Research Article

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Accessible chemistry: the success of small-scale laboratory kits in South Africa

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Abstract: Chemical innovations enhance our quality of life by responding to challenges in e.g., energy production, medical care, and material development. Studying and understanding chemistry is essential for future solutions. However, chemistry is not accessible to all learners. In South Africa, the challenge is to make chemistry accessible to all participants, especially in the North West province, in poor schools without easy access to resources and with inadequately trained teachers. One way to make chemistry more accessible is through micro-scale chemistry. With this goal in mind, the MYLAB small-scale chemistry kit was designed. The kit was developed around the 5 ml test tube (our size determinant). We wanted all learners and teachers to have hands-on, minds-on chemistry practical experience. Thus, workshops were organised to (i) train the teachers in the use of the kits and (ii) to allow learners to experience practicals hands-on. This article gives an overview of how the use of the MYLAB small-scale chemistry kit was successful in making chemistry accessible to all.

Keywords: small-scale apparatus; chemistry education; teacher training; hands-on experiments; kits for practical work

1 Introduction

Chemistry is a subject where physical resources and practical experience are needed (Abdullah et al., 2009; Kimel et al., 1998; Tesfamariam et al., 2014, 2017). The subject cannot be taught on a purely theoretical basis. Science teachers should emphasise practical work in science (Kerr et al., 1963).

One way to make chemistry more accessible is through micro-scale chemistry. As stated by Singh et al. (1999), “Micro-scale chemistry is a laboratory-based, environmentally safe, pollution-prevention approach accomplished by using miniature glassware and significantly reduced amounts of chemicals”. Micro-scale chemistry can be implemented without compromising educational standards or analytical rigour and is a laboratory-based green chemistry approach, which means that no hazardous products are generated or used (Singh et al., 1999). With micro-scale and small-scale, there is a reduction in contact with toxic materials, solvent use, reaction times, the cost of chemicals, and storage space. The possibility of fires and explosions are almost eliminated (Abdullah et al., 2009; Kimel et al., 1998; Singh et al., 2000).

The Chemistry Education Policy of the Royal Society of Chemistry (Royal Society of Chemistry, 2023) has a catchphrase on its website: “Everyone deserves an engaging, relevant, and inspiring chemistry education”. We would also like this to be true in South Africa. Currently this type of chemistry education is not reflected in international achievement data of student success in South Africa (TIMSS, 2019).

Hence, in South Africa, the challenge is to make chemistry accessible to all participants in the subject, especially in rural schools in far-flung regions without easy access to resources, to address the poor academic results we experience in chemistry at school level (du Toit, 2021; Kimel et al., 1998; TIMSS, 1999, 2019). The absence

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of practical work at the school level was addressed in a South African study about chemistry for the masses (du Toit, 2021). It was found that the lack of practical work negatively impacts the understanding of chemistry concepts and does not contribute to eliminating chemistry misconceptions. The appeal by Howie (2001) still holds: "There is an urgent need for programmes to be put in place, which will nurture the apparent positive attitudes towards science, to build up pupils' fundamental knowledge and understanding of the basic concepts in science as well as that of the teachers".

Therefore, at the North-West University (NWU) in South Africa, the MYLAB small-scale kit (MYLAB, 2022) was developed to make chemistry more accessible to all teachers and learners. The development was based on the concept that "better visualisation leads to better concept formation in chemistry". The kits are self-sufficient for teaching Physical Sciences or Natural Sciences in South African schools and can overcome some resource barriers. We wanted all learners and teachers to have hands-on, minds-on chemistry practical experience.

Ethiopia has similar challenges to South Africa, and they also experimented with the MYLAB small-scale chemistry kits in selected secondary schools in their country. The Ethiopian results indicated enhanced learner understanding of chemistry concepts and teachers' and learners' enjoyment of using the kits. The highlighted features were cost-effectiveness, time-saving, easy usage, and safety factors (Tesfamariam et al., 2014).

Furthermore, in another Ethiopian study, the MYLAB kits were investigated as an application in undergraduate chemistry classes. Due to various challenges, practical work is not carried out in chemistry classroom instruction in developing countries. The MYLAB kits were researched to increase learners' chemistry concept formation and encourage positive attitudes toward chemistry. These results showed an improvement in learners' attitudes (similar to traditional scale apparatus); however, small-scale kits were more effective in increasing learners' understanding of chemistry concepts. The MYLAB kits were a successful strategy for teaching chemistry practical work to first-year undergraduates (Tesfamariam et al., 2017).

The aim of this paper is to demonstrate the effectiveness of using small-scale chemistry kits to make chemistry accessible to all, especially in rural areas. Chemistry is made accessible when: (i) apparatus is provided where laboratories and apparatus are absent; (ii) Teacher Manuals (the memo) and Learner Manuals are provided to address lack of knowledge and knowledge transfer; and (iii) workshops are given to train teachers in presenting practical work. Therefore, workshops were organised for selected local teachers and learners in the North West province. The goal of the workshops was to support the local teachers in presenting chemistry practical work. With workshops in rural and urban areas, we support and empower teachers to be confident and knowledgeable in performing all the experiments required in the curriculum. Thus, the MYLAB small-scale chemistry set provides an inexpensive solution to the problem of inadequate apparatus in the school and the workshops to the inadequate teacher subject knowledge and pedagogical content knowledge.

1.1 Challenges faced by South Africa schools

Focusing specifically on science education, according to the TIMSS (Trends in International Mathematics and Science Study) reports (1999, 2019), South African pupils performed poorly compared to other participating countries. Only the most proficient pupils in South Africa attained the level of the lowest-achieving pupils from Singapore. A few problem areas were identified, including the fact that the knowledge level of most teachers is insufficient due to the shortage of graduate science teachers (Ntuli & Mudau, 2023; TIMSS, 1999, 2019). As early as 1995, many well-educated and experienced teachers in critical areas such as mathematics and science left the profession because of teacher retrenchments and redeployments. Schools were forced to employ teachers with insufficient science knowledge (Spaull, 2013; TIMSS, 1999, 2019). Learners also lacked basic science knowledge and appeared unable to express themselves in writing. The learners had a very poor self-concept in science which is defined as the self-perception of their skill in an academic subject and is directly related to their motivation for learning the subject (Schroeders & Jansen, 2022). They find chemistry difficult and believe science is not their strong point (TIMSS, 1999, 2019). The lack of laboratories and the prevalence of incompetent teachers further hinder the opportunity for learners to do chemistry experiments (Ejidike & Oyelana, 2015; TIMSS, 1999, 2019).

Consequently, only a few teachers are capable of doing the experiments and doing them regularly as required by the textbook or syllabus (Department of Basic Education, 2021). Over the years, South Africa has improved internally from only 13 % of its science learners acquiring basic science abilities to 36 % of the science learners demonstrating basic science abilities. However, South Africa is still the lowest-performing country in the science section, with only 1 % of learners reaching the advanced benchmark by communicating a clear understanding of science concepts (TIMSS, 1999).

Therefore, despite four curriculum changes since 1994, the reality of South African education is problematic and inadequate (Wolhuter, 2020). There is an ongoing crisis, and the system is failing most of the South African youth. Of every 100 learners starting in grade 1, only 37 pass the matriculation examination, with only 14 being granted university admission (Council for Higher Education, 2017). In addition, according to an analysis done by Spaull (2012), two education systems exist in South Africa: functional schools (25 %) and dysfunctional schools (75 %). The dysfunctional schools are characterised by a lack of a culture of learning, weak teacher content knowledge, high teacher absenteeism, slow curriculum coverage, extremely weak learning, and most learners fail standardised tests. The system is unequal, inefficient, and underperforming (Spaull, 2012, 2013).

Many South African schools experience resource barriers as well. Townships and rural schools lack basic amenities, infrastructure and learning resources. Sometimes available resources are used inefficiently with little accountability and transparency (Mouton et al., 2013). Several learners in these areas come from families affected by poverty, hunger and parents with little or no education (Mouton et al., 2013). Considering this, the failure of the Education Departments to deliver on their core responsibilities is challenging for the schools.

1.2 National curriculum and assessment policy statement (CAPS)

The CAPS is a National Curriculum and Assessment Policy Statement that is a single, comprehensive, and concise policy document that combines the subject statements, the learning programme guidelines, and the assessment guidelines for each school subject.

South Africa follows an integrated science curriculum set out in the National Curriculum Statement (Department of Basic Education, 2021). The four curriculums since 1994 are: (i) the Common Basic Syllabus (1969), (ii) the Outcomes-Based curriculum, Curriculum-2005 (1997), (iii) the revised National Curriculum Statement, R-NCS (2002) and finally, (iv) NCS with CAPS (2011). Chemistry and physics are integrated into one subject called physical science. From grades 10 to 12, each year, learners have roughly half a year of chemistry and half a year of physics. A very brief overview of the chemistry content areas is presented in Table 1. The National Curriculum and Assessment Policy Statement (CAPS) for physical science is designed to form a framework for innovative teaching and learning in the classroom.

Table 1: Chemistry content areas in South Africa for grades 10 to 12 (Department of Basic Education, 2021).

Matter and materials	Grade 10	Matter and classification; states of matter and the kinetic molecular theory; atomic structure; periodic table; chemical bonding; particles substances are made of.
	Grade 11	Molecular structure; intermolecular forces; ideal gases
	Grade 12	Optical phenomena and properties of materials; organic chemistry; organic macromolecules.
Chemical change	Grade 10	Physical and chemical change; representing chemical change; reactions in aqueous solution.
	Grade 11	Stoichiometry; energy and chemical change; types of reactions (acid-base, redox reactions, oxidation numbers).
	Grade 12	Reaction rate; chemical equilibrium; acids-bases (titrations and salt hydrolysis); electrochemical reactions (cells, cell half-reactions, cell reactions, applications).
Chemical systems	Grade 10	Hydrosphere
	Grade 11	Lithosphere
	Grade 12	Chemical industry (fertiliser industry)
Skills for practical investigations	Grades 10 to 12	Two prescribed chemistry practical activities for formal assessment and four recommended practical activities for informal assessment per grade.

2 Methods

2.1 MYLAB small-scale kits

The kit was designed around the 5 ml test tube. The MYLAB project team wants to empower science teachers, especially chemistry teachers of grades 10 to 12. With the MYLAB small-scale Chemistry and Natural Science kits, we help schools do all the practical work needed in the CAPS curriculum (Department of Basic Education, 2021). The MYLAB kit contains all the apparatus and chemicals for doing the experiments (MYLAB, 2022). The only general apparatus (besides the MYLAB kits) that schools needed was a 2-L milk bottle with water, two 2-L plastic containers and one roll of micro-towels (toilet paper) per kit. Practical work was done in a classroom with ordinary desks. In some cases where laboratories were available, the laboratories were used. The learner and teacher manuals and DVDs for all grades are included in the kits.

2.2 Workshops

Workshops were organised in the North West province of South Africa (Figure 1). The province comprises a land area of 116,000 km^2 with a population of approximately 4 million in primarily rural villages and towns. We report on two specific workshop periods, namely, 2004 to 2006 and 2017 to 2019. The later period was a project funded by Engen (2022). During both workshop periods, the aim was to train teachers to facilitate chemistry practical work for school learners. Teachers were given hands-on experience with the MYLAB kit relevant to their teaching grades whilst having expert help (in the form of university lecturers) available. Problem areas were addressed, and complex theory was discussed. Two independent reports were also commissioned to evaluate the MYLAB kit.

2.3 2004 to 2006 workshops

The request for the workshops came from the North West Education Department, which supplied 400 schools with 20 MYLAB kits per school. The teachers needed training with the kits to facilitate the practical work of the learners. We trained the workshop teams at the university, and the workshop teams trained the teachers in the province. Each workshop team comprised a current or retired chemistry lecturer and a postgraduate chemistry student. We started the workshops for grade 10 teachers in 2004, grade 10 and 11 teachers in 2005, and grade 10, 11

Figure 1: The North West province of South Africa with workshop locations shown in red.

Table 2: The number of workshops that were organised per year and the number of teachers that were trained.

Year	Teachers	Schools	Workshops	Venues
2004	110	110	18	6
2005	262	250	36	12
2006	478	450	69	23

Table 3: The main regions and venues where workshops were organised by the five workshop teams.

Workshop team	Region	Venues
1	Potchefstroom	Potchefstroom & Klerksdorp
2	Mahikeng	Mahikeng & Delareyville & Lichtenburg & Zeerust
3	Vryburg	Tierkloof & Ganyesa & Taung & Mothibistad & Bloemhof
4	Brits	Brits & Mabopane & Temba & Moretele
5	Rustenburg	Rustenburg & Moses Kotane east & Moses Kotane West & Kgetleng river

and 12 teachers in 2006. Tables 2 and 3 show the number of workshops, schools and teachers per year and the main regions (Figure 1) and venues where the workshops were hosted.

2.4 The purpose of the 2004–2006 workshops

For teachers, scientific and technological literacy is the primary purpose of science education today. The workshops were provided to enable teachers to acquire a high level of knowledge and skills in science (a principle of the curriculum) and to persuade teachers to do chemistry experiments in schools. The workshops were also held to help teachers cope with the national curriculum statement (NCS) of South Africa and to train teachers to use the small-scale chemistry kit (provided to schools in the North West province). The teachers became familiar with the specific curriculum experiments and the relevant small-scale chemistry apparatus of the kits. The supplied kits solved the resource problem of the participating schools.

The purpose for learners was to enable them to learn by constructing concepts of experiences they gained from the small-scale chemistry kit. Additionally, it gave learners the experience to do their own hands-on and minds-on investigation and experimental work in chemistry and to be actively involved in inquiry and design experiments.

2.5 Program of the 2004–2006 workshops

All workshops were started with pre-workshop questionnaires and theoretical pre-tests based on the background knowledge needed to complete the practicals for each grade successfully. Participants were introduced to the experiments using a video, explanations, and troubleshooting discussions. Afterwards, the participants did the selected experiments by following and completing the supplied worksheets. Workshop participants then had to complete a post-workshop questionnaire. These teachers completed three two-day workshops to prepare them for each school term of the year. Practical worksheets and theoretical tests were administered by the workshop teams and assessed by the chemistry lecturers to provide a benchmark for awarding a certificate from the university.

2.6 2017 to 2019 workshops

The request for the 2017 to 2019 workshops came from Engen. Engen is an African energy firm that markets petroleum, lubricants and functional fluids, chemicals, and retail convenience services through an extensive network of service stations in Sub-Saharan Africa and the Indian Ocean Islands (Engen, 2022). They were worried about the career possibilities for learners in the district. They wanted learners to have a better chance to succeed in mathematics and physical science to improve their job opportunities. To enhance learners' academic performance, we need knowledgeable teachers. In physical science, teachers needed training, especially in practical work and the use of resources. Engen supplied MYLAB kits for the training of the teachers to enable them to facilitate the practical work of the learners.

In 2017, the Education Department in the Bojanala District (Figure 1) partnered with Engen and One On One Community Based Programmes (Sethole, 2022) as a service provider to start a program in the Moses Kotane municipality to train teachers to improve the learners' performance in Physical Science and Mathematics. The Bojanala Platinum District Municipality is one of the four districts of the North West province of South Africa (Figure 1) and Moses Kotane is one of the five local municipalities under the Bojanala District Municipality.

The project in Moses Kotane East started in January 2017 and ran until 2019, with training for teachers and classes for learners on Saturdays. The six teachers presenting the Saturday classes and 20 additional teachers from nearby schools were trained. The learners enrolled in the program were from three rural schools identified by the Education Department.

Initially, diagnostic tests were done to determine the learners' entrance-level subject knowledge and understanding. Continuous assessments were done to guide the teacher's instruction and to determine subsequent conceptual understanding of the learners. Comparisons between project assessment and school assessment were analysed to determine the effectiveness and impact of the project for the participating learners. The success of the teachers' training was determined informally by post-workshop questionnaires and class discussions.

Unfortunately, similar training plans for Moses Kotane West were cancelled due to COVID-19.

2.7 The purpose of the 2017–2019 Engen workshops

The main purpose of the workshops was to train the six teachers responsible for the Saturday classes. We gave the training to prepare them for the subject content, teaching strategies, chemistry practical work, and possible technology support they could use in the Saturday classes. The 20 additional teachers who attended the training were invited to include them in the program even though their learners were not necessarily part of the current (possible pilot) project.

The aim for ENGEN was to give poorly performing learners a better chance to succeed. Due to time constraints improving underperforming grade 12 learners were not possible. Only stronger Gr 12 learners were included to give them a better chance to get enrolled in a tertiary institution (Table 4). Each grade had an expert Mathematics and Physical Science teacher to present the Saturday classes. In the case of Physical Science, the emphasis was on hands-on, minds-on teaching and practical work and not more "school". The objective was to empower learners with better and deeper conceptual understanding. Again the kits made the project possible and solved the resource problem of the schools.

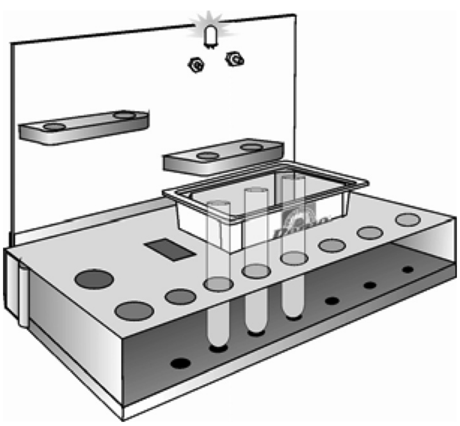
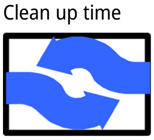
2.8 Program of the 2017–2019 workshops

The six presenting teachers, additional teachers from the three schools from which the learners were chosen, and more teachers from surrounding schools benefited from extra workshop training to develop their professional skills and knowledge. Again, we used pre- and post-workshop questionnaires to enhance and enrich our workshop program on an ongoing basis. We worked on an average of eight Saturday workshops per school term. The purpose of the workshops was to prepare the specialist teachers to present the Saturday classes for the learners

Table 4: The selection criteria of the Education Department for 50 learners per grade from Grade 10 to 12.

Learner participants	Grade	Achievement criteria for selection
50	10	Learners performing between 30 % and 40 %
50	11	Learners performing between 30 % and 40 %
50	12	Learners performing above 50 %

Table 5: Examples from the experiment worksheet about intermolecular forces (IMF) in chemistry in the MYLAB grade 11 manuals.

Experiment 11 (grade 11) outlay (length of the total experiment 35 pages)	– Start with problem question. – Practical outcomes. – Background knowledge questions. – Warning about dangerous chemicals. – Execution of the experiment to answer the problem question(s) – Practical activities (in this case 6) – Home experiments – Cleaning and waste disposal – Learner self-evaluation – Facilitator evaluation
	The MYLAB apparatus stand is about the size of an A5 page (or an A4 page with a centre fold at 90°) All actions in the experimental procedure are illustrated with diagrams or photos to enhance understanding. This is the diagram for the effect of IMF on the solubility of solid substances in different liquids.
	Activities (1) IMF and evaporation (2) IMF and viscosity (2 methods) (3) IMF and surface tension (4 methods) (4) IMF and solubility of solids in liquids (5) IMF and boiling points (6) IMF and capillary action (photo)
Clean up time 	Discuss cleaning and safe waste disposal.

and for the rest of the teachers to transfer those same skills to their regular classes during the week. We did all the curriculum experiments, tested online resources regarding their relevancy and used and discussed complex theory concepts and teaching methods. An example of the experiment about intermolecular forces is shown in Table 5.

The standard procedure for all workshops was one questionnaire for demographic information and one pre- and one post-workshop questionnaire. We used the information to improve workshop presentations and to address specific teaching-learning problems in specific regions. We asked subject advisors and workshop principals for official reports. The teachers' questionnaires are anonymous, allowing them to express concerns or comments. The official reports are not anonymous. We have the participants' consent to use the material for further research and publication.

2.9 Independent evaluation reports

The North West Education Department funded and requested the first report about the 2004–2006 workshops. They invested in the MYLAB project and wanted an independent report on its success (or not) before recommending or denying further development. They gave us permission to use and publish the conclusions of the report. The project was evaluated in October 2006 by the North West province Quality Assurance Chief Directorate as commissioned by Professional Support Services.

The second report was completed by the Sci-Bono Discovery Centre (Sci-Bono Discovery Centre, 2023) as requested by MYLAB on 15 June 2012 as an independent report of the MYLAB kit and training. The centre is a "world-class science centre that supports maths, science and technology education and offers innovative, dynamic learning experiences" in Johannesburg. They also permitted us to use and publish the conclusions of the report.

3 Results and discussion

Our purpose was to make Chemistry accessible to everyone, whether teachers or learners. We used the MYLAB small-scale Chemistry kits to address the lack of physical resources in South African schools and to give teachers and learners a chance to gain valuable experience with practical work. The discussions below indicate the positive results in teacher engagement and learner outcomes.

3.1 2004–2006 workshops

The results of the 478 teachers are documented in Table 6.

There were 478 teachers in the system attending the workshops. 226 Teachers could not attend all three workshops due to the issues faced by rural teachers, such as a lack of transport and the priority of school responsibilities over workshop attendance. Of the 252 teachers (with more than 83 % attendance), 10 % failed, 60 % passed, and 21 % achieved distinction. The 49 teachers (10 % of 478) that failed had insufficient subject

Table 6: The workshop attendance and achievements of the participating teachers (2004–2006) (du Toit, 2006).

Workshop teams	Number of teachers	Incomplete attendance[a]	Fail[b]	Pass[c]	Distinction[d]
Potchefstroom team 1 (4 venues)	73	31	4	25	13
Mahikeng team 2 (5 venues)	112	52	12	37	11
Vryburg team 3 (5 venues)	94	52	11	24	7
Brits team 4 (5 venues)	105	37	16	45	7
Rustenburg team 5 (4 venues)	94	54	6	20	14
TOTAL	478	226	49	151	52
	100 %	47 %	10 %	32 %	11 %

a = less than 80 % attendance. b = mark is less than 50 % and attendance is more than 80 %. c = mark is 50 % or more and attendance is more than 80 %. d = mark is 75 % or more and attendance is more than 80 %

knowledge, underlining the inadequate academic backgrounds of many teachers (TIMSS, 2019). In contrast, the 52 teachers that achieved distinction were encouraged because they could act as mentors for weaker teachers in their school region.

The pre-workshop questionnaire analysis confirmed that too many teachers are underqualified to teach at grade 10 to 12 school level (TIMSS, 2019). Schools still do not have sufficient apparatus and chemicals to do practical work in chemistry, and too few chemistry experiments are done by learners. These challenges are reflected in the teachers' low marks.

The participants had an average test score of 57 %, indicating poor subject knowledge (du Toit, 2006). As the difficulty of the subject matter increased, the test results fell. However, the practical results generally increased as the teachers became confident and gained experience in doing practical work. The worksheet results were roughly 10 % higher than the test results. The peer discussions and peer support during practical experiments positively influenced practical worksheet results.

In Table 7, a summary of positive and negative feedback from the teachers and subject advisors is given. The feedback from the teachers was recorded in the anonymous post-workshop questionnaires. The feedback from the subject advisors was received from their comments in the official reports they sent after the completion of a workshop series. According to the feedback, the workshops are important because they use a hands-on approach to teaching Physical Science. This approach is a requirement for the implementation of the CAPS.

The workshop was well handled, and teachers enjoyed it because it encouraged participation and peer teaching. The facilitators were approachable, always on the alert to assist, and enjoyed what they did. Table 8 includes selected testimonials from various participants.

Table 7: Feedback from teachers and subject advisors (2004–2006).

Role	Positive	Negative
Teachers' comments (obtained from anonymous questionnaires)	Enjoyed, excellent, improved skills, gained knowledge, empowered, good organisation, good facilitators, quality subject matter, MYLAB kit suitable for teaching chemistry.	Some experiments were too long, teachers lacked knowledge and skills, the background knowledge of learners was lacking, and too few kits at school. [Appendix A]
Subject advisors' comments (obtained from official reports)	MYLAB is suitable, workshop format conducive to reasoning skills, hands-on approach, gained confidence, excellent presentations encouraged participation, and integrate theory and practical work, capacity building.	Appreciate it if every learner could ultimately have their own MYLAB kit (too few kits), I would like worksheets in a workbook, and more time is needed for experiments.

Table 8: Testimonials of 2004–2006 workshops.

I am so happy to have been a part of this workshop. The workshop was so educative and motivating. The professors were good in their presentations, we were so free to voice our frustrations if they were there. Help was just a second away. Thanks very much for everything. The workshop developed me a lot. It was an eye-opener. I Wish it could be done for all science and technology teachers. Well done to our presenters. We really enjoyed the workshop.
Keep up the good work. The cascading of these workshops will encourage learners to do and appreciate chemistry. The gap of not having done the experiments after our graduation was breached. The passion, the love and enthusiasm will keep the interest in doing physical sciences at school level high.
To reflect on the success, value and esteem in which teachers perceive the MYLAB workshops, I shall use the words of one teacher from Zeerust when she said, "if it was upon me, I would abandon all other workshops and concentrate on this one as it has immensely empowered us as science teachers.
One of the grade 11 learners said, "this was absolutely an experience. It has broadened my knowledge, and I really want to do it again!"
Observing professor from Norway: It very quickly became apparent that the workshops were successful. All the teachers were engaged in experiments over the two days; they were thus busy and more engaged than is often the case when theoretical instructions take place.
Observing professor from USA: Having now worked in the Sediba program, I am even more impressed with the overall quality of the program, with the MYLAB kits and materials that have been developed, and, most especially, with the people involved in the program.

In summary, the teachers' knowledge improved, although the test results are still poor (test average 57 %). Teachers claimed that their practical skills improved and that they were more confident and less afraid to do practical work (worksheets score 66 %) (du Toit, 2006). The workshops helped teachers prepare to present chemistry experiments in schools by allowing them to practice the experiments. The teachers claimed that they were better informed to implement the National Curriculum Statement (Curriculum 2005). Teachers were trained to use the Small-Scale Chemistry kits and became familiar with the experiments and the apparatus, even designing their own experiments. The kits made practical work possible especially in resource deprived schools.

After working with the MYLAB kits and completing the post-workshop questionnaire, teachers had a high expectation that the availability of MYLAB kits could improve teaching in schools. In addition, the MYLAB videos that form part of the kit were considered a good resource for teachers and learners to see the correct experimental techniques before they do the experiments to obtain results and afterwards to review experimental procedures.

3.2 2017–2019 Engen workshops

The teachers and the learners completed post-workshop questionnaires at the end of each school term. The learners' attitude towards the Engen project was very positive; they found the classes interesting and participated fully. The learners also enjoyed working with the kits and doing practical work. All learners attended on Saturdays according to the timetable, with only two to three learners absent. The workshops were well-liked, with one boy even stealing a school uniform from a participating school to enable him to attend.

Nevertheless, there were a few specific problems experienced by the learners. Some learners had significant knowledge gaps, and several schools did not cover all relevant topics according to the curriculum, causing problems during the workshops because of a lack of prior knowledge.

The hands-on, individual practical experiments were good for the teachers and the learners. The MYLAB kits were well-used, and experiments like forces in equilibrium (force board with pulleys and mass pieces), intermolecular forces with evaporation, surface tension, and solubility were performed. Nonetheless, some learners needed further training on handling the MYLAB apparatus because they had never done hands-on practical work. The teachers and the learners experienced the kits as user-friendly, and the explanations in the manual were very helpful and detailed with diagrams (e.g. molecules). The setup of the experiments and subsequent cleaning instructions were easy to do with the kits as they are straightforward to use and to pack and unpack. Furthermore, chemicals and apparatus are easy to replace on request. Each experiment in the MYLAB learner's manual is a research project about a relevant concept. The teacher's manual is the memorandum of the experimental investigation.

The testimonials in Table 9 are randomly selected from the anonymous post-workshop questionnaire comments by participating teachers and the comments of the project principal from the official report at the end of the Engen project.

Table 9: Testimonials from the teachers of the 2017–2019 Engen workshops.

(Teacher) The time allocated for experiments allowed me to be thorough and engaging to learners, thus making me reach or achieve my objective every time I teach. The interaction with learners from different schools and the opportunity to share ideas with colleagues, experts, and lecturers from the university, was special.
(Teacher) the engen project (maths and science and organisation etc.) was good. Every year we need to review the program and reconsider our approach. The program developed teachers professionally, especially when performing experiments. The different methods of conducting experiments were innovative and it was easy to adapt. Our teaching skills and methods improved.
(Project principal): The project in my view was successful. The facilitators applied themselves to the best of their ability. The facilitators were dedicated and committed. They made sure they attended all the sessions that was important for continuity and consistency purposes. The support the facilitators received from you (North-West University lecturers) was very much appreciated.
The learners appreciated the efforts of the facilitators, and many benefited to have been exposed to different voices and approaches in Maths and physical Science during Saturdays.
However, the project was not without its challenges. The selection of average performing learners in G10 and G11 was problematic as many proved to be below average. The other challenge was the irregular attendance of especially the weaker learners due to lack of transport. All in all, the project in my view was a resounding success and I look forward to continuing it.

In summary, the advantages of the Engen project were visible from the questionnaires and the learners' academic results. The special teachers contributed to the academic performance of the weak learners. The learners' practical skills and academic results were improved, and their misconceptions were addressed during class discussions (e.g. misconceptions about interatomic and intermolecular forces; misconceptions about different types of intermolecular forces; and the misconception that covalent forces are broken when molecular substances change state). The practical experiments deepened the learners' conceptual understanding, with learners and teachers developing new skills. The project was successful and yielded good results. However, many other schools in the region need similar support, with many promising learners missing out on achieving their dreams.

3.3 Independent evaluation of the effectiveness of the MYLAB project

The feedback from the North West Education Department about the 2004–2006 workshops was the following:

> In summary, the project has been successful in most aspects and is a model of education and industry partnerships. The Nort-West University is to be applauded for their foresight in establishing this programme in 2003. The verification of the need for such programmes in South Africa has only increased since then. There are significant quantitative advantages to learners studying chemistry through the NWU modules. Project material should continue to be developed with consideration given to the directions indicated in the national curriculum, and the project should be more widely implemented within the province.

Secondly, the Sci-Bono Discovery Centre (2023) reported the following on the MYLAB kit and training:

(1) Educational Value

The kits offered by MYLAB have great educational value due to their versatility and the vast number of experiments that can be done just by adding and detaching apparatus. We found that this would not only allow a learner to practice experiments related to the school curriculum but also enable them to plan and execute their own experiments. Access to proper lab apparatus and equipment is sometimes challenging for teachers, and MYLAB offers a great learning experience for the learners to be hands-on. Teachers are also able to easily demonstrate practicals which will improve and enhance learner's understanding of physical science concepts.

(2) Relevance to learners and teachers

All the equipment supplied in the MYLAB kit enables the teachers to perform experiments found directly in CAPS and are, therefore, very relevant to the delivery of the curriculum by the teacher. The kits can also enhance the understanding of the learners by allowing them to perform the experiments themselves.

(3) Quality of Equipment

Due to the scaling down of the equipment, extra precautions need to be considered when handling the apparatus. Small test tube brushes supplied in the kit enabled easy cleaning of the test tubes. Overall, the equipment will be easy to maintain.

(4) Learner and teacher manuals

There are manuals for the various grades which comprehensively lay out each experiment. The learners are guided through the experiment and have many questions that they need to complete at various stages of the experiment. The manuals ensure that the learners collect the correct data and follow the correct procedures. The safety of each experiment has also been considered, and notes and information are readily available if an accident happens.

(5) Training

The team offers sufficient personal training sessions on the equipment for teachers with regards to its handling, usage, and safety, as well as the performing of different experiments with the use of the kits. There is a training DVD that is also included with the kit. It is very important that teachers receive the correct training on this equipment because of the uniqueness of some of the apparatus.

4 Conclusions

The aim of this paper was to demonstrate the effectiveness of using small-scale chemistry kits to make chemistry accessible to all, especially in rural areas. Our viewpoint was that practical work is essential and contributes to visualisation. Inadequate visualisation can lead to poor concept formation and rote learning. Practical work also promotes positive attitudes towards Chemistry. One of our purposes was to teach chemistry through practical workshops. We wanted to bring practical work and practical investigation back into schools. To ensure accessibility, the requirements for the Natural Science and Chemistry apparatus were that it must be cost-effective, true to real laboratory experiences, learner-friendly, portable, and according to the Green Science Principles. The results of the workshops proved that we attained this aim of making chemistry education more accessible to learners. The small-scale apparatus kits are easily portable and can be used without the necessity of laboratories, running water or electricity. The manuals, memos and DVDs make knowledge transfer and guidance in practical work easy. The workshops facilitate teacher training in obscure rural areas.

Hence, the MYLAB small-scale chemistry kits made chemistry more accessible, effectively limiting misconceptions and increasing chemistry understanding, especially in rural regions. Teachers and learners quickly understood the apparatus and became comfortable handling the apparatus. The supporting manuals made independent, individual work possible. Each participant could progress at their own pace. Very little facilitation was needed. Teachers and learners became engrossed in their work and were highly motivated to do the practical experiments. The small-scale kits shortened the turnaround time for experimental mistakes, and participants could proceed without losing time or opportunity. They could stay completely focused because they could remain seated with everything they needed at hand; thus, the experiments could be performed quickly, and new activities were proceeding all the time. Participants were never eager to leave the workshop at the end of the day; they would rather continue experimenting with the kits. We were able to bring the chemistry to the people instead of taking the people to the chemistry.

Appendix A

Clarity for comments of Table 7

The teachers gave cryptic comments under a heading for general comments at the end of the questionnaire. The rest of the questionnaire was a Lickert scale response to questions asked.

(i) Some experiments were too long

Explanation

Some experiments have more than one activity, some have up to 7 activities. Teachers inexperienced with hands-on practical work, take a long time to complete one activity, never mind 7 activities.

(ii) Teachers lack knowledge and skills

Explanation

This is a very real occurrence in South Africa: either they give the subject while trained for another subject OR they had inadequate or only theoretical training at their training facility.

(iii) The background knowledge of learners was lacking.

Explanation

The learners have poor subject knowledge due to a poor learning culture OR inadequately trained teachers. Difficult family circumstances can also result in sketchy subject knowledge.

(iv) Too few kits at school

Explanation

Schools or Companies buy 10 to 20 kits per school and quite often classes are up to 60 learners in one class. Three (maximum 4) learners on one kit are still acceptable. One learner can do the completion of the worksheet, and two learners can assemble and perform the experiment. For hands-on you want everyone to be actively involved and not just looking on.

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