Broadening Access to Problem-Based Learning: Design of the Shell Eco-Marathon Car-In-A-Box concept

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Abstract – **Problem-based learning has proven to develop teamwork, problem solving skills, communication and critical thinking skills amongst learners. Due to these advantages, secondary schools in South Africa engage with problem-based events to promote the participation of learners in Science, Technology, Engineering and Mathematics (STEM). However, many schools face lack of time, lack of available funds and lack of the required technical skill set, which limits them from participating in these events. The Car-In-a-Box concept was developed to broaden access to a STEM problem-based learning event, called the Shell Eco-Marathon. The Car-In-A-Box concept addresses the three challenges that would normally prevent a school from entering the Shell Eco-Marathon, disenabling learners to harness the advantages of problem-based learning. The impact of the Car-In-A-Box concept for broadening access to problem-based learning is discussed.**

Keywords – **Car-In-A-Box**, **Design, Problem-based learning, Shell Eco-Marathon**

I. INTRODUCTION

South Africa has one of the highest unemployment rates globally, where Statistics South Africa reported an unemployment rate of 26.7% in March 2016 [1]. With the unemployment rate in the country remaining high, it is startling that businesses have difficulty to fill positions, where engineering is reported to be one of the roles most difficult to fill [2]. According to the Future of Jobs study of the World Economic Forum, students enrolled in South African universities cannot satisfy the growing demand for Science, Technology, Engineering and Mathematics (STEM) graduates. Organisations state that they struggle to find graduates with complex problem solving skills, critical thinking, cognitive flexibility and good decision-making and judgement [5]. The high unemployment and high skilled vacancy rates in the country confirm the lack of technical skills which has a negative impact on South Africa's economy [2][3]. It is therefore critical to ensure a steady stream of graduates in the STEM fields, as it is vital for the technological, scientific and economic advancement of South Africa [4][21].

The shortage of skills in STEM can be partly attributed to the low standard of mathematics and science education in South Africa. [8][4]. The Sasol Inzalo foundation paint the following picture relating to STEM education: fewer than 10% of children who start school will pass secondary education with the necessary requirements to attend university. Of those, fewer than 20% will qualify to study for a STEM degree. Of those who study towards a STEM degree, fewer than half will graduate [6]. A report Commissioned by the Centre for Development and Enterprise indicates that the poor quality education provided by the South Africa schooling system limits the youth's opportunity for higher education [7].

As a result, multiple organisations are investing in tools and resources to assist in STEM education amongst South African youth [9]. These investments aim to support a steady flow of skilled people into the engineering, technological and scientific fields. The initiatives are problem-based learning (PBL) STEM events such as science and technology expositions, engineering and design competitions aimed at primary and secondary school learners. Examples include the Shell Eco-Marathon (SEM) [10], AfricaBot [11], F1 in Schools [12] and the Eskom Expo for Young Scientists [13].

Participation in these events requires learners to solve real-world, open ended problems, mostly by group work. These activities address both theoretical content and problem solving skills as learners are encouraged to analyze, understand and apply factual knowledge to a problem they would normally only receive in a lectured format [14-16]. STEM PBL events have proven to develop learner motivation, critical thinking, problem solving, reading and communication skills [17]. Due to the advantages of these STEM PBL events, primary and secondary schools in South Africa promote learners' participation. Participation not only improves science and technology literacy, but also encourages the youth to pursue tertiary education in the field of science and engineering [18].

Unfortunately, the participation in these PBL events come with their own challenges, which include a lack of time, lack of funding and a lack of the required technical skill set. These challenges faced by many secondary schools limit the access of learners to these supplementary STEM education events [19].

This paper presents a concept solution, called Car-In-A-Box, which aims to address the three challenges faced by schools for participation in the Shell Eco-Marathon in South Africa [10]. The Car-In-A-Box is designed with the purpose of broadening access to the Shell Eco-Marathon challenge, especially for previously disadvantaged schools with limited funding, time and technical skills and knowledge. This Car-In-A-Box concept will enable schools to participate in the event by producing an affordable basic car capable of safe handling and acceptable performance, enabling learners to benefit from the advantages of this STEM PBL event.

The outline of this paper is as follows: A brief background on PBL and the Shell Eco-Marathon will be provided in Section II. The design considerations for the Car-In-A-Box concept are discussed in Section III. Section IV provides the Car-In-A-Box design requirements where Section V discusses the design and assembly of the car. Section VI includes a discussion on the impact of the Car-In-A-Box concept and Section VII concludes the paper.

II. BACKGROUND

A. Problem-Based Learning

Problem-based learning is an approach to education where course material is presented to learners in such a manner that they gain the theoretical knowledge of the subject, and also understand the content and can apply it in real world applications [15]. PBL comes in the form of open-ended problems which are posed to learners in groups. Through the process of finding solutions to the problems, learners develop critical communication skills, critical thinking skills and problem solving abilities [17]. The learner gains a better understanding of the subject matter, retains the knowledge and is able to apply the knowledge practically [20].

PBL focusses on the development of six skills in learners, which include [14-17]:

1) Developing problem solving skills so that learners can use the scientific method, systematic approaches and critical thinking to solve real-life problems.
2) Developing cognitive flexibility to enable learners to adapt to a changing environment.
3) Developing self-directed learning skills so that learners are able to understand the value of research and analytical skills.
4) Developing collaboration skills to enable learners to work and learn effectively as members of a team.
5) Developing responsibility amongst learners which encourages self-directed and lifelong learning.
6) Developing self-reflection and self-appraisal habits to enable learners to conduct honest self-assessment of their strengths and weaknesses and to set realistic goals.

Since South Africa currently faces an education dilemma, the development and cultivation of these skills in South African youth are critically important.

C. Shell Eco-Marathon

The Shell Eco-Marathon competition was started in 1939 amongst employees of the Shell oil company to determine whose car could achieve the furthest distance using a single liter of fuel [10]. Since then the competition has grown to main competitions on three continents namely the Americas, Asia and Europe with smaller Challenger events hosted typically in Turkey and South Africa. The challenge allows for two main classes of entry: the prototype class for pure experimental cars and the urban concept class for more traditional car designs. Energy sources allowed are gasoline, diesel, compressed natural gas, methanol and electric energy (with two sub-classes of battery electric and hydrogen fuel cells). The aim of the marathon is the demonstration of the furthest distance obtained on an equivalent liter of fuel or on a kilo-watt hour of electrical energy. Cars are subject to the global set of rules contained in the Shell Eco-Marathon Chapter 1 rule guide [10]. The primary purpose of the official rules is to ensure the safety of the car.

III. DESIGN CONSIDERATIONS

The Car-In-A-Box concept is designed keeping in mind specific considerations aimed at broadening access to the Shell Eco-Marathon challenge especially for previously disadvantaged schools. The three most prohibiting factors limiting participation in problem-based challenges such as the Shell Eco-Marathon were identified as a lack of funding, a lack of time and the lack of the required technical skill set for the construction of advanced energy efficient cars. The following design considerations were drafted for the Car-In-A-Box concept in order to promote participation in the Shell Eco-Marathon. The design is not aimed at delivering a top end performance car but rather a basic car capable of safe handling with acceptable performance.

A. Modularity

The reason for choosing a modular design is to give learners options matched to their abilities while still minimizing the barrier to entry. The design should allow a selection from modules with progressively more functionality, ranging from a basic structure to a complete "get in and drive" car. The highest level of modularity allows the choice of the standard supplied propulsion system or a self-designed and installed system. As the learner's ability increases through participation in the event, the component modules of the car can be progressively replaced by self-designed components in subsequent events.

B. Cost

One of the biggest prohibitive barriers to entry into problem-based learning challenges is the cost of participation. In previously disadvantaged or rural schools already struggling to curb costs, funding is not readily available for participation in these problem-based challenges. Usually the largest cost contributing component is the equipment required for constructing the car. In addition, for many schools the process of sourcing the materials and equipment required to construct the car falls outside the normal school operating procedures which then elevates the barrier to entry. An upper limit for a fully functional Car-In-A-Box was determined to be less than US$1000. Experience has shown that sponsorships from companies supporting a team could reasonably be obtained for this amount. More financially able teams can opt for replacing modules with more expensive and technically superior components.

C. Skills

The assembly of the car is to be accomplished using only basic tools. The technical skills required for assembly of the car should be limited to the skills prevalent at academic schools at the level of Grade 11 learners. The competition is deliberately not aimed at Grade 12 learners so as to prevent interference with their final school year of the South African curriculum. The skills required for the assembly of the Car-In-A-Box do not exclude those academic schools which generally would not have access to technical workshops as would learners from a technical school. The assembly skills are limited to basic assembly using hand tools such as spanners or socket sets. The modular design allows for the progressive development of the assembly skills of the learner. Learners with more technical skills can opt for the less complete Car-In-A-Box set allowing for more complex assembly or even manufacturing of specialized parts. The Car-In-A-Box not only allows for the development of basic assembly skills but also the development of project management, communication and team work skills afforded by the participation in the Shell Eco-Marathon.

D. Time

The Shell Eco-Marathon demands extracurricular participation and subsequent time from learners. The current curricula do not include time for PBL events and learners therefore have to find and plan time outside of the academic workload in order to participate. In disadvantaged schools the social demands placed on learners further limit their spare time.

A design criterion for the Car-In-A-Box concept is therefore ease of construction and assembly within 20 hours. This translates into 4 hours per day for a week or 4 weekends which is considered an acceptable and non-disruptive time investment for a Grade 11 learner.

IV. DESIGN REQUIREMENTS

The Car-In-A-Box was designed to comply with the following high level requirements:

- The car shall comply with the Shell Eco-Marathon Chapter 1 rules [10].
- The car shall be able to be assembled using only basic hand tools.
- Non-special technical skills shall be required for the assembly of the car.
- The car shall be able to be assembled within 20 hours.
- The total cost of the car shall be less than $1000.

V. DESIGN

Building on skills developed through student involvement in post graduate Shell Eco-Marathon racing, these students formed part of the design team which initiated the Car-In-A-Box concept. Together with all the parts required to construct a basic car, a complete user manual is also provided. This manual details how the car should be assembled and what basic tools are needed to do so. Based on the high level requirements provided in Section IV, the following car was designed for the Car-In-A-Box concept.

A. Rolling Chassis

The car makes use of standard bicycle components that can be readily replaced or upgraded. These include hydraulic brakes, 20 inch rims and corresponding tires. All the components required for the vehicle to meet minimum requirements are provided, while the assembly is still sufficiently “incomplete” to ensure students are required to incorporate their own build creativity and problem solving skills into the final product. Figure 1 shows a computer aided design model of the basic shell and rolling chassis of the Car-In-A-Box concept.

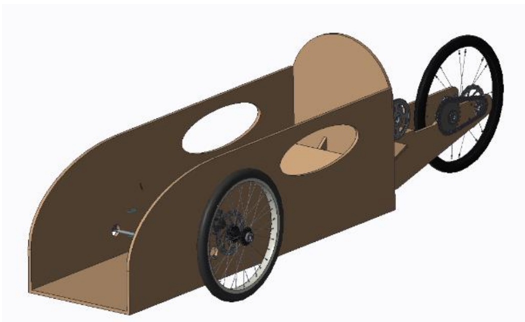

Fig. 1. Computer Aided Design model of the "Car-In-A-Box" concept.

The main structure of the car is manufactured using low cost marine plywood, cut to shape to fit together as various “puzzle pieces”. Once interlocked, these “puzzle pieces” support one another to give a rigid structure that will protect the driver as required. Wheels and aluminium hubs are mounted directly to the wooden structure through pre-marked holes.

B. Steering Mechanism

The steering mechanism is kept simple and easy to understand. One of the design considerations is that a standard steering wheel found in commercial vehicles would obscure the vision of the driver. Therefore, a double pushrod steering system was devised. The driver would simply need to press one control arm, while simultaneously pulling the other to execute a turn, as shown in Figure 2. Minimum turning circles have been calculated and incorporated into control arms and students can adjust steering sensitivity to their preference.

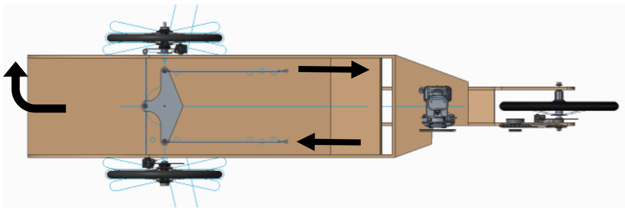

Fig. 2. Steering mechanism CAD model.

C. Propulsion Systems

The chassis is designed primarily to house a 35 cc internal combustion engine, with rear wheel geared chain drive, shown in Figure 3. The modular design does however allow for any propulsion system, such as battery-electric. Students are required to follow assembly instructions, which include basic gear theory. This in turn teaches the students the basic operating principles behind the mechanism.

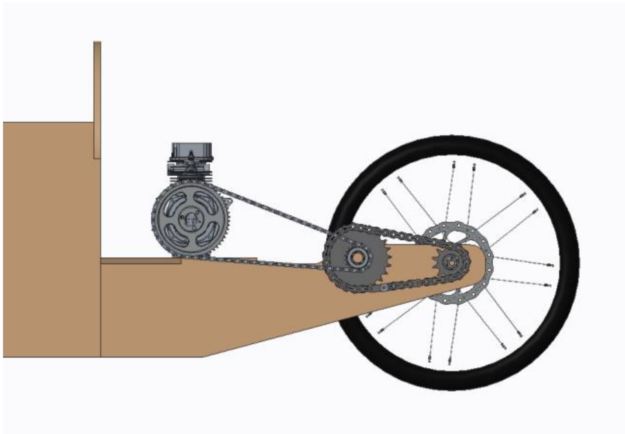

Fig. 3. Internal combustion engine chain drive propulsion system.

Various protective covers are also included to protect the driver and students from moving parts.

D. Aerodynamic Shell

The aerodynamics of the vehicle are left up to the learner teams to refine. Examples of vehicle layouts and the theory behind energy consumption due to air flow are provided in the manual to ensure learners understand the impact of poor aerodynamics. This is the avenue where creativity and research skills are tested.

E. Assembly

To ensure students can assemble the vehicles using the provided step-by-step user manual and simple tools at their disposal, the vehicle has been designed to not require any special welding or adhesives. Sections are assembled by hand using standard hardware store wood screws and low grade nuts and bolts that can be easily replaced. The goal is for this first entry to teach teams the basics required to compete and for these teams to be able to build their own cars from the ground up in the future.

These assembly methods also support the car's modular design, where components of the car can later be replaced by self-designed components in subsequent events.

F. Other Recommendations

Once the car has been built and tested, learner teams then have the opportunity of "making the vehicle their own". The marine plywood structure can easily be painted and altered to create a unique team identity, through their vehicle, thus adding some fun to the learning and racing environment.

VI. IMPACT

Participation by learners in the Shell Eco-Marathon event will enable companies to reach out to and support the participating schools. This event can also serve as a platform for universities to reach out to potential future STEM graduate students.

In addition to the academic advantages of such an event, it can also lead to a positive social communal impact. Secondary school teams can encourage community support which in turn can have a positive effect on the community.

It is clear, when one considers this Car-In-A-Box concept, that it is designed to accommodate teams with only basic technical skills and knowledge. By enabling these learner teams to participate in the Shell Eco-Marathon, these learners can gain more advanced technical skills and knowledge pertaining to automation, manufacturing and other science and technology-related skills. As the Car-In-A-Box concept was designed to be modular, the now experienced teams can improve upon their designs, allowing them to participate in future Shell Eco-Marathon events with improved designs. Participation in the South African Shell Eco-Marathon South Africa event by school learners can spark an interest in studying towards a STEM degree and, possibly pursuing a career in STEM by studying toward a STEM qualification.

At university level, these learners may be granted the opportunity to continue participation in these events by building more advanced cars, and gaining more advanced skills and knowledge in the process. Also, the experience gained by the learners can be used to assist and mentor other teams/learners in future. A good example of the impact of this initiative is the case where students, previously involved with the Shell Eco-Marathon, formed part of the team who conceptualized and designed this Car-In-A-Box concept.

VII. CONCLUSION

This paper presented the Car-In-A-Box concept, developed to broaden the access to the PBL such as the Shell Eco-Marathon, a STEM based learning event. The Car-In-A-Box concept was developed to address the three challenges which normally limit schools from participating in these events, namely a lack of funding, a lack of time and the lack of the required technical skill sets. The Car-In-A-Box concept enables learners to construct a basic energy efficiency car costing less than $1000 by only using basic hand tools. The assembly of the car also does not require any advanced technical skills with the assembly time of the car being less than 20 hours.

Through the participation in the Shell Eco-Marathon, learners develop problem solving, communication and critical thinking skills along with technical knowledge in the STEM field. Development of these skills is critical for the technological, scientific and economic advancement of South Africa.

Further work includes the evaluation of the concept in a number of schools and the determination of the impact thereof.

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