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# A SUSTAINABLE MODEL FOR PROBLEM BASED LEARNING IN A SOUTH AFRICAN SCHOOL

**S von Solms**
University of Johannesburg
Faculty of Engineering and the Built Environment
Department of Electrical Engineering Science
University of Johannesburg, PO Box 524, Auckland Park, 2006
svonsolms@uj.ac.za

**WS Hurter**
University of Johannesburg
Faculty of Engineering and the Built Environment
Department of Electrical Engineering Science
University of Johannesburg, PO Box 524,Auckland Park, 2006
warrenh@uj.ac.za

**J Meyer**
University of Johannesburg
Faculty of Engineering and the Built Environment
Department of Electrical Engineering Science
University of Johannesburg, PO Box 524, Auckland Park, 2006
johanm@uj.ac.za

## ABSTRACT

South Africa is currently facing an education dilemma with high numbers of youth unemployment and a growing specialized skills shortage in Science, Technology, Engineering and Mathematics (STEM). STEM problem based learning events, hosted by government and the corporate sector, has shown to improve science and technology literacy and to encourage the youth to pursue tertiary education in the field of science. Unfortunately, schools face a range of challenges which restricts them from participating in these learning methods, depriving learners of the advantages offered by problem based learning. This paper presents a model for the sustainable provision of STEM problem based learning opportunities in South African schools. The presented model is based on a two-team mentoring model which makes problem based learning sustainable in a South African school environments. The Shell Eco Marathon is in its third year, and the students that have passed through the program will now be progressing to university. The impact of this program, therefore, will be become evident by the success of the students' studies in the near future.

## INTRODUCTION

Problem based learning (PBL) is an approach to education where carefully constructed, open-ended problems are posed to a group of learners to find solutions. This method avoids simply transferring factual knowledge from teacher to learner, but aims to assist in the better understanding, retention and application of new information [1].

The implementation of PBL in secondary schools in South Africa (SA) has proven to develop teamwork and communication skills, encourage critical thinking and promote problem solving amongst learners. Skills which are of particular importance when viewed against the backdrop of South African education dilemma where youth unemployment and the growing specialized skills shortage in STEM (Science, Technology, Engineering and Mathematics), has reached a crisis level [2-3].

A good example of STEM PBL opportunities in South Africa is the participation of learners in organized science competitions, expos or technology events. These events include: The Shell Eco Marathon [4], AfricaBot [5], F1 in Schools [6] and the South African Expo for Young Scientists [7]. Despite the many advantages that PBL offers, the resource implications associated with PBL activities pose a major challenge to the implementation and maintenance thereof in South African schools. The challenges faced by schools relating to these competitions include limited available time as result of already time constrained curricula, limited funding and a lack of knowledge retention. The critical shortage of these resources prohibitively restricts schools from participating in these learning methods, depriving learners of the advantages offered by PBL.

The objective of this paper is to present a model for the sustainable provision of PBL opportunities in South African schools, overcoming the restrictions commonly known to halt the implementation of PBL in learning institutions.

Section 1 provides an overview of PBL where Section 2 provides a motivation for the participation in PBL events by South African secondary schools. Section 3 details the challenges faced by South African secondary schools to participate in these learning events. Section 4 presents the sustainable model for PBL in secondary schools and details the implementation thereof. Section 5 discusses the observed advantages of this model and Section 6 concludes this paper.


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## PROBLEM BASED LEARNING OVERVIEW

There exist many instances in classrooms where learners are not motivated to gain new knowledge as they cannot see where and how this information will be used in real life situations. Learners are aware and know how to use various devices and machines, but have no understanding of the technology that underlies the useful functionality. Transferring factual knowledge from teacher to learner though lectures places the learners in a passive rather than an active role, which can quickly loose the interest of the learner and hinder learning [4].

The premise of problem based learning (PBL) is to present course material so that learners not only gain the theoretical knowledge of the subject, but also understand and apply the gained knowledge in real world applications [8]. In PBL, learners are challenged to solve real-world problems in groups developing the critical communication skills associated with group work. By posing open-ended problems, teachers act as the facilitators and help learners become self-directed learners which fosters lifelong learning [9]. Through this process, PBL addresses both theoretical content and problem solving skills where learners are encouraged to analyze, understand and apply factual knowledge they would normally only receive in lecture format [7, 8,10]

When compared to traditional class room -based teaching methods, PBL proved to have many advantages. It improves learner motivation, critical thinking, problem solving, reading and communication skills [11]. PBL mainly focuses on six different areas of skills development, each with a specific objective [8-11]. These six areas include:

1. Learners learn to use the scientific method to solve the real-life problem. They learn how to form various hypotheses, to critically evaluate them and to select a hypothesis to be tested. This allows learners to develop a systematic approach to problems solving as well as critical thinking and decision making skills.
2. Learners develop cognitive flexibility which enables them to easily adapt their behaviour to a changing environment. The required knowledge and skills are not acquired and understood in a compartmentalised fashion only to pass a test, but in an extensive and integrated fashion which can be applied in variable situations.
3. Learner develops self-directed learning skills, where learners are led by the teachers to review information, find solutions and continuously determine what knowledge and skills are still required. This process helps learners to understand the necessity of thorough research and analytical skills.
4. Learners develop collaboration skills and learn how to be team players. As many problems in real-life can only be solved through collaborative efforts, the development of collaboration skills will provide learners with the necessary skills to work and learn effectively as members of a team.
5. PBL supports learner-centered, teacher facilitated learning. The objective of learner-centered learning is to inspire the learner to take responsibility for the improvement of themselves and to cultivate a habit of approaching a problem with initiative and diligence.
6. Learners develop self-reflection and self-appraisal habits which enables them to do honest self-assessments of their strength and weaknesses and to set realistic goals for themselves.

## MOTIVATION FOR PBL IN SOUTH AFRICAN SECONDARY SCHOOLS

The skills obtained through PBL are critically important for South African youth, as South Africa is currently facing an education dilemma where youth unemployment has reached a crisis level [2]. It has been reported by the World Economic Forum (WEF) that South Africa has the third highest unemployment rate in the world for youth, where approximately 50% of young South Africans between 15 and 24 are unemployed [16].

In addition, South Africa has a growing specialized skills shortage in STEM, partly due to the low standard of mathematics and science education in South Africa. [3][17]. According to reports from the Department of Basic Education, the number of learners writing math and science exams in school declined by 17% for both subjects between 2009 and 2013, where only 26% of learners writing in 2013 scored above 50%. According to the 2013 Annual National Assessment results, only 39% of Grade 6 and 2% of grade 9 learners scored higher that 50% in maths. Less than 10% of children who start school will obtain their senior certificate with a pass rate enabling them to attend a university. Of those 10%, less than 20% will qualify to study for a STEM degree where less than half will graduate [18].

From these statistics it is clear to see that the pool of learners who are able to pursue a career in STEM is severely limited. This state is disastrous for a developing country such as South Africa where engineering, geology, minerology, mining and technology play an important role in the South African economy. [3][19]. Ensuring a steady stream of graduates in the STEM fields are vital for the technological, scientific and economic advancement of South Africa [17].

South African Government and the corporate sector are keenly aware of the importance of extending the STEM talent pool and that is why various corporate sector partners work with government to invest in tools and resources to enable effective teaching of STEM subjects in schools [20]. This does not only benefit the corporations requiring a steady inflow of skilled people in the engineering, technological and scientific fields, but plays a major part in alleviating the national skills crisis and unemployment which contributes to sustainable economic growth in South Africa. When evaluating the various programmes put in place by the corporate sector partners, it can be seen that many of the programmes includes science centres, organized science competitions, science and technology expos and festivals as well as technology programmes at secondary schools promoting STEM education through PBL initiatives. Though participation in science expos and technology events, learners are required to address real-world problems while they


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gain valuable skills in the process [17-20]. Although many primary and secondary schools in South Africa promote learners' participation in these events to improve science and technology literacy and to encourage the youth to pursue tertiary education in the field of science, participation remains limited as result of the challenges stated. [21].

## CHALLENGES OF PBL IN SOUTH AFRICAN SCHOOLS

Despite the many advantages that PBL offers in the field of STEM, the resource implications associated with these activities pose a major challenge to the implementation and maintenance thereof in South African secondary schools. The challenges faced by schools relating to participation in these competitions include limited extra-curricular time, minimal available funds and a lack of knowledge retention.

A North American study showed there is a correlation between learners' success in science fairs and access to resources, such as finances and professional research and science facilities, universities and mentorship. [12-15]. These results showed resource shortages can restrict schools from successfully participating in PBL opportunities, making the use of science expos and technology events unsustainable for STEM education in secondary schools creating the unfortunate situation where learners are deprived of the advantages offered by STEM PBL. This trend is evident in South African secondary schools where limited resources effect education standards, as the lack of available time and other support resources hinder their participating in these events [22-25].

The participation of learners in science expos and technology competitions must take place outside normal school hours as this is supplementary to the standard school curriculum. The PBL process must be monitored throughout and teachers have to do the extra supervision and guidance work. This requires additional contact hours from teachers and study outside of class time from learners which is a concern to both teachers and learners [30].

Not only does the preparation and participation in these competitions take place after school hours, in most cases it cannot be financially supported by the school. All materials, equipment and additional learning material required for the projects must be funded by the learners.

The third challenge teachers face when entering learners in science expos and technology competitions is the lack of knowledge retention. In many cases, the learners build up a valuable body of knowledge during PBL participation which is lost when the learners graduate from year to year or leave the school upon final completion of their last year resulting in the teachers having to instill the basic scientific knowledge on top of the advanced knowledge required for the expos and competitions year after year. In some cases the teachers does not have the required technical knowledge or skills to support the projects.

These challenges faced by many South African secondary schools unfortunately makes the participation in science expos and technology competitions unsustainable, depriving them from the opportunities offered by supplementary STEM education.

The effectiveness of science expos and technology events to further STEM education are therefore reduced as results of these challenges.

## SUSTAINABLE MODEL FOR PROBLEM BASED LEARNING

This section details the presented model for the sustainable provision of STEM PBL opportunities in South African schools, overcoming the three challenges mentioned above in Section 3.

### Model structure

The model is based on three main pillars which was designed to addresses the challenges preventing successful participation in technology events. The three pillars are the following:

1. Available Time
2. Technical Knowledge
3. Funds

Time: The available time of learners and teachers are not an unlimited resource and therefore it must be managed carefully. This model considers the time available by teachers and learners after regular school hours in which to compete in a technology competition. This pillar ensures that all parties participating in the STEM PBL event does not spend an unreasonable amount of time on the project.

Knowledge: As result of the school progression structure senior learners leave the school or grade upon promotion to the next year. With senior learners participating in these events, the specific knowledge gained over the year through STEM PBL participation is lost to the remaining learners when the senior learners leave school. Many of the STEM events require some level of technical knowledge and skills. Most academic schools do not possess the required technical facilities or workshops as a technical school may have, preventing their participation in these events. This model considers this fact and therefore makes use of a continuous mentoring system. This pillar ensures that the basic scientific and technical knowledge required for successful participation in STEM events are retained and transferred through mentoring allowing the accumulation of an advanced knowledge base.

Funds: Available funding for the STEM PBL event is limited and must be considered. This model takes into account that the school implementing PBL may not have additional funds available for such activities. The Funds pillar ensures that the school does not carry the burden of excessive amounts of funds flowing out of the school budget to these PBL events. In many cases the additional funding required cannot be supplied by already financially burdened parents therefore engagement with sponsorship entities are encouraged and nurtured.

The consideration of all three of these aspects are required in order for the model to be sustainable. If any one of these pillars are weak, a lack of sufficient funding or the dwindling in technical knowledge or overloading of learners will result in the model as a whole being unsustainable. By following this balanced approach to address long-term funding, time management and knowledge transfer, through a mentorship

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approach, the participation in STEM PBL events can be a sustainable method for advancing of science and technology skills development in South African secondary schools.

**Implemented model**

The model which will be described in detail in this section was successfully implemented at Kings School, a secondary school in Johannesburg, South Africa with the help of the Faculty of Engineering and the Built Environment at the University of Johannesburg (UJ). The STEM PBL event that the learners of this school participates in is the Shell Eco Marathon (SEM) South Africa project. The Shell Eco- Marathon is a global event that challenges learner teams to design, build, test and drive energy-efficient vehicles [27]. A lineup of the SEM vehicles that competed in the 2015 Shell Eco- Marathon can be seen in Figure 1.

*Figure 1: Shell Eco-marathon vehicles*

The first year of participation for this school was in 2014 when the South African leg of this global event was launched.

The implemented two-team, continuous mentoring system, which work in the following manner. In 2014, a single team, Team A, participated in the Shell Eco Marathon. Initial funds were invested by the University of Johannesburg. Engineers from the Faculty of Engineering and the Built Environment at the University of Johannesburg invested time to mentor the learners in the technical subject matter and to assist them with the design and construction of the SEM vehicle. The first designed vehicle can be seen in Figure 2.


*Figure 2: Initial SEM vehicle design*

In 2015, the experienced team, Team A, as well as a junior team, Team B, was entered in the Shell Eco Marathon. Team A, as the senior team, mentored Team B. Team B received the vehicle used by team A in 2014 to compete in the 2015 race. Team A, as the experienced team, built a new SEM vehicle with assistance from engineers from the Faculty of Engineering and the Built Environment at the University of Johannesburg. Through their knowledge gained by previous year's participation, it was easier for them to obtain sponsorship and build a new vehicle for participation in 2015. The time management of Team A is also better as they have the experience of the previous year to draw from. The second SEM vehicle design, used by Team A, is shown in Figure 3.

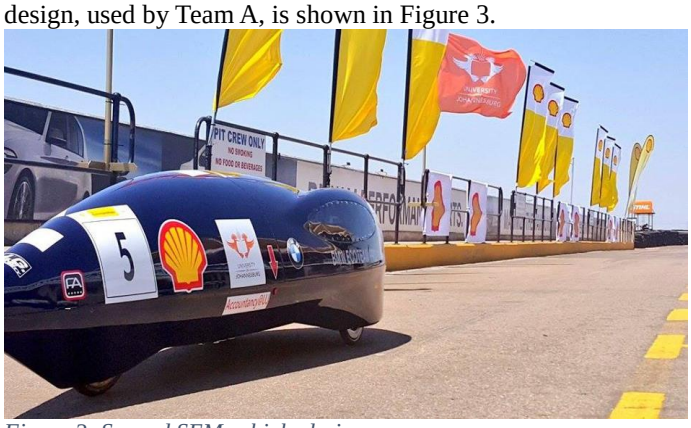


*Figure 3: Second SEM vehicle design*

In 2016, Team A, as the senior team, leaves the school due to the school progression structure. Team B now becomes the advanced team, where Team C is the new team being mentored by Team B.

The process repeats annually, with a senior team mentoring the junior team. The junior team gets support and assistance from the senior team and learns about time management, technical subject matter and the functionality of a SEM vehicle that is already constructed and competition ready.

This proposed model to enable PLB at the school addresses on the three main challenges relating to PBL implementation at secondary schools, detailed in Section 3. The three main


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challenges was addressed by ensuring a strong focus on all three pillars of the sustainable model.

Available Time:

The project was started in collaboration with the active Science Club at the school. This school recognized the existence of a group of learners who are interested in science and technology and created an extra-curricular activity to address this need. The Science Club meets once a week after school. The school provided a small facility for the club's activities and the science teacher facilitates and runs the Science Club.

It was found, however, that the time allocated for the Science Club is not sufficient for the learners to complete the project. In the past, the learners dedicated their September holidays to completing the project as the Shell Eco-Marathon competition is hosted in October of each year. The learners generally had no objection in dedicating their September holiday period to completing the project, but this put additional strain on the teacher running the club. By applying the mentorship model where learners who participated in the previous year's event supported the new learners, the time pressure on the Science Club teacher was reduced.

The Science Club welcomes and encourages the helps of engineers from the Faculty of Engineering and the Built Environment at the University of Johannesburg as well as parents with technical knowledge to mentor and assist the learners. A new initiative started by the Science Club teacher in 2016 was to invite alumni who have previously participated in the project to also act as mentors. The assistance provided be these individuals enables the project to be completed within the required time frame.

Technical Knowledge:

The project was started by an initiative by the University of Johannesburg in 2014 where staff members of the Faculty of Engineering and the Built Environment were responsible for the initial training, skills development and guidance in building the first energy-efficient vehicle.

The engineers from the university, parents as well as the alumni mentors not only assist the learners to complete the project on time, they are also critical role players in the preservation of STEM knowledge. This model relies heavily on mentors to ensure that the basic scientific knowledge relating to the Shell Eco Marathon are preserved so that the focus can lie in gaining and utilizing advanced knowledge to improve upon the previous year's cars.

In addition to the use of outside mentors, the project also implements a two-team system where a junior (grade 8 to 9) and senior team (grade 10 to 12), enter the Shell Eco Marathon annually. This two-team system ensures that leadership, experience and knowledge gained by the senior learners are transferred to the junior learners through mentoring. The junior learners, in turn, becomes the senior learners who mentors and leads the new junior team. The participation of two teams enables the senior team to design and build a new concept vehicle, where the junior team uses the vehicle used by the senior team the previous year.

In the cases where the teachers do not have the required technical knowledge or skills to support the projects, the teams are encouraged to engage with industry, Universities and parents to solicit technical skill support.

This two-team system ensures sustainable science and technology skills transfer and advanced knowledge generation as a team will never leave the school at the same time.

Funds:

The project was started with initial seed funding from the University of Johannesburg for the advancement of STEM education in secondary schools. The university also provides the equipment and tools required for the design, building and improvement of the SEM cars. In successive years, the funding from the university decreased and the school must secure funding through industry sponsors. Securing industry sponsorships proved to be a realistic aim as the school has a successful Shell Eco Marathon track record and produced better cars each year. These opportunities teach learners to engage with industry through the seeking of sponsorships, which forms part of the learner's development.

It was demonstrated how the implementation of the proposed two-team model makes STEM PBL events sustainable in a South African secondary school environments. Although this model was implemented at a school where the learners participated in the Shell Eco marathon, the fundamentals can easily expanded and be implemented in other PBL scenarios.

## OUTCOME

The Science Club teacher at the participating secondary school shared her experience and enthusiasm relating to the STEM PBL event with positive feedback. The teacher remarked that the learners are very enthusiastic to participate in this event and is willing to offer up their free time and holidays to participate.

She also noted that these STEM learning events supported the normal STEM curriculum. She noted an improvement in the participating learners' understanding and knowledge application of science and technology concepts. She could also easily explain scientific concepts like friction, internal and external forces and power in class as she can refer to a concrete example which the learners were familiar with to provide context. She established that the Science Club learners also proved to have better problem solving skills. They were able to better apply their scientific knowledge to answer questions and solve problems. Feedback from the learners were also very positive. They relished the opportunity to learn technical skills like welding, drilling and how to work with technical equipment as they feel they would not get an opportunity to learn those skills elsewhere. At least one learner decided to pursue a career in STEM as results of participation.

The method of mentorship also proved to work effectively. The teacher stated that the second year of participating in the Shell Eco Marathon was much easier as the learners had


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experience in the events, but also a basic understanding of the scientific knowledge un which they could build.

As the group only participated in two events, there are some problems that must still be addressed. Working in the September holidays in preparation for the competition in October leads to logistical and safety concerns. Although the learners are always supervised, some parents find it problematic to transport the children during the holidays. In the days leading up to the competition, parents have concerns when the work continues until late at night. The teacher, however, is positive that these challenges will be addressed in future as they learn how to handle the problems through experience.

Apart from the few problems experienced, the model implemented at the school is sustainable to promote STEM PBL at a secondary school in South Africa. This opportunity enables learners to improve their science and technology literacy, learn valuable skills and to learn more about the possibilities of pursuing a career in the field of science.

Students that have come from this program have volunteered on other projects at the university and have proved to be effective problem solvers. In the next few years these students will go on to further their studies where enrollment numbers can be measured.

## CONCLUSION

STEM PBL is an education approach where children learn through solving problems. It is proved to develop teamwork and communication skills, encourage critical thinking and assist in the better understanding, retention and application of new scientific knowledge. These skills are of critical importance as South Africa is facing a skill shortage in STEM as well as high numbers of youth unemployment.

Various STEM PBL events are presented and hosted by corporate institutions to improve science and technology literacy and to encourage the youth to pursue tertiary education in the field of science. Despite the many advantages that these events offer, the participation in these events pose many challenges for schools. Limited time, funds and knowledge retention faced by many South African secondary schools makes the participation in science expos and technology competitions unsustainable for supplementary STEM education.

This paper presented a model for the sustainable provision of PBL opportunities in South African schools, overcoming the restrictions commonly known to halt the implementation of PBL in learning institutions. This model was successfully implemented at a South African secondary school and, currently in its third year, proved to be a successful method to aid in the education of STEM subjects. As some of these students are participating in further projects at the university. Students who participated in this program have volunteered their time engage in university community engagement projects, which are all based on the PBL model.

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