# NATIONAL SCIENCE AND TECHNOLOGY FORUM

**proSET/NSTF DISCUSSION FORUM: STEM EDUCATION AND MATHS REFORM**

**Date:** 6–8 August 2018  
**Venue:** Premier Hotel, Kempton Park, Gauteng

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DAY 1

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 proSET, 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 proSET 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 everywhere, 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 Plet 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 that highlights 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 learners 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 B.Ed. (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 B.Ed. 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. proSET 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 happens 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.

The MASTEC Institute was established in Limpopo in 2008 for continuing professional teacher development (CPTD) 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 for residential training in content and methodology. The training course is 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, on site 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-up support has been seen to instil confidence in 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 province will 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-of-the-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 Basic 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 do 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 schools?

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 the majority 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, learners are 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 Babelo 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, namely that 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 the America 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 is practised often enough, it tends to become permanent.

The dictionary definition of an ‘engineer’ is a person who applies mathematics and science for problem solving, but this 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 integrates them.

**An engineering perspective on required skills in STEM (Ms Teresa Hattingh, University of the Witwatersrand and 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, and 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, and moving 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 to change 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 proSET interactive cartoon (Mr Richard Gunderson, proSET 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 proSET 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 proSET 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 proSET members can play is to identify suitable material from within their membership for inclusion in the cartoon.

proSET 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 proSET for follow up.

Panel discussion: Panel of representatives of organisational beneficiaries of proSET grants

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. It is 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) (Mr MS Hoosain, University of Johannesburg)**

Mr Hoosain spoke about integrating engineering projects in community service and industry 4.0 projects into engineering curricula to develop graduate attributes. 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) (Dr Mark Herbert, University of the Western Cape)**

Dr Herbert gave an overview of the Natural and Physical Sciences Teacher Development Programme of the 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 (SAARMSSTE) (Prof Hamsa Venkatakrishnan, University of the Witwatersrand)**

Prof Venkatakrishnan gave a presentation on the ways in which SAARMSSTE supports STEM education and STEM education research.

SAARMSSTE 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, proSET): 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 in the National Development Plan and Human Resource Development Strategy (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, the 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 increasing university 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: Technical and vocational education and training (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’!

DAY 2

**Realistic mathematics education (RME) and its challenges (Prof Koeno Gravemeijer, Professor of Science and Technology Education, Eindhoven University of Technology)**

A layman’s view of learning is that people learn by making connections between what is known and what needs to be known. Mathematics learning requires the learner to make connections with an abstract, formal body of knowledge; however, the problem is not the abstract nature of mathematics but the gap between the abstract knowledge of the teacher and the experiential knowledge of the students. Teachers and textbook authors tend to mistake their own more abstract mathematical knowledge for an objective body of knowledge that the students can connect with.

An example of the gap in knowledge of the abstract mathematical knowledge is the lack of understanding by young children of the question ‘How much is 4+4? They know that 4 apples plus 4 apples makes 8 apples and the number therefore refers to countable objects and not to a number that you can reason with. On a lower level the number is tied to countable objects, and at a higher level 4 is associated with number relations and ultimately as a mathematical object. In geometry, students do not see a square as a rhombus unless it is tilted, even though the two objects have the same specifications.

We perceive mathematics as an independent body of knowledge, but this body only exists in the minds of teachers and textbook authors as students cannot connect to a body of knowledge that does not exist for them. Some people may advocate learning first and understanding later; however, most students learn definitions and algorithms by hearing these but then have problems with application and understanding. This is a source of mathematics anxiety.

A bottom-up process of concept formation is necessary for the understanding of mathematics. The mathematics of mathematicians cannot be conveyed by explanations or definitions; students need to go through a process of concept formation within which operational conceptions precede structural conceptions.

People construct their own knowledge, and students have to construct or reinvent mathematics. According to Paul Cobb, students construct their own knowledge, even in the most authoritarian of instructional situations. The question is not whether students should construct, but what is it that we want them to construct. We need students to see mathematics as a human activity for problem solving and organising subject matter. Students need to be engaged in mathematics as an activity and supported and guided in reinventing mathematics.

There are many theories related to realistic mathematics education (RME) including a domain-specific instruction theory for RME education by Treffers (1987), which was later reviewed in terms of design heuristics of guided reinvention, didactical phenomenology and emergent modelling by Gravemeijer (1989). The guided reinvention identifies starting points that are experientially real for students and also the end points of the reinvention route. Design characteristics would include looking at the history of mathematics from the viewpoint of potential conceptual barriers, dead ends and breakthroughs, and at informal solutions that ‘anticipate’ more formal mathematical practices or potential reinvention routes. An example is a guided reinvention of addition and subtraction up to 20. The starting point would look at the informal solutions, procedures and contexts, including doubles, five and ten referenced number relations or basic counting on fingers. The end point would be the flexible use of
number relations and derived facts, with students using the facts that they know rather than just following a procedure.

The didactical phenomenology of mathematics requires one to consider how mathematics concepts, procedures or tools organise certain phenomena. This would include envisioning how task-setting could create the need to develop the intended thought process, which would be a starting point for a reinvention process. In the addition and subtraction up to 20 process, the didactical phenomenology is not just structuring and combining sets of objects, or cardinal activity; it is also counting events and measuring or ordinal activity, the coordination of cardinality and ordinality. Problems that are stated cardinaly (for example 4 marbles and 3 marbles) are solved ordinarily through the use of counting, which is a reinvention process.

The learning paradox according to Bereiter (1985) is: ‘How is it possible to learn the symbolisation that you need to come to grips with new mathematics, if you need to have mastered this new mathematics in order to be able to understand those very symbolisations?’ In order to circumvent the learning paradox, the emergent model focuses on a shift in attention and the development of mathematical relations. This is a dynamic process in which symbolisations and meaning co-evolve and are modelled as a student activity in the service of the learning process. The model is actually a series of sub-models that, from the perspective of the researcher or designer, constitute an overarching model that co-evolves with some new mathematical reality. The model starts to derive its meaning from a framework of mathematical relations and becomes a model for mathematical reasoning.

The arithmetic rack with rows of beads showing individual numbers and tens is a means of support and of scaffolding and communication. The rack can also assist in visualising situations such as the double decker bus with passengers on both lower and upper levels and facilitate subtraction and addition up to 20. This can also assist in shifting thinking to a model for reasoning about number relations.

With regard to mathematics innovation in the Netherlands, there was little perceived benefit to curriculum innovation and little room for teacher professionalisation. Curriculum innovation was only through textbooks, and RME innovation was not enacted as intended. National surveys showed a decline in operations and standard algorithms, but an improvement in number sense and global arithmetic. Three independent surveys were carried out, one by Kraemer (2011) on subtraction up to 100, one by Bruin-Muurling (2010) on the multiplication of fractions, and one on algebra by Van Stiphout (2011).

In the Kraemer study, the most common method of computing was by jumping or skip-counting. Other methods, which produced many incorrect answers, were splitting tens and ones, reasoning or deriving number facts using arithmetic properties, and knowing or reproducing known facts. Problems associated with these methods of computing were buggy algorithms, incorrect forms of splitting, incorrect forms of reasoning, and difficulty with tasks that involved bridging ten. In other words, the students acquired a restricted set of computing methods and reached only a limited level of conceptual understanding. With regard to textbooks in this area, it was found that sound grounding was given in particular informal strategies, but that continuation towards a higher level of understanding was missing.

In the study by Bruin-Muurling (2010) amongst ninth graders (higher general secondary education) on multiplying fractions, the students did not grasp the underlying big ideas such as units, fractions as a number, or the relationship between fractions, multiplication and division. It was found that primary school textbooks aim at number-specific solution methods that are context related; however, the next step is not taken. In order to understand the rule, it is necessary to reason at the level of numbers as objects. The inability to do so creates problems in the transition from primary to secondary school level. What is lacking in Dutch primary and secondary schools is the move from number-specific procedures to general rules.

The study of algebraic skills by Van Stiphout (2011) found that in this domain conceptual tasks were difficult for secondary school students. When asked to solve \((x-5)(x+2)(x-3)=0\) in grade 9, only 51% got the correct answer, and even in grade 12 only 75% were correct. Students were familiar with two factors, but the use of three factors was unknown to them. Textbooks showed a dual track, starting out with conceptual thinking but shifting to procedural.
The research into mathematics innovation in the Netherlands demonstrated that students ground their mathematical understanding on situations that are experientially real to them, well understood and procedurally situation specific. These situation-specific solution procedures produce correct answers on which teachers and textbooks capitalise to create routine methods of teaching and learning, but the next step is lacking.

The findings of all three studies were essentially the same. There is a lack of development of more sophisticated and generalised understanding. The inclination of both teachers and textbook authors is to think of instruction in terms of individual tasks that students have to master. This task propensity counteracts inquiry in mathematics by focusing on procedures that can quickly generate correct answers, instead of supporting students in coming to an understanding of the underlying concepts.

Resnick and Hall (1998) developed the popular view of classic associative theories of learning. Knowledge consists of connections between mental entities, and learning is a matter of creating and strengthening these bonds. Frequent testing of individual items tests whether bonds have been formed. The idea of proficiency in terms of mastery of individual items also permeates goal descriptions in curriculum documents, and testing supports this type of teaching. More advanced conceptual mathematical goals are necessary with the inclusion of constructing mathematics transitions processes and mathematical objects, which in turn become subject to new processes and derive their meaning from frameworks of mathematical relations.

Advanced goals from the perspective of researchers in the area of addition and subtraction up to 100, are that numbers should be viewed as objects in networks of number relations, for example unitising numbers such as 63 into 6x10+3, and expansion to make structures such as 63=40+23. The interconnectedness of addition and subtraction should be taught. Instead of procedures, students should work with number relations. In the domain of multiplication of fractions, there should be a move from fractions of identifiable units, to rational numbers as mathematical objects. Relations between operations such a multiplication, division and proportions are essential. Students eventually have to see a product such as 16x3/4 and 3/4x16 as the same thing (a mathematical object in itself). In algebra, an advanced goal would be the development of a sense of structure and symbols and a move from computational prescription to object thinking.

In summary, the research that was conducted demonstrated that students acquired a restricted set of computing methods and reached only a limited level of conceptual understanding. There is a propensity of focus on individual tasks, and the more advanced conceptual mathematical goals are not addressed. The advanced goals are also not addressed in textbooks or in curriculum documents. The culture of an inquiry classroom is not sufficiently developed.

These problems are not unique to the Netherlands, where the mathematics education community has been trying to get problem-centred inquiry mathematics implemented for several decades. The obstacles and the factors for success have been determined as the establishment of adequate social norms and socio-mathematical norms; fostering tasks orientation over ego orientation; cultivating mathematical interest; framing topics for discussion; and designing and adapting hypothetical learning trajectories.

In traditional school mathematics social norms, students have to come to grips with the knowledge that the teacher already has; the teacher’s role is to explain and clarify. The student’s role is to try to figure out what the teacher has in mind. In the social norms of the inquiry classroom, there is an obligation to explain and justify one’s solutions and what counts as a mathematical problem or a mathematical solution. More sophisticated solutions are also explored, which cultivates the intellectual autonomy of students.

In order to establish new social norms, the teacher has to convince students that what is valued and what is rewarded have changed. Teachers will need to use concrete instances of infringements of the new norms or of exemplary behaviour as opportunities to clarify the norms. It will be essential to cultivate the culture of an inquiry classroom by asking for explanations, asking clarifying questions, passing the problem along, asking for personal judgment, and promoting listening and understanding. In this environment, the teacher needs to play a proactive role, try to explain so that everybody can understand, listen carefully and encourage students to question, and provide additional information and solutions.
Task/ego orientation was identified as important by Jagacinski and Nicholls (1984). Students also have to be willing to invest effort in solving mathematical problems, considering solutions and discussing the underlying ideas. Two sorts of orientation have been identified: ego orientation where the student is very conscious of how he or she might be perceived by others and could withdraw from discussions for fear of ridicule, and task orientation where the student's concern is the specific task. It is important to cultivate the task orientation of students and to create a classroom culture in which students measure their success by comparing their results with their own earlier results and not the results of others.

Mathematical interest is cultivated by moving away from the pragmatic interest of problem solving to examining the underlying mathematics. This can be achieved by asking questions such as: What is the general principle here? Why does this work and does it always work? Can this be described in a more precise manner? Teachers can cultivate interest through showing a genuine interest in students' mathematical reasoning. A mathematical interest is a prerequisite for reinvention. As illustrated by Cobb (1997), there is a need to frame topics for discussion. Teachers could promote discussion by identifying differences in mathematical understanding in the class, or by selecting topics for whole-class discussions.

The Hypothetical Learning Trajectory was developed by Simon (1995). This process requires teachers to think through the mental activities in which students might engage as they participate in envisioned instructional activities; to investigate whether the thinking of the students actually evolved as conjectured; and then to revise and adjust accordingly. This requires teachers to shift from an observers' point of view to an actors' point of view. Teachers should be offered support for construing and revising hypothetical learning trajectories.

Local instruction theory, which was developed by Gravemeijer (2004), is a theory about a possible learning process for a given topic, with theories about the means of supporting the process through tasks, tools and classroom culture. Local instruction theory can also serve as a frame of reference for designing hypothetical learning trajectories.

In research conducted by Fullan (2006), it was found that most innovations do not have a lasting impact on teacher professionalisation. Teachers do not get feedback on what they do in their classrooms, and collaboration is needed. An ideal situation would be groups of teachers who commit themselves to improving their teaching by working collaboratively. Work has been done on lesson studies models in which teachers work together to elaborate on a given local instruction theory in order to make it work in their own classrooms. Instructional designers will have to invest in designing the means of supporting lesson-study type activities.

In the work by Cathy Fosnot on the context of teacher development, workshops and coaching are considered important. Instructional materials have been developed (one topic every two weeks) for use by teachers alongside traditional textbooks.

In developing a strategy, we need to put a spot on the horizon to define our ambition. We need the support of the wider society for the importance of mathematics, and we need to consider the changes that moving increasingly towards a digital society will bring.

**Classroom culture, teachers' beliefs and learners' beliefs (Alwyn Olivier, Editor-in-Chief, Pythagoras)**

In the book entitled *The Teaching Gap: Best Ideas from the World's Teachers for Improving Education in the Classroom* by James W Stigler and James Hiebert, the concept of mathematics as a cultural activity is introduced. This is likened to the family dinner as a cultural activity in which everyone knows how it works, what to expect and what to do. This is also true of the mathematics classroom. Cultural scripts are learned implicitly through observation and participation rather than by deliberate study.

Teachers reproduce the classroom scene that they have known since childhood without having to think; it comes automatically. Just as teaching is a cultural activity and difficult to change, teacher learning is also a cultural activity and thus subject to many of the same forces that keep traditional teaching practices in place. Efforts to improve teaching cannot succeed without changes in the culture of teacher learning.
Great innovation cannot happen without change, and cultural change is very difficult to bring about. We all know what the mathematics classroom looks like, and that is where the change must start. What learners learn is determined as much by non-cognitive influences as by intellectual and cognitive influences.

The classroom culture is formed by the teacher’s beliefs about mathematics, learning, teaching and learners, and the learners’ beliefs about mathematics, learning, teaching and self. What is true and indeed very sad is that the inquisitiveness, enthusiasm and engagement that characterise children’s early years fades away and is replaced by a strong belief that mathematics is all about following instructions and rules.

Alan Schoenfeld, in considering curriculum reforms that include issues such as relevance and problem solving, believes that this reflects an attempt to embed a selected aspect of mathematical thinking into what is an essentially alien culture, that of the traditional classroom. Schoenfeld felt that as long as the two cultures differ so radically, it may be impossible for the embedding of these concepts to succeed. Fragments of the mathematical culture, in isolation, are likely to wither in the classroom for lack of support, or they may be so changed by their absorption into the classroom culture that they will not translate back outside of it.

When new ideas are taken into the normal classroom, the classroom culture is changed. The didactical contract that outlines the unwritten expectations and obligations of teachers and learners and determines daily classroom rituals is also substantially altered. The teacher, who traditionally does not expect learners to be able to do anything that has not been demonstrated, undertakes to show learners and expects the learners to learn. Similarly, learners do not expect the teacher to ask them anything that has not been demonstrated, and they undertake to listen and learn.

The orientation of students could be described in two ways: mastery orientation that focuses on learning the content, or performance orientation that focuses on competitive performance. To encourage a change in the traditional classroom, teachers should promote a mastery orientation and growth mindset, pose challenging tasks, encourage learners to engage and persist, and emphasise the connections between persistence and learning. It is essential to do something radical in order to change important issues.

Jeannie Oakes, who did much of her initial work in the area of tracking and streaming systems in the USA, explained that in searching for solutions to education problems, the focus was almost exclusively on the characteristics of children. Sources of education failure in homes and neighbourhoods were researched, as were languages and cultures and the possibility that what happens within schools was almost entirely overlooked as a contributing factor in unequal educational opportunities and outcomes. Ms Oakes’ research showed that tracking, streaming and ability grouping influence the attitude of learners towards mathematics. She recommended that extrinsic reward, such as rewards for finishing first, should be replaced by intrinsic reward that reflects the love of the subject. Mathematics teacher trainers should also bear responsibility for the courses that are provided and the thinking that these engender.

The type of thinking that should be encouraged is clear in an example from a class of grade 1 learners. Dice were thrown and revealed an answer of 4 and 2. In addition to adding the two numbers, the learners were asked to say which numbers were on the bottom of the dice, the side that was not visible. The first student with the answer had walked around and by logical elimination of the numbers that could be seen came up with the correct answer. When the learners were asked to arrive at the answer by looking at the pattern, three distinct types of learning emerged: the first group were incredulous and called this magic, the second group tried to remember how the numbers appeared on the dice, and the third group recognised the pattern.

In another example of an exercise in addition, multiplication, division and subtraction, 20 rows of sums were presented and worked through easily by the learners. When asked what they thought they had learned, it was clear that the patterns had not been recognised. The first and last numbers in the line were always the same, which was an example of an inverse operation. The purpose of the exercise was to develop an understanding of an inverse operation, but the children did not expect to find a pattern and therefore did not look for a pattern, and thus learned very little.
These and other examples are not bad activities or tasks, but the classroom culture will decide what type of learning the children will experience. Children’s beliefs influence what they learn as much as intellectual facts.

The intended curriculum was always assumed to be the best, and teachers were blamed when it did not work. A better-intended curriculum would possibly include why, heuristics and big ideas.

In 1935, CE Beeby expressed the following doubt: ‘The black doubt that lurks in the bottom of every honest pedagogue’s heart is not so much whether he is teaching correctly as whether what he is teaching is worth teaching at all. The real doubt is not teaching the right things inefficiently, but that we shall teach the wrong things more and more efficiently.’ The danger is not that we could get there, because we are already there.

In commenting on the intended curriculum and the desirability of the inclusion of big ideas and problem-solving strategies, Guy Brousseau made the following statement in 1984: ‘The more explicit I am about the behaviour I wish my students to display, the more likely it is that they will display that behaviour without recourse to the understanding that behaviour is meant to indicate; that is, the more likely that they will take the form for the substance’.

A very useful tool to promote understanding and encourage the autonomy of learners is the ability to change difficult problems into an easier equivalent, or into a problem that the learner already knows how to solve. All calculations involve three phases. The first phase is the transformation of the numbers to more convenient numbers e.g. $23=20+3$. The second is transforming the given task into a series of equivalent easier tasks – for example, $8(20+3) = 8\times20+8\times3$. The third phase is computation to reach an answer. In order to use this tool, it is necessary to have an understanding of the concept of numbers, the properties of operations, mental arithmetic and problem-solving abilities. These attributes are listed separately in the curriculum but are never brought together. Given the correct guidance in the classroom, children can use this powerful tool. It should be included in the curriculum and form part of teacher training.

What is important is that breaking down the numbers and deciding on the transformation is not taught, but children are allowed to make their own choices and to explain them to others. This free choice of transformation and computation methods affords the child autonomy.

Mathematics education reform should attempt to help teachers and learners to break out of the self-perpetuating cycle by experiencing mathematical power. The overriding strategy is to immerse teachers and learners in a typical mathematical culture.

**Coherence and taskification issues: a long walk to quality mathematics teaching in South Africa (Prof Hamsa Venkatakrishnan, University of the Witwatersrand)**

In engaging with the work of overseas colleagues, it is comforting to note that we are not the only ones with problems in the domain of mathematics teaching and that many of the same problems occur in other countries. Task propensity in South Africa is compounded and can be complicated by evidence of gaps in teachers’ mathematical knowledge in the middle grades and beyond. In addition, this lack of content knowledge feeds into the side-lining of higher cognitive demand tasks in teaching. The evidence of limited coverage of these types of tasks leads to changes in curriculum coverage. Possible teacher buy-in exists, but very little learning occurs. Instruction in schools is highly teacher directed, often with choral chant learner input in response to closed questions. All these factors contribute to low levels of mathematical performance at all levels.

In examples from classroom interactions, it became clear that part of the problem was not necessarily a lack of understanding of the problem by the teacher but that the instructions given to the class were not coherent and the teacher narrative did not quite match the representations of the task on the blackboard. Answers were reached, but because of the lack of accurate instruction these were not always the correct mathematical answer. Teachers can obviously do division, but in the instructional stage things go wrong.

There are many examples to illustrate the lack of coherence in the instructional phase; for instance, the problem on the board in a high school classroom was $x^2 > 4$, which the teacher solved, created the parabola and then moved on to the algebra without any intervention from the students. This type of scenario is described by Sfard (2017) as ‘the teaching seems to indicate the teacher’s conviction
that choices of steps can only come from memory and require no explanation…references to mnemonics were numerous and frequent. Another example that that of a grade 2 class that was asked to give two numbers that added up to 16 and then to check their answers by counting rather than viewing them as connected objects.

This type of teacher intervention can be categorised as ‘teaching without a mathematical sensibility’. Steps, rules and representations are seen as arbitrary rather than ‘reason-able’. There are gaps in the coherence of the narrative, though often accompanied by a ‘correct’ answer. Even at a very early stage, mathematics is taught as separate empirical results, rather than as ‘derive-able’ connected results. Any interventions designed to improve mathematics teaching need to build mathematical sensibility and to support teachers to teach mathematics coherently and in connected ways.

From the research conducted by Prof Gravemeijer, it is clear that the emphasis should be on curricula focused on advanced conceptual mathematical goals, which are not the same as conceptual understanding or high cognitive demand. Curricula are generally framed without this goal, and textbooks miss the attention to realistic mathematical education. In the absence of the goals and given the shortcomings of the textbooks, students developed well-grounded ways of solving specific problem types but could not manage tasks that transcend this set.

Advanced conceptual mathematical goals include foundations in reification of processes into objects, and emphasis on structure sense linked to operational sense. Numbers, sums and differences have to become mental objects that can be composed and decomposed in different ways, which in turn forms the basis for flexible arithmetic and an expansion to bigger numbers, and later to integers and algebra. Interventions should focus on the curriculum and textbooks.

The Wits Maths Connect group develops projects and processes that could be implemented nationally to improve mathematics teaching. Three projects have been undertaken, the first of which was the Structuring Number Starters project. The focus of this project is on number structure with tasks that attend to number relationships alongside a focus on calculations. The primary maths curriculum stipulates 20 minutes in each lesson for mental maths and consolidation of concepts, but the evidence points to a predominance of choral chant counting activities during this part of the lesson. This activity keeps everyone busy, but does not go further than that. This time was used to introduce the Structuring Number Starters project. Workshops are held with the participating teachers to discuss the models that are employed and their use. Once a term, pre and post diagnostic assessments are made. In marking the exercises completed by learners, there is a focus on where the children have succeeded. Rather than moving on, we linger and consider language and symbols that highlight the relationships of the numbers to enhance understanding. The results are encouraging and showed a marked increase of more sophisticated methods being used by 23.9% of learners in 2011 and 53.4% in 2014.

The second project focused on multiplicative reasoning. This involved solving multiplication and division problems through attention to structure, relations and calculation. This work was underpinned by a hybrid theoretical base involving realistic mathematics education (RME), variation theory to get children thinking and analogical reasoning. Lesson plans and materials were discussed with teachers and made available online. The project included a pre-test, a four-intervention sequence (with one lesson per week) and a post-test across participating teachers. The first cycle of the project involved six schools, with data from another four schools functioning as a control sample.

The project lesson principles included that learners should be fluent in rapid recall of multiplication and division facts; that learners could identify different problem types and have the language to describe these; and that learners should work with key representations such as T-tables and arrays to help them to be more efficient. The outcomes of the project showed considerable improvements in understanding and working methods of learners also improved.

The third project was a collaborative initiative between the South African Numeracy Chairs (SANC) Project, the Department of Basic Education and professional and research bodies. It focused on looking at a possible foundation phase diagnostic assessment tool.

While the curriculum stipulates strategic calculating, the assessment process works against this by marking for correct answers rather than for efficient flexible calculation. The development of items focused on key early number strategies: bridging through 10, jump strategies, re-ordering, the
relationship between + and -, compensation, doubling and halving. All of these strategies rest on known or rapidly recalled facts, mostly set in the 1–20 number range.

Three item categories were identified, namely rapid recall, which includes basic doubles, add/subtract and triples in the 1–20 range; strategic calculating which shows that items such as 99+99 are laborious when done in procedural calculation orientation but can be easy to compute mentally if recognised in relation to 100+100; and strategic thinking which includes items focused on number structure, properties and relationships, and the behaviour of operations, rather than on operating.

A two-to-three week testlet format focused on a particular cluster (e.g. bridging though 10) and included rapid recall, strategic calculating and strategic thinking items. The tests were time limited to avoid pages of counting and were marked by teachers. Guidance was provided regarding activities related to specific clusters. Re-testing provided feedback on the success of the teaching intervention.

The results in the initial feasibility trials in Gauteng and the Eastern Cape are promising, and the Department of Basic Education has made a commitment to rolling this out at a national level, probably in three provinces. The South African Numeracy Chairs will be involved in the teacher training.

In the South African context, we need to resist task propensity whilst dealing with the well-grounded ways of solving a specific set of problem types. We also need to develop practical policy/curriculum/textbook assessment messages to support research initiatives. We need to assess what is the same and what is different across the examples that we have. We need to focus on key questions such What further results could we work towards? How do we talk to teachers about the type of mathematics teaching that we value? How do we build mathematics connections that will start to build structure and generality?

DAY 3

Improving the quality of mathematics teaching and learning on a large scale: challenges and opportunities (Paul Cobb, Vanderbilt University, Nashville, USA)

The work of the university research team over the last 12 to 13 years has focused on improving mathematics teaching and learning through the development of the Middle-school Mathematics and the Institutional Setting of Teaching (MIST) project.

The USA has a decentralised educational system in which each state is divided into many independent school districts. These school districts have control of schooling in terms of textbooks and support to teachers and set their own standards and assessments. A national programme entitled No Child Left Behind (NCLB) was introduced to improve the standard of mathematics and English in schools. Targets were set and increased each year, but the process achieved only limited success as it did not necessarily align with state thinking and was very procedural in nature. More recently, a new process of standardisation called the Common Core State Standards for Mathematics (CCSSM) was introduced, which has improved assessments at a more perceptual level of understanding.

The MIST programme works at an urban district level and is a reorganisation rather than a mere extension or elaboration of current practices. The scope of the project between 2007 and 2011 involved four large urban districts with 360,000 students and focused on analyses to inform the revision of district instructional improvement strategies. From 2011–2015, the project team worked in two large urban districts with 180,000 students and co-designed and co-led professional development for principals and coaches. In this phase a research practice partnership was established, and the concept that the team do research with rather than on schools was reinforced.

The teaching districts are generally characterised by limited financial resources since all their funding comes from local sources and they generally have a high proportion of students from traditionally underserved groups, with up to 50% of students not having English as their first language. In these districts, there is high teacher turnover and a high proportion of novice teachers.

The research practice partnership was formed with districts that were aiming at rigorous goals for all students’ mathematical learning and were attempting to improve the overall quality of instruction. These districts had also typically implemented reasonably coherent sets of improvement strategies and forged a common improvement agenda with district leaders. Partner districts adopted materials of instruction consistent with rigorous learning, and the lesson structure first introduced rigorous
mathematical tasks followed by small group or individual work and then whole-class discussion. Teachers encouraged students to explain and justify their reasoning and to make connections between different solutions. Tasks followed a basic structure but also involved number string tasks including sequencing.

The pragmatic goal of the MIST project was to add value to the districts’ instructional improvement efforts. The research goal was to develop an empirically grounded theory of action for instructional improvement in mathematics. It was envisaged that this theory would include a set of policies or strategies to support the learning of teachers and others, and a rationale to explain why it is reasonable to expect these strategies to be effective.

Literature reviews were conducted to assess the real situation and test the initial conjectures. It was initially felt that there would be a need to research mathematics education, teacher education and education policy and leadership as well as instructional materials and associated resources. Teacher professional development, teacher collaborative groups, school instructional leadership and district leadership also formed part of the initial thinking. The selected research process entailed testing, revision and elaboration of initial conjectures to form the basis for the development of a theory of action for large-scale instructional improvement in mathematics.

The initial participants included six to ten schools and 30 middle-grade mathematics teachers in each district, as well as mathematics coaches and school leaders. The position of coach is common in the USA and should ideally be an accomplished teacher charged with supporting other teachers. Principals, assistant principals and district leaders were also included. In total, some 200 people were involved.

Data were collected in annual cycles and analysed, and the results were fed back to participants. The cycle started in October with interviews with district leaders to document current strategies for improving middle-school mathematics. From these interviews, district design documents were prepared and checked with district leaders. These design documents formed the basis for the ongoing work.

From January to March, data were collected on how district strategies were actually being implemented in schools and classrooms. Audio-recorded interviews were conducted with some 200 participants, which included questions specific to particular schools and districts where participants were employed. The interviews explored sources of support, reporting structures and what participants are held accountable for. Teachers, coaches and school leaders also completed online surveys. The data were analysed, and the results provided feedback on the pragmatic goal of the MIST project.

In order to provide feedback on the research goal of the project, video recordings were made of two consecutive lessons in the participating teachers’ classrooms. The video recordings were coded using a specially developed Instructional Quality Assessment (IQA) tool and assessments included teachers’ and coaches’ Mathematical Knowledge for Teaching (MKT). In addition, video recordings were made of district professional development interventions as well as audio/video recordings of teacher collaborative time. An on-line assessment of teacher networks was completed by all the mathematics teachers in the participating schools. To assist in providing comprehensive feedback the research team was given access to district student achievement data.

From February to May, the transcripts of the 200 interviews were analysed and the gaps and differences between the intended and implemented improvement strategies of each district were identified and explained. A detailed report of the findings, together with actionable recommendations, was prepared for the leaders in each district.

In May, meetings were held with district leaders to discuss the findings and recommendations. It was encouraging that when the plans for the following year were reviewed, up to 67% of the recommendations from the project had been implemented, which showed some progress in achieving the pragmatic goal of the MIST project.

The research team includes project leaders and co-project leaders from Vanderbilt University, University of California, University of Washington and Michigan State University. Several postdoctoral fellows and doctoral students have also been involved, and there has been additional collaboration with members of staff at Duquesne University.
A coherent instructional system needs to include a teacher learning sub-system with teacher collaboration, mathematics coaching and teacher networks aligned with the central goals and vision. Another component that was found to be important was supplemental support for currently struggling students. Instructional materials and assessments must also form an integral part of planning. Support to struggling students was not included in the initial scope of the study, but it was found that all districts were providing some form of support. It was found that most of the extra lessons provided were not necessarily very useful and were focused at a very basic level, which was unfortunate as these were an additional expense for the district and a drain on limited budgets.

Teachers’ knowledge and instructional practices were assessed through the Instructional Quality Assessment (IQA) process using video recordings of lessons, assessment of potential tasks and assessment of the quality of task implementation. The IQA coding scheme ranks the assessments from 1 to 4 as follows:
1. Memorising or reproducing facts, rules, formulae or definitions.
2. Using specified procedures.
3. Using procedures with connections to underlying mathematical concepts.
4. Doing genuine mathematics, including exploring, justifying, explaining and generalising.

A multiple-choice instrument was designed to assess MKT. The assessments included testing mathematical knowledge that is specific to the practice of teaching and the Vision of High-Quality Mathematics Instruction (VHQMI). Interviews were conducted to discuss the nature of the tasks, the nature of the whole-class discussions and the role of the teacher. The teachers’ VHQMI was that the Instructional Quality Assessment of teachers with higher VHQMI scores was more likely to improve. Teachers’ VHQMI related to selecting cognitively demanding tasks and maintaining a level of challenge throughout lessons.

Teachers’ Views of Students’ Mathematical Capabilities (VSMC) were tested through interviews and were grouped into two dimensions. A diagnostic dimension which included explanations of the source of student success or failure, and a prognostic dimension which provided descriptions of the support provided to students who are perceived as struggling.

In describing student difficulties less than 20% of teachers attributed these difficulties to limited instructional or schooling opportunities, almost 30% attributed difficulties of students to their families or their communities and less than 20% described making productive adjustments to their instruction. Teachers with productive VSMC are more likely to maintain the cognitive demand of tasks and conduct higher-quality classroom discussions in which students have opportunities to explain their reasoning. It also became clear that teachers are influenced by the racial, ethnic and linguistic composition of the classes they teach. Teachers’ instruction is unlikely to improve unless they have developed both relatively sophisticated VHQMI and productive VSMC.

From the data collected, two dimensions were identified and the answers were coded accordingly. One of these dimensions was unproductive and did not form part of the education system over which teachers could have an influence, and the other dimension was productive in that interventions could be introduced to improve students’ understanding.

The implications of these results show that MKT clearly matters, but that supporting improvements in teachers’ MKT is not sufficient unless there is a focus on continued support to encourage the hard work required to improve the quality of instruction. Support and motivation were shown to increase the level of challenge of the tasks that the teachers select, the extent to which they maintained that level of challenge and the extent to which they elicited and built on their students’ thinking.

High-quality professional development is organised around the instructional materials that are used. Interventions are sustained over time, with each session building on the previous ones. The interventions focus on a small set of high-leverage aspects of instruction and on the students’ thinking in relation to the instruction. The goals of pull-out teacher professional development are to support teachers in reorganising their current practices. It was found that often pull-out professional development interventions were not specific to mathematics and were thus of limited value in the mathematics classroom. Support for teachers’ learning include pull-out professional development, teacher collaborative time and coaching. None of these interventions were found to be very helpful in isolation. The different types of support need to be coordinated and combined to build a complete system.
The rationale for instructional coaching is that coaches who have developed ambitious instructional practices can be of assistance to colleagues. Coaches co-participate with teachers in activities close to instructional practice, conduct one-on-one sessions in teachers’ classrooms and attend teacher collaborative meetings. In identifying potentially productive one-on-one coaching activities, criteria are set, interactions are sustained over time, and the focus is on high-leverage aspects of instruction. Students’ thinking is in the foreground, and the process involves both investigating and enacting ambitious forms of practice. Empirical evidence can support teachers’ development of ambitious instructional practices.

Several activities are recommended as a result of working one-on-one with teachers in their classrooms, include modelling instruction with a coach teaching and the teacher observing; support for the development of a vision of specific instructional practices; and the development of productive views of their students’ current mathematical capabilities. Co-teaching is another positive outcome of coaching as well as support for the implementation of specific instructional practices. Coaches provide valuable feedback to teachers based on observation.

Coaches require content-specific pedagogical expertise, ambition and equitable instructional practices. Relatively sophisticated mathematical knowledge is required for teaching, as well as productive views of students’ current mathematical capabilities. It is essential for coaches to build relationships and trust, as it can be intimidating for teachers to make their work public. Listening and the ability to negotiate improvement goals with teachers are other important attributes for a coach.

It was found that successful groups used a facilitator who could press and support teachers to explain their pedagogical reasoning while maintaining trust, and could provide detailed descriptions and analyses of students’ thinking. Facilitators should consider how instruction might be improved to support students’ learning more effectively.

In teacher advice networks, interaction with colleagues with more sophisticated instructional practices supports the development of the teachers’ instructional ability. The quality rather than the quantity of teacher collaborative time influences whether teachers seek advice from one another outside of meetings, and in general the advice-seeking relationships tend to last.

In a teacher learning subsystem, coaches can play a key role in coordinating the various elements and fill a leadership role in pull-out professional development sessions that focus on particular aspects of instruction. Coaches can lead or participate in teacher collaborative meetings that focus on a specific aspect of instruction and support teachers in implementing these aspects of instruction in their classrooms.

Project papers, redacted feedback reports, interview protocols and surveys can be downloaded http://vanderbi.lt/mist.

Managing a plurality of ideas and recommendations (Prof Satsope Maoto, Faculty of Humanities, University of Limpopo)

Classroom reform is understood to be a shift towards goals and classroom practices as advocated in theories such as Realistic Mathematics Education (RME) from Holland, Didactical Situations from France, Problem-centred Learning from the USA and South Africa, and Cognitively Guided Instruction from the USA. RME focuses on learner-centred instructional approaches that enable learners to move from their own intuitive solutions to more sophisticated formal strategies of working on problems.

The word ‘realistic’ in RME refers to presenting learners with problem situations that they can imagine, either from the real world or the more formal world of mathematics. A distinction is made between horizontal mathematisation which involves going from the real-life world into the world of mathematics, and vertical mathematisation within the world of mathematics, including the process of reorganisation resulting in shortcuts using connections between concepts and strategies.

The principles associated with RME include the activity principle in that learners are active participants in the learning process; the reality principle aimed at students’ ability to apply mathematics, which occurs at both the beginning and the end of the learning process; the level principle in that learners pass various levels of understanding in learning mathematics; the intertwinenment principle in that mathematical domains or topics are not considered as isolated
curriculum chapters but as integrated areas; the interactivity principle, which makes the learning of mathematics not only personal but also a social activity with a preference for whole-class teaching activity; and the guidance principle in that learners are provided with a guided opportunity to reinvent mathematics.

The core tenet is that mathematics should be meaningful, and learners should be active in constructing their own knowledge and experience mathematics as a human activity. Students should also be able to reinvent conventional mathematics by mathematising both subject matter from reality and mathematical matter under the guidance of a teacher.

The ultimate aim would be the development of a reform classroom in which the programme of work would consist of learning activities that provide for the development of basic skills and factual knowledge representations. These programmes would be interspersed by periods or sessions in which learners engage with challenging tasks and productions that emerge from the basic skills. Ideally, the process would be to engage, articulate, reflect, refine and extend, which is not a linear process and should be re-enacted frequently where appropriate in the learning process. The expectations of a reform classroom are that more than procedural and factual knowledge will be produced, and that learners would learn to act mathematically and acquire conceptual knowledge. With this new knowledge, learners will acquire productive dispositions with respect to mathematics and will engage in mathematical practices in increasingly sophisticated ways. Reform will not be immediate, but should grow and bring gradual sophistication to procedures and articulation.

There is general agreement that learners should be put at the centre of learning and that they should be taught to engage in challenging tasks. The issue is how to engage with and support learners. Given South Africa’s Curriculum and Assessment Policy Statements (CAPS) for various phases, many views still exist on the teaching and learning of mathematics. A draft document has been prepared by the Ministerial Task Team on the Mathematics Teaching and Learning Framework for South Africa, entitled Teaching Mathematics for Understanding, but this still has to be formally presented to the wider mathematics education community.

The South African CAPS defines mathematics as ‘a language that makes use of symbols and notations – it is a human activity which helps to develop mental processes that enhance logical and critical thinking, accuracy and problem-solving that will contribute in decision-making’. In interpreting this definition in the context of the mathematics classroom, mathematics teachers should plan and present lessons that engage learners in conceptual thinking about mathematical ideas and develop their mathematical language. Teachers should also build learners’ procedural competence in ways that enable them to use mathematical procedures effectively in both routine and problem-solving activities.

Teachers’ are at the epicentre of the learning process and must be supported. Changing the teaching and learning of mathematics requires the designing of quality tasks for learning, articulating advanced curriculum goals, and providing adequate initial teacher education and in-service training. In South Africa, a quick response to the question of what makes reform difficult would be that as long as teachers do not see their role changing with reforms, nothing will change in the classroom. Without teachers experiencing the kind of teaching and learning envisaged, the good intentions will never be realised. Teachers are trying their best from their own perspective; they have done the teaching, but the question is whether learning has taken place.

The mathematics performance of learners is affected by a variety of teaching and learning styles found in mathematics lessons, each of which depends on or is influenced by the teachers’ knowledge of mathematics. Teachers are very special people, but we seem to want them to be superhuman. We do not have time to experiment with learners; we have only one chance to educate them and equip them for the future. The kinds of tasks, questions, classroom interactions and targeted content that ground mathematics teaching and learning within and across the various levels of education generally seem to lack coherence, focus and appropriate articulation.

At the centre of teaching for conceptual understanding is the learner, who could be a student, teacher or educator. The goal is for the learner to be involved in the development of learning materials and to develop self-identity. Learner–learner and learner–facilitator engagement is expected in all classrooms, and whole-class involvement is essential.
Different levels and types of engagement enable learners to make sense of mathematical concepts and assist in the formation of opinions for use in later engagements. Learner–learner engagement promotes spontaneity and provides a base for further refinement of thought. Learner–facilitator engagement offers the opportunity to engage individual learners through productive engagement situations followed by reflection and the development of capacity to act mathematically. Whole-class engagement is the ultimate forum for clarifying and consolidating thoughts. There is a need for the creation of an environment that nurtures and refines learners’ intuitions and technical skills through engagement.

Success in mathematics requires a shared philosophy of teaching and learning. Unless teachers, tertiary educators, curriculum developers and material developers (textbook authors) see their roles changing through reforms, nothing will change in the classroom. Quantity and quality are national needs and require educators to design good tasks, policy writers to clearly articulate advanced curriculum goals, teachers to receive sufficient training and professional support, and textbook writers to design effective materials. Quality is everyone’s responsibility.

Constructive alignment is essential. If we agree that students should be given room to work on their own solutions, there is also room for teachers, teacher educators, teacher counsellors, researchers and developers of mathematics education, and textbook authors to include their own nuances in the core ideas of reform. Implementation accompanied by ownership for all involved in the reform process is an essential value.

There should be constructive alignment among the kinds of tasks, questions, classroom interactions and targeted content that ground mathematics teaching and learning within and across the different educational levels. The teaching and learning of mathematics should remain anchored in the bigger picture in such a way that mathematics is meaningful, accessible, expandable and transferable.

Reform requires the professional development of teachers. Teachers learn in the same way as learners. In order for teachers to expose learners to experiencing mathematics, they should have experienced it themselves. An integrated approach is important, since it has been said that there is no mathematics worth learning that can be broken down into lesson-size pieces. Teacher education requires constructive alignment across and within all levels, and curriculum design should take care of expectations at school level. Classroom interactions should model what we expect student teachers to practice in schools.

Greater achievement requires effort and focus, and the heights can only be achieved by those who are inspired to do so.
APPENDIX 1: SUMMARY OF POLICY ISSUES THAT EMERGED FROM THE PROSET/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 learners 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 Mathematics, Science and Technology (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 B.Ed. 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
- proSET should discuss how they could help to lift the low ceiling of STEM education.
- The NSTF should consider awarding Oscars to MST educators.
## APPENDIX 2: LIST OF ACRONYMS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ANA</td>
<td>Annual National Assessment</td>
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<tr>
<td>B.Ed.</td>
<td>Bachelor of Education</td>
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<tr>
<td>CAPS</td>
<td>Curriculum and Assessment Policy Statement</td>
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<td>CPTD</td>
<td>Continuing professional teacher development</td>
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<tr>
<td>FET</td>
<td>Further Education and Training</td>
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<td>GET</td>
<td>General Education and Training</td>
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<tr>
<td>HRDC</td>
<td>Human Resource Development Council of South Africa</td>
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<tr>
<td>IQA</td>
<td>Instructional Quality Assessment</td>
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<tr>
<td>MIST</td>
<td>Middle-school Mathematics and the Institutional Setting of Teaching</td>
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<tr>
<td>MKT</td>
<td>Mathematical Knowledge for Teaching</td>
</tr>
<tr>
<td>MST</td>
<td>Mathematics, Science and Technology</td>
</tr>
<tr>
<td>MTT</td>
<td>Ministerial Task Team</td>
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<tr>
<td>NDP</td>
<td>National Development Plan</td>
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<tr>
<td>NGO</td>
<td>Non-government organisation</td>
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<tr>
<td>NSTF</td>
<td>National Science and Technology Forum</td>
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<tr>
<td>proSET</td>
<td>Professionals in science, engineering and technology</td>
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<tr>
<td>RME</td>
<td>Realistic Mathematics Education</td>
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<td>SACE</td>
<td>South African Council for Education</td>
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<td>SAARMSTE</td>
<td>Southern African Association for Research in Mathematics, Science and Technology Education</td>
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<tr>
<td>SEACMEQ</td>
<td>Southern and Eastern Africa Consortium for Monitoring Education Quality</td>
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<tr>
<td>SAMF</td>
<td>South African Mathematics Foundation</td>
</tr>
<tr>
<td>SET</td>
<td>Science, engineering and technology</td>
</tr>
<tr>
<td>STEM</td>
<td>Science, technology, engineering and mathematics</td>
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<tr>
<td>TIMSS</td>
<td>Trends in Mathematics and Science Study</td>
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<tr>
<td>VHQMI</td>
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<td>VSMC</td>
<td>View of Students’ Mathematical Capabilities</td>
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### APPENDIX 3: LIST OF DELEGATES

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
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<tbody>
<tr>
<td>Dr Motshidisi Lekhu</td>
<td>Central University of Technology (CUT)</td>
</tr>
<tr>
<td>Mr Watson Manduna</td>
<td>CUT</td>
</tr>
<tr>
<td>Ms Sister Mapiyeye</td>
<td>CUT</td>
</tr>
<tr>
<td>Mr Odirile Mashalane</td>
<td>CUT</td>
</tr>
<tr>
<td>Mr Itumeleng Phage</td>
<td>CUT</td>
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<tr>
<td>Prof Wendy Setalentoa</td>
<td>CUT</td>
</tr>
<tr>
<td>Mr Johan de Koker</td>
<td>Chamber of Engineering Technology</td>
</tr>
<tr>
<td>Mr Simangaliso Twala</td>
<td>COUNT Educational Institute</td>
</tr>
<tr>
<td>Miss Sindiswa Mcosana</td>
<td>Department of Basic Education</td>
</tr>
<tr>
<td>Mr Pranay Devchand</td>
<td>Gauteng Department of Education</td>
</tr>
<tr>
<td>Dr Dudu Mkhize</td>
<td>Human Resource Development Council of South Africa</td>
</tr>
<tr>
<td>Mr Mohamedn Sameer Hoosain</td>
<td>Institute of Electrical and Electronic Engineers</td>
</tr>
<tr>
<td>Mr Michael Cameron</td>
<td>Institute of Technological Professionals of SA</td>
</tr>
<tr>
<td>Dr Mampone Seopa</td>
<td>Limpopo Department of Education</td>
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<tr>
<td>Dr Lynn Bowie</td>
<td>OLICO Mathematics Education</td>
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<tr>
<td>Mr Julius Olubodun</td>
<td>ORT South Africa</td>
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<tr>
<td>Mr Peter Horszowski</td>
<td>PERT Industrials</td>
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<tr>
<td>Mr Fannie Matumba</td>
<td>Programme for Technological Careers</td>
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<tr>
<td>Mr Richard Gundersen</td>
<td>proSET Committee Member</td>
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<tr>
<td>Dr Bruce Brown</td>
<td>Rhodes University (RU)</td>
</tr>
<tr>
<td>Dr Nyameka Kangela</td>
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<tr>
<td>Dr Trueman Goba</td>
<td>SA Academy of Engineering</td>
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<tr>
<td>Dr Gerda Botha</td>
<td>SA Council for Natural Scientific Professions</td>
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<tr>
<td>Mrs Theresa Hattingh</td>
<td>SA Institute of Industrial Engineers</td>
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<tr>
<td>Mr Mark Herbert</td>
<td>SA Institute of Physics</td>
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<tr>
<td>Mr Herman Bosman</td>
<td>SA Mathematics Foundation (SAMF)</td>
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<tr>
<td>Prof Kerstin Jordaan</td>
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<tr>
<td>Mr Bjorn Hufkie</td>
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<td>Mr Dawie Botha</td>
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<td>Dr Janine Victor</td>
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<tr>
<td>Mrs Carine Steyn</td>
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<td>Mr Waldo Viljoen</td>
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<td>Prof Dirk Wessels</td>
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<td>Dr Linda Bosman</td>
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<td>Ms Jeanne-Mari du Plessis</td>
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<tr>
<td>Mr Andrew Hofmeyer</td>
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<tr>
<td>Prof Piet Human</td>
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<tr>
<td>Mr Enoch Masemola</td>
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<td>Mr Humphrey Nkgogo</td>
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<tr>
<td>Mrs Cally Kuhne</td>
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<tr>
<td>Dr Busisiwe Alant</td>
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<tr>
<td>Dr Angela James</td>
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<tr>
<td>Mr Zwelithini Bongani Dhlamini</td>
<td>University of Limpopo (UL)</td>
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<tr>
<td>Prof Satsope Maoto</td>
<td>UL</td>
</tr>
<tr>
<td>Mrs Kgaladi Maphutha</td>
<td>UL</td>
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<tr>
<td>Mr Lekwa Mokwana</td>
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</tr>
<tr>
<td>Mr Dimakatjo Muthelo</td>
<td>UL</td>
</tr>
<tr>
<td>Mr Monare Setati</td>
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</tr>
<tr>
<td>Prof Hlengani Siweya</td>
<td>UL</td>
</tr>
<tr>
<td>Mrs Babele Moletsane</td>
<td>University of the Free State</td>
</tr>
<tr>
<td>Prof John Bradley</td>
<td>University of the Witwatersrand (Wits)</td>
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<tr>
<td>Dr George Ekol</td>
<td>Wits</td>
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<tr>
<td>Mrs Samantha Morrison</td>
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<tr>
<td>Dr Williams Ndlovu</td>
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<tr>
<td>Dr Craig Pournara</td>
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<tr>
<td>Mrs</td>
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</tr>
<tr>
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<td>Ingrid Sapiere</td>
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<tr>
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<td>Hamsa Venkatakrishnan</td>
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<tr>
<td>Dr</td>
<td>Lyn Kok</td>
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<tr>
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