST directorate.

STEM education is a teaching and learning process that integrates concepts taught in separate subjects and different grades and emphasises the application of knowledge to real-life situations.

What do we expect from STEM education teachers? It is hoped that they are proficient in mathematics and science and can teach STEM effectively. It is also important that they remain abreast of developments in their field, seek opportunities for professional development and collaborate with other institutions involved in STEM education. It is also critical for teachers involve learners in teamwork and group work.

The quality of the system cannot exceed the quality of its teachers. No nation is better than the quality of its education. The teacher is at the centre of the delivery of quality STEM education.

A continuing professional teacher development (CPTD) centre was established in Limpopo in 2008 focusing on mathematics, science and technology. The centre offers the CPTD MASTEC programme, which was originally envisaged as a three-month programme. It was realised that expecting teachers to be away from their classrooms to participate in a three-month programme would mean considerable disruption at schools, so the programme was reduced to three weeks. Teachers are identified per district twice a year and sent to for residential training in content and methodology. The training endorsed by the South African Council for Educators (SACE). Each academic year, 320 teachers are trained on this programme.

The content of the professional development programme is informed by research literature, new topics introduced to the curriculum, examination results, onsite school support reports by subject advisors, and on-site follow-up teacher support by CPTD facilitators. The integrated quality management system reports on the professional development requirements of teachers.

The programme is presented by relevantly qualified staff ready to capacitate teachers in mathematics and science content and pedagogy. Teachers who participate in the programme complete a pre-attendance test -to test the impact of the programme.

Facilitators from the course visit teachers who have completed the training at their schools, and subject advisors provide regular onsite support for teachers. The follow-upsupport has been seen to instil confidence mathematics and science teachers.

In order to determine the impact of the programme, National Senior Certificate results over the past three years are used as indicators, looking both at learner participation in STEM subjects and at learner performance in these subjects.

Although the statistics are from a very small base, Limpopo has performed well in both the mathematics and physical science domains and has high pass rates in both areas. The provincewill continue to focus on support and education of teachers to ensure the quality of teaching in the classroom.

Discussion

Question (Mr Zwelithini Dlamini, University of Limpopo): How does Limpopo perform with respect to facilities in schools such as laboratories? How will you convince government to focus on CPTD as a priority?

Question (Mr Lekwa Mokwana, University of Limpopo): What criteria are used to select the teachers that attend the MASTEC programme?

Question (Dr Bruce Brown, Rhodes University): What tool is used to understand whether teachers have learned from the MASTEC programme?

Response: An audit of laboratories in schools has been done and the situation is not promising. The Limpopo Department of Education has embarked on building fully-equipped state---art schools, but there are not many such schools in the province. Schools are being closed and moved away from areas where there is less need to areas with higher pupil numbers. Physical infrastructure is the responsibility of the Department of Public Works rather than the Department of Education.

The selection of teachers to attend the programme is the joint responsibility of subject advisors and the school. Schools that are underperforming are especially targeted for teacher training. On the question of understanding the learning from the course, there is follow up at schools and there is generally an improvement between the pre-test and post-test results. Subject advisors sit in on lessons and provide feedback to teachers.

Question (Craig Pournara, University of the Witwatersrand): which grades the teachers who participate in the MASTEC programme teach? The measures of success do not seem to provide appropriate evidence of success. The National Senior Certificate is not a good baseline, and the statistics presented do not show that the programme is making a difference.

Question: When teachers attend the programme, who replaces them in irschools?

Question (Prof Dirk Wessels, Stellenbosch University): We are all looking for better teachers and hoping that better students will enrol for teaching programmes. What is the Limpopo Department of Education doing to attract higher-performing students to education?

Question (Julius Olubodun, ORT South Africa): How do you encourage a positive attitude towards professional training among teachers?

Response: The MST directorate emphasises the importance of belonging to professional associations. The Limpopo Department of Education assists financially with costs such as

membership fees of professional associations for teachers, or travel when they present a paper at a professional seminar.

The teachers attending the course generally teach grades 8–12, and themajority teach grade 12.

It is acknowledged that the impact assessment measures could be improved, and ultimately better methods will be developed.

When teachers attend the MASTEC programme, learnersare not left on their own. There are temporary teachers on a database that can be employed to fill in.

It is difficult to attract high-performing students to the teaching profession, and there is a need to look at incentives for MST teachers. In an attempt to encourage talented learners, they are taken to a camp at MASTEC in the holidays. Forty grade 11 and forty grade 12 learners attend the camp.

Question (Mr Enoch Masemola, Ukuqonda Institute): How do you retain trained teachers in the system, as it is human nature to want to move on with new knowledge? Is there a system of follow up when learners go to universities (especially promising students)?

Question (University of the Witwatersrand): What is the proportion of college-educated teachers to university graduates among the teachers that you recruit?

Question (Mrs Babele Moletsane, University of the Free State): What is the reason for the small numbers of learners taking technology at school?

Response: The reason for the low numbers enrolled for technology is the lack of resources at schools. The Department of Education would like to increase the number of technical high schools.

With regard to the retention of teachers, there are no conditions attached to participation in the MASTEC programme to stay on at schools afterwards; they are free to move wherever they want.

With regard to the success rate at universities, we have not made it a responsibility to follow up on learners. High-performing learners often fail at university, which seems to be the result of over-teaching learners rather than developing learning skills.

I do not have statistics available on where teachers were trained. These would be held by the Department of Education's human resources department.

Teachers have to be well prepared, as the learners of today are quite well informed.

ENGINEERING PERSPECTIVE ON REQUIRED SKILLS IN STEM ENGINEERING SCIENCES AT THE UNIVERSITY OF THE FREE STATE
Mr Louis Lagrange, South African Institute of Agricultural Engineers (SAIAE)

Engineering can be said to employ the Einstein approach, namelythat with 60 minutes to find a solution to a life-threatening problem, 40 minutes would be devoted to observing the problem from all perspectives (in other words, the engineering design process), ten minutes would be spent devising a possible solution (the reflection process), followed by five minutes to confirm the best solution, and five minutes for implementation of the solution.

Science, engineering and technology (SET) was broadened to become science, technology, engineering and mathematics (STEM) when the importance of mathematics was recognised. This happened first in the UK. The thinking behind the introduction of STEM is to provide a link to deeper student learning with real-world connections and critical thinking. This is a very complex and lofty ideal. Unfortunately the engineering component of STEM is often an afterthought, with mathematics and science receiving more instructional time and attention.

In 2006 US authorities were concerned about the declining state of education. In an effort to address the problem, legislation was passed to authorise funding for STEM activities from kindergarten level, namely theAmerica Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act of 2007 (America COMPETES Act). Progress with implementation has been slow, and in promoting STEM subjects instructional time in the arts has unfortunately

decreased. The main objective of both art and science is discovery. It is by intuition that we discover, and by logic that we prove.

In optimising the way learners are taught, it is essential to take into account how the brain works. Left-brained people view things sequentially and work from the inside to the outside with a focus on facts, whereas right-brained people like to see the bigger picture and work from the outside in. It is important to combine the two. Human beings adapt to circumstances and constantly move between using the right and left sides of the brain.

Classroom situations tend to reach only a portion of the audience,as there is a lack of teacher knowledge of how to use the prime time and down time that occur in any lesson or lecture. Instead of assessing the quality and accuracy of the learning towards the closure to the session, lecturers and teachers tend to summarise the lesson, which does not contribute to understanding or learning. Before one looks for solutions, one needs to identify the problem. In general, what happens in class is not effective. If the wrong approach ispractisedoften enough, it tends tobecome permanent.

The dictionary definition of an 'engineer' is a person who applies mathematics and science for problem solving, butthis is a misconception. The attributes that are needed to be an engineer are creativity and systems thinking. Engineers add value through people, for people and society. Science is about knowing, whereas engineering is about doing – doing the right things, in the right way, for the right reasons, at the right time.

STEM skills are critical, and innovative organisations rely on the regular intake of good quality STEM graduates, of whom there is a shortage. Despite the acknowledged need for engineering skills, generally only about 10% of learners are exposed to engineering-related coursework at school. Engineering is taught only sporadically, and there is a great deal of confusion about what engineering is.

The current focus on STEM provides an opportunity to introduce more engineering education. Engineering can unify both STEM and STEAM (science, technology, engineering, art and mathematics) subjects without the addition of large volumes of content. The engineering design process places emphasis on the process and design of solutions.

The engineering professional lifecycle has several stages:

- At school level, the achievement of literacy, numeracy and first-level mathematics, science and language proficiency
- At higher education level, the completion of an accredited programme and attainment of a required level of engineering education
- Candidacy phase,programme of training and experience
- Practice as a registered professional.

The engineering lifecycle begins in the early school years. The mind of a five year old represents, in a sense, the height of creative power.
The Engineering Council of South Africa defined 11 exit-level outcomes for engineering graduates that provide direction:

1. Problem solving
2. Application of scientific and engineering knowledge
3. Engineering design
4. Experiments and data analysis
5. Engineering methods, skills and tools
6. Professional and technical communication
7. Sustainability and impact of engineering activity
8. Individual, team and multidisciplinary working
9. Independent learning ability
10. Engineering professionalism
11. Engineering management

Most schools teach STEM subjects separately, whereas the engineering process is integrate them.

AN ENGINEERING PERSPECTIVE ON REQUIRED SKILLS IN STEM
Ms Teresa Hattingh, University of the Witwatersrand, South African Institute of Industrial Engineers

Industry has recognised what is missing in the graduates they employ, and universities have also observed student deficiencies. These shortcomings are believed to be a function of many things, including the school system, the university system, the attitude of companies to further education and indeed of society as a whole. The six key attributes that are missing, and the six ideas about how the University of the Witwatersrand is trying to address the problem, were presented.

What is missing?

1. Curiosity: An interest in what is going on in general and outside of specific subjects.
2. A questioning mindset, challenging the how and the why, and a practical awareness of what they are doing.
3. Proactiveness and agency: Students increasingly seem to expect someone else to do the work, to pose the questions and to feed them information. It is important that they learn to take back the agency of learning.
4. Chasing understanding not methods: The race for high matric marks and performance leads to the chasing of methods rather than understanding. It is indeed possible to get through a degree course by rote learning without understanding the underlying context.
5. Integration: This is very much a function of the curriculum. Subjects tend to be compartmentalised, and students struggle to combine the concepts from the various modules.
6. Group work and soft skills: This is a requirement of industry, but is not included in any of the engineering modules.

What are we trying to change?

1. Pace: Students need synthesis time to process the information that they have been given, and the pace of this varies from learner to learner.
2. Content versus developing essential qualities: Courses have far too much content. It would be preferable to develop attributes in graduates such as lifelong learning. There is a need to reflect on the qualities that should be cultivated in graduates.
3. Using self and peer assessment, getting people to communicate, work in groups and nurture the ability to self-reflect.
4. Shaking up assessment: Tests and examinations are not a good way of testing and assessing students. It is important to align assessment with practical examples that structure knowledge.
5. Making learning fun: Most learning happens when one is having fun. There are many creative ways to have fun without special facilities or a large budget.
6. Consciously shifting agency, andmoving responsibility away from lecturers and back to students.

Discussion

Comment (Prof Dirk Wessels, Stellenbosch University): Engineering is not taught at primary school; mathematics is, but it is often taught badly. The introduction of engineering into the school programme would include the introduction of modelling and problem solving. A PhD student at Stellenbosch University is working with low performers in mathematics and has had great success in developing competences through modelling.

Comment: I am very encouraged by the two speakers. The curriculum includes all the attributes that were highlighted, but teachers of mathematics have to know what mathematics is in order to be able to prepare students for studying engineering and to prepare students for the wider world.

Comment (Johan de Koker, Chamber of Engineering Technology): At school students are taught to pass examinations. Then they go to university with the aim of becoming a professional of some sort, until the first test when their aspiration tends tochange to that of just passing tests and examinations. The problem is that despite the engineering council's outcomes and graduate attributes, we teach students to pass examinations rather than to understand concepts.

Response: It is gratifying that there is agreement that something has to be done.

Comment (Andrew Hofmeyer, Ukuqonda Institute): The Ukuqonda Institute has many stories that align with what has been said. An example is a group of first-year engineering students who were enrolled in a problem-solving course. The entry requirement for the course was at least 80% for mathematics or science and at least 70% for English. Half way through the first day, 25 students had to be removed from the group as it was clear that they had very little concept of numbers. These

included a student who was the top learner in her province. The question is what spaces we need to establish in our classrooms to allow learners to become autonomous and to learn to think.

DEMONSTRATION OF pro*SET* INTERACTIVE CARTOON
Mr Richard Gunderson, pro*SET* committee member

Some 10–15 years ago, the South African Institution of Civil Engineering launched a project to increase knowledge about the built environment. A cartoon picture was developed that included all the engineering disciplines, particular on civil engineering. This proved very useful in explaining the built environment and the professions involved in various activities. The picture was widely distributed and used at all levels of interaction, from small children up to cabinet ministers. The dream was to animate the picture. This project is now run by the pro*SET* executive committee and includes all professions and the sciences.

Mr Richard Gunderson gave a demonstration to show progress and stimulate interest in the further development of the project. As pro*SET* is the home of all the professional bodies, this project targets areas that are common to all. The focus of the present Discussion Forum, STEM, is one of the many pieces in the jigsaw puzzle that can stimulate an interest in the natural sciences and the built environment. The target audience for the project is early high school learners who have to make subject choices, rather than older learners who have already selected their subjects.

The original cartoon picture produced by the Institution of Civil Engineering was enhanced to a 2D model with the addition of simple gif animations and photos, but it was realised that static content would not hold the attention of children who are used to a gaming environment, and that interactive content was needed. Producing this kind of high-level content is expensive, and additional funding needs to be sourced.

The design criteria are that this must be a stand-alone programme that can be loaded on to an 8 GB memory stick. The focus of the content would be on items of general interest such as human beings, transport, water and weather. The content would be aimed at providing access to a world beyond the audience's reach both physically and visually. The text would be limited, and in a later phase of the project the model could include internet access with hyperlinks to richer resources.

We have the makings of a gaming backbone and would like to elevate the project to the next level and inspire sponsorship and funding. We are hoping to move into a 3D world that would incorporate gaming concepts with a great deal of click-through information. The role that pro*SET* members can play is to identify suitable material from within their membership for inclusion in the cartoon.

pro*SET* members represent their respective fields, but share common interests and concerns, one of which is the number and quality of students in the STEM pipeline. This project is aimed at stimulating an interest in the natural and engineering world.

Delegates spent time discussing possible ideas for the further development of the project among themselves. These ideas would be communicated to pro*SET* for follow up.

PANEL DISCUSSION

A panel of representatives of NGOs shared their contributions to mathematics education.

SA Mathematics Foundation:
Prof Kerstin Jordaan, University of South Africa

The SA Mathematics Foundation is an NGO that was established in 2004. Itis managed by a board of directors that includes government representatives. SAMF provides a forum for communication and relies on funding to run its activities. Four thrusts have been identified for particular focus: learner development, teacher development, advocacy and research. The South African National Olympiads are an example of the learner development programme. In the area of advocacy, SAMF cooperates with National Science Week.

The teacher development project is aimed at teaching mathematics for understanding and is based on the pillars of conceptual understanding; strategy, use and development; problem solving; procedural fluency and logical reasoning.

To promote conceptual understanding, My Maths Buddy was developed to improve the accessibility of terminology that describes concepts. For strategy development, problem-solving courses have been developed for primary and high school teachers. The focus areas of the course include reading and understanding the question, drawing a figure, looking for a pattern, the introduction of appropriate notation, and the use of a logical argument. The course includes games and puzzles.

Olympiads have different rounds and are aimed at getting learners involved. The initial rounds are not very difficult and the real value is in participating. The focus is on presenting problems in way that encourages innovative thinking.

Institute of Electrical and Electronic Engineers (IEEE): Integrating Engineering Projects in Community Service (EPICS) and Industry 4.0 projects into engineering curricula to develop graduate attributes
Mr MS Hoosain, University of Johannesburg

The Engineering Projects in Community Service (EPICS) initiative involves engineering students in community projects that count as their final-year project and combine classroom learning with hands-on experience of problem solving. Students are required to identify a high school with which to collaborate and then be actively involved in feeding the solution back to the community. This process not only provides valuable experience for students, but also involves pre-university learners in engineering projects.

Industry 4.0 is the next industrial revolution. In order to prepare students, funding was obtained to set up a MakerSpace laboratory equipped with up-to-date equipment, such as 3D printers, where children were encouraged to bring ideas to life. In conjunction with the University of Johannesburg's Technolab, high school learners were invited to visit the robotics laboratory and were taught coding, the basics of robotics and how to interact in challenges. 3D printers were then employed to bring their ideas to reality.

With technology for humanity in mind, there is room for vast improvements in pedagogy. To quote Nelson Mandela, 'Education is the most powerful weapon which you can use to change the world'.

South African Academy of Engineering (SAAE)
Dr Trueman Goba, Hatch Group

The South African Academy of Engineering is a small non-profit institution with about 200 members that promotes excellence in science and engineering. The focus is not to serve the professions, but to draw on the knowledge and experience of members to provide advice to the nation. The members are a multidisciplinary group of experts from universities, research organisations and industry.

The academy maintains links with overseas academics, and members attend international meetings where global issues are discussed. This year public lectures will be held around the country to share the learning from overseas conferences.

STEM education is important for our economy and the advancement of our people.

South African Institute of Physics (SAIP): An overview of the Natural and Physical Sciences Teacher Development Programme of the University of the Western Cape
Dr Mark Herbert, University of the Western Cape

The South African Institute of Physics in partnership with the Council on Higher Education identified the major challenge of under-preparedness of university students entering undergraduate physics programmes. As a result, student throughput and retention remain a concern for universities in South Africa.

The Natural and Physical Sciences Teacher Development Programme aims to address some of the scarcest skills in South Africa. The aim is to improve pass rates at schools by improving physics content knowledge and pedagogical skills of natural and physical science teachers.

The programme comprises physics for physical science educators, and modelling instruction for natural science teachers. The programme is run in partnership with the high schools in the area surrounding the University of the Western Cape. The success of the programme will be reviewed and, based on the findings,will be expanded to include chemistry and other modules. In response to a need expressed by subject advisors, it is hoped that a master's degree in physics education will commence by 2020.

The current 'course is an accredited year-long CPTD course comprising physics mainstream modules aligned with the Curriculum Assessment Policy Statement (CAPS). The course promotes the professional development of grade 10–12 in-service physical science teachers and provides comprehensive training in physics and pedagogy knowledge. Classes have been kept small and are very interactive.

The modelling instruction for natural science teachers is a three-year pilot project between the University of the Western Cape, Missouri State University and Metro South Education District. This is a cross-faculty project with the vision to prepare grade 8 and 9 teachers to become knowledgeable leaders as they learn to teach the physics component of the natural sciences curriculum.

The partnership with schools provides teachers who have successfully completed the physics course with ongoing support. The resources and services of the university's departments of physics and astronomy are made available to schools.

The challenges with regard to the programme are the provision of ongoing support in implementing effective teaching and learning practices in the classroom, and providing incentives to encourage teachers to participate. Funding is always an issue, particularly with regard to possible expansion of the programme. Monitoring and evaluating the success of the programme is difficult to implement.

Southern African Association for Research in Mathematics, Science and Technology Education (SAARMSTE): Supporting STEM education and STEM education research
Prof Hamsa Venkatakrishnan, University of the Witwatersrand

SAARMSTE presents an annual Doctoral Science Research School. Most PhD courses have very little course work, but PhD students the of STEM education have a passion for the subject. The opportunity to work with other people in the field provides a welcome space and a relief from formal academic schools of education.

Another issue is that supervision capacity at many higher education institutions, but there are also notable pockets of expertise. The research school is a welcome opportunity for PhD students in STEM education to focus on their studies. Many of them are from teaching backgrounds; they are often older than other students; they may be studying part time, and finding dedicated time for their studies is difficult.

The goals of the research school are to develop capacity for STEM education, cultivate networks of STEM researchers and build a regional research culture. The school is an annual off-campus residential four-day intervention with regional and national rotation of the venue. Since South Africa has the largest body of doctoral students participating, the school is usually held in South Africa. Between 40 and 50 doctoral students in STEM education and early career scholars from universities in South Africa and the region attend the course, which is facilitated by national and regional experts. The research school activities focus on the process of writing a PhD in the education field, with plenary sessions, workshops and small group activities. Delegates have open access to experts.

The school has been well supported by funders, but most of the costs are borne by students and supervisors. This is not an ideal situation, as it can lead to inequity in that well-endowed institutions are better able to support the participation of students in the research school.

The successes include the fact that there is an institutional home for this initiative; funding has enabled the progress to date; over 500 students have attended the school; and there is some support for a transformed academy in STEM education. The challenges that need to be addressed are sustainability and funding.

CONVENTIONS: A DRIVER FOR ECONOMIC DEVELOPMENT
Mr Bjorn Hufkie, South African National Convention Bureau, South African Tourism Board

The usual question that is asked is what tourism is doing at an event focused on STEM education. The SA National Convention Bureau has little to do with tourism even though it is housed within the SA Tourism Board. The aim of the unit is to provide support to organisations bringing international conferences to South Africa.

A range of services are provided such as assistance with compiling bidding documents for international meetings. National government has made funds available in order to meet hosting requirements. It is recognised that conferences and meetings will improve the competitiveness of the country and that the sharing of knowledge will have a positive impact on South Africa and the region. The activities of the bureau focus on the areas and targets of the National Development Plan.

Details of how to contact the bureau will be published on the NSTF website.

Discussion

Comment (Mr Dawie Botha, pro*SET*): We do not always see the opportunities in terms of tourism or the advantages, for example, of study tours by professional associations from other countries. Another area of focus could be the publication of South African engineering achievements.

STEM ACCORDING TO HUMAN RESOURCE DEVELOPMENT STRATEGY – 2030 AND NATIONAL DEVELOPMENT PLAN
Dr Dudu Mkhize, Human Resource Development Council of South Africa

The National Development Plan (NDP) is extremely important and all government departments should use it to underpin their activities and strategies. The NDP sets targets for 2030 in which STEM features prominently.

At school level, he NDP sets targets for 80% of schools to achieve a 50% pass rate in mathematics and science; for the number of students eligible to study mathematics or science at university to reach 450 000 per year; and for the number of people embarking on a career in science and technology to triple from current level.

At higher education level, the targets set in the NDP include increasinguniversity science and mathematics entrants to 450 000 by 2030, and significantly increasing the number of STEM graduates. According to the NDP, science and mathematics education should be revitalised by 2030.

The Human Resource Development Council of South Africa (HRDC) is an advisory council chaired by the deputy president of the country, with oversight responsibility by the minister of Higher Education and Training. The council has over 50 members, more than half of whom are government ministers. The HRDC is intended to guide and shape the human resource development agenda and provide a platform for dialogue and consensus building. In order to advance the development agenda, it is important to identify blockages and recommend solutions.

The key priorities of the HRDC are divided into five programmes, each headed by a champion:
- Programme 1: Foundation education with mathematics (STEM), languages and life orientation/skills
- Programme 2: TVET and the rest of the college system
- Programme 3: Higher education and training, research and innovation
- Programme 4: Skills for the transformed society and the economy
- Programme 5: Developmental/capable state

In taking stock of the progress made towards the NDP goals, it should be noted that it was difficult to source reliable statistics. Even with the limited statistics available, however, it is clear that we are far from reaching the targets.

Learners are the victims of poor STEM performance in high schools. Learners are being let down due to lack of recognition of the cognitive growth of children. The literature indicates that physical growth among adolescents is coupled with unobserved drastic cognitive growth gives adolescents an array of newly acquired cognitive abilities. The current focus of STEM education and textbooks is on method.

Adolescents do not want to learn about method, but need to be presented with the broader picture to inspire them.

In terms of progress, in 2015 the Department of Higher Education and Training published the National Policy on the Minimum Requirements for Teacher Education, and in 2007 the Funza Lushaka Bursary Programme was launched a strategy to attract learners into teaching, especially those with good passes in mathematics, science and languages. It is disappointing that among a sample of 26 rural teachers who were Funza Lushaka bursary holders, only one has a BSc degree the rest are all BEd graduates.

The NDP vision is that by will be characterised by learners and teachers who are highly motivated. The legacy outlined in the White Paper on Education and Training of 1995 is that the majority of South Africans were denied access to technological and professional careers requiring a strong basis in mathematics and science because of the chronic inadequacy of teaching in these subjects. There is a chronic scarcity of mathematics and science teachers today, and South Africa continues to have problems with STEM skills.

Measuring progress and work on the blockages has to focus on quantitative and qualitative factors. Funza Lushaka should be strengthened. Rural students remain an untapped potential. We need a shift from, 'Oh no! Not maths' to 'Perhaps I should study mathematics!'

CLOSURE

Ms Jansie Niehaus thanked everyone for their participation in the Discussion Forum.

APPENDIX 1: LIST OF ABBREVIATIONS

ANA	Annual National Assessment
BEd	Bachelor of Education
CPTD	Continuing professional teacher development
FET	Further Education and Training
GET	General Education and Training
HRDC	Human Resource Development Council of South Africa
MST	Mathematics, Science and Technology
MTT	Ministerial Task Team
NDP	National Development Plan
NGO	Non-government organisation
NSTF	National Science and Technology Forum
pro*SET*	Professionals in science, engineering and technology
SAARMSTE	Southern African Association for Research in Mathematics, Science and Technology Education
SEACMEQ	Southern and Eastern Africa Consortium for Monitoring Education Quality
SAMF	South African Mathematics Foundation
SET	Science, engineering and technology
STEM	Science, technology, engineering and mathematics
TIMSS	Trends in Mathematics and Science Study
TVET	Technical and Vocational Education and Training
UWC	University of the Western Cape

APPENDIX 2: LIST OF DELEGATES

Dr	Motshidisi Lekhu	Central University of Technology (CUT)
Mr	Watson Manduna	CUT
Ms	Sister Mapiyeye	CUT
Mr	Odirile Mashalane	CUT
Mr	Itumeleng Phage	CUT
Prof	Wendy Setlalentoa	CUT
Mr	Johan de Koker	Chamber of Engineering Technology
Mr	Simangaliso Twala	COUNT Educational Institute
Miss	Sindiswa Mcosana	Department of Basic Education
Mr	Pranay Devchand	Gauteng Department of Education
Dr	Dudu Mkhize	Human Resource Development Council of South Africa
Mr	Mohamedn Sameer Hoosain	Institute of Electrical and Electronic Engineers
Mr	Michael Cameron	Institute of Technological Professionals of SA
Dr	Mampone Seopa	Limpopo Department of Education
Dr	Lynn Bowie	OLICO Mathematics Education
Mr	Julius Olubodun	ORT South Africa
Mr	Peter Horszowski	PERT Industrials
Mr	Fannie Matumba	Programme for Technological Careers
Mr	Richard Gundersen	proSET Committee member
Dr	Bruce Brown	Rhodes University (RU)
Dr	Nyameka Kangela	RU
Dr	Trueman Goba	SA Academy of Engineering
Dr	Gerda Botha	SA Council for Natural Scientific Professions
Mrs	Theresa Hattingh	SA Institute of Industrial Engineers
Mr	Mark Herbert	SA Institute of Physics
Mr	Herman Bosman	SA Mathematics Foundation (SAMF)
Prof	Kerstin Jordaan	SAMF
Mr	Bjorn Hufkie	SA National Convention Bureau
Mr	Dawie Botha	South African Academy of Engineering
Prof	Louis Lagrange	South African Institute of Agricultural Engineers
Dr	Janine Victor	South African National Biodiversity Institute
Mrs	Carine Steyn	Southern African Association for Research in Mathematics, Science and Technology
Mr	Waldo Viljoen	Southern African Institute for Industrial Engineering
Prof	Dirk Wessels	Stellenbosch University (SU)
Dr	Linda Bosman	SU
Ms	Jeanne-Mari du Plessis	SU
Mr	Andrew Hofmeyer	Ukuqonda Institute
Prof	Piet Human	Ukuqonda Institute
Mr	Enoch Masemola	Ukuqonda Institute
Mr	Humphrey Nkgogo	Ukuqonda Institute
Mr	Nic Pieterse	Ukuqonda Institute
Mrs	Cally Kuhne	University of Cape Town
Dr	Busiswe Alant	University of KwaZulu-Natal (UKZN)
Dr	Angela James	UKZN
Mr	Zwelithini Bongani Dhlamini	University of Limpopo (UL)
Prof	Satsope Maoto	UL
Mrs	Kgaladi Maphutha	UL
Mr	Lekwa Mokwana	UL
Mr	Dimakatjo Muthelo	UL
Mr	Monare Setati	UL
Prof	Hlengani Siweya	UL
Mrs	Babele Moletsane	University of the Free State
Prof	John Bradley	University of the Witwatersrand (Wits)
Dr	George Ekol	Wits
Mrs	Samantha Morrison	Wits
Dr	Williams Ndlovu	Wits

Dr	Craig Pournara	Wits
Mrs	Yvonne Sanders	Wits
Mrs	Ingrid Sapire	Wits
Prof	Hamsa Venkatakrishnan	Wits
Dr	Lyn Kok	University of Zululand
Ms	Cynthia Malan	Write Connection (Scribe)