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SYSTEMS ENGINEERING EDUCATION IN AN ACCREDITED UNDERGRADUATE ENGINEERING PROGRAM

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ABSTRACT

Developing countries are mostly reliant on external technologies and this augments the need for systems engineering capability in these economies. It is therefore imperative that systems engineering as theory and practice is included in undergraduate engineering curricula to strengthen the internal technological capability of a country's developing engineers. In South Africa, the quality of undergraduate engineering programs is governed by the Engineering Council of South Africa (affiliated under the Washington Accord); and the exit level outcomes of the programs are predetermined explicitly per module. Systems engineering was introduced to an undergraduate electrical engineering program offered in the Faculty of Engineering and the Built Environment at the University of Johannesburg; and a framework developed to ensure that the program still meets the requisite ECSA exit level outcomes and therefore international standards. This paper presents the design and implementation of the framework, as well as the challenges that students are exposed to when faced with real-world systems engineering practice. Students were grouped into independent product development teams using a software support tool which promotes diversity and skill-level targets for each team. The independent team structure required the use and application of the systems engineering process and supported the development of management and communication skills. Furthermore, the framework allowed assessment of the performance of each product development team towards achieving the overall project objectives. One of the accreditation requirements of undergraduate engineering programs is peer assessment and this was achieved by the process. The paper closes by presenting the results of the stated framework implementation in an undergraduate electrical engineering program offered in the Faculty of Engineering and the Built Environment at the University of Johannesburg.

INTRODUCTION

The advanced needs of large, modern societies demand successful design of increasingly complex products and systems where engineering and business are integrated. "Rapid developments in technology, in particular the increasing use of information-based technologies in manufacturing and service systems require a *systems approach* to design socio-technical systems" [1, p.437]. Education and skills in science, technology, engineering and mathematics (STEM) are vital in a global economy focused on high-growth, technology-driven occupations that require innovation and enterprise. The major technological changes of the past century necessitate the need for engineering education to adapt programs such that customers of engineering education, students and employers remain satisfied with educational product quality [2]. An adequate and well-educated supply of graduates with the necessary skills underpins the requirements of global growth and innovation. The challenge presented to educators of undergraduate engineering programs is how to instill systems engineering skills in students whilst ensuring that the exit level outcomes of an accredited undergraduate engineering program are met.

The definition of Systems Engineering (SE) according to the International Council on System Engineering (INCOSE) is the following [3]:

> “Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem. Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs”.

SE originated from the early space exploration programs where it was crucial to integrate several disciplines into a first-time working system. It has since developed into a discipline mandated for all defense acquisitions and accepted as essential for engineering product development. The SE process presents a formal methodology for product development applicable to all life-cycle phases from product inception to disposal. SE therefore "refers to a distinctive set of concepts, methodologies, and organizational structures that have been developed to meet the challenges of engineering functional physical systems of unprecedented complexity" [4, p.1]. The authors presented a framework for the integration of the SE process into undergraduate engineering curricula in support of the accreditation outcomes of the program. In the Framework engineering students apply SE methodology according to the ISO-15288 standard [5] to solve a real world energy efficiency challenge in the form of participation in the Shell Eco-Marathon [6]. The framework develops the student’s theoretical knowledge and demands practical demonstration of each student’s comprehension of the systems engineering process.

Associated skills developed by the students during the academic course included problem solving, multidisciplinary teamwork, leadership, discipline, accountability, communication, time management, and project management. "Because tackling the most complex and challenging problems often requires professional experience in addition to education, developing a systems mindset – that is the ability to think like a system engineer – is a high priority at any stage of life" [4, p.1]

The paper is organized as follows: the Introduction provides an overview of the framework followed by the qualification standard as required by the ECSA accreditation authority. The Systems Engineering pedagogy process is introduced by presenting the elements of the systems methodology applicable to the engineering curriculum; and this is followed by an overview of the Shell-Eco Marathon competition and the implementation of the SE framework. The paper concludes with a summary of the findings and lessons from the work presented.

SYSTEMS ENGINEERING PEDAGOGY

Asbjornsen and Hamann (2000) describe the need for systems engineering pedagogy as follows [7, p.175]:

> As technical, societal, and economic systems become more and more complex, there is a need for integrated views and evaluations, not only of the systems themselves but also of their mutual interactions and their interaction with the environment. There is a need for education in this area, and systems engineering is an approach, a process and a discipline, which addresses the complex challenges of integrated views of large and small systems in the engineering education.

The Systems Engineering and Design Module (SEDM) is offered to third year electrical engineering students in the second half of the year. The students are presented with a complex real world engineering design problem for which they have the basic scientific and technical knowledge to construct a solution. The students were previously taught the theory of SE and they are required to solve the problem using the methodology of the SE process.

The SEDM is designed with the following module outcomes and associated assessment elements:

TABLE I. SYSTEMS ENGINEERING AND DESIGN MODULE OUTCOMES

Module Outcome	Description	Assessment Elements
A	Demonstrate a working knowledge of the Systems Engineering process applied to problem solving.	a. SE management plan b. Class assignments c. Class attendance
B	Demonstrate a working knowledge of the Systems Engineering specification process.	a. Development specifications b. Architecture diagrams c. Interface control specifications d. Product specifications
C	Demonstrate the ability to work as an individual team member in a project team.	Contribution assessed by other team members
D	Demonstrate the ability to do an engineering design.	Scrutineering pass: 50% Competition ranking : 20% First, second or third placement: 30%
E	Demonstrate the ability of technical communication to a broad audience	a. Preliminary Design Review b. Critical Design Review

A VEHICLE TO TEACH A SYSTEMS ENGINEERING METHODOLOGY

In 2010 the Graduate School of System Design and Management at Keio University in Yokohama, Japan tested a trial course on systems engineering for one year. After the year, Keiko Shimazu and Yoshiaki Ohkami, the two engineering educators responsible for the course, found that students with no or little industry or practical experience have difficulty in understanding and appreciating the value of systems engineering and its various methodologies. This finding motivated them to introduce a hand-on approach to teach the subject matter employing commercially-off-the-shelf components in the design of an automated vacuum cleaner [8, p.65].

Similarly, the Systems Engineering module introduced by the Department of Electrical and Electronic Engineering Science at the University of Johannesburg decided to employ the international competition, The Shell Eco-Marathon, to ensure that students obtain experience in the practical implementation of systems engineering concepts.

The Shell Eco-Marathon event was started in 1939 amongst employees of Shell Oil [6]. The event has since grown with annual participation from students in America, Europe and Asia; and its purpose is to demonstrate the ability to design and race a high energy-efficient vehicle. Energy efficiency is measured in distance achieved for an equivalent amount of energy contained in one liter petroleum fuel. The marathon allows energy sources such as liquid petroleum fuel, diesel, natural compressed gas, ethanol, battery electric and hydrogen energy; and allows for two competing classes. These include the Prototype class with the aim of maximum energy efficiency; and the Urban Concept class for more conventional mobility designs.

COMPANY ORGANIZATIONAL STRUCTURE

The engineering class was divided in company groups to facilitate the implementation of the requisite communication processes inherent to SE. The company structure allowed each company to have an organizational structure consisting of the following members:

- The Chief Executive Officer (CEO) responsible for project management which includes the management of the available resources such as time, money and human capital.
- The Chief Systems Engineer (CSE) responsible for the overall technical effort of the project as well as assuming the role of the design authority.
- Engineering specialists (E) for each component of the product.

The company organizational structure is mapped to the CEO and the SE as shown in Table 2; and allowed responsibility for the system life cycles processes as defined in the ISO/IEC 15288 standard. The responsibility for the organizational processes lay solely with the CEO whilst Systems and specialist engineers were responsible for the technical processes. The CEO and CSE were jointly responsible for the project and agreement processes.

The following companies were established to each fulfil an independent function towards achieving the overall project objectives:

- **SysCo**: a Systems Engineering Company responsible for the systems solution in fulfillment of the client requirements.
- **EnergyCo**: an Energy Company specialising in the design and production of propulsion sub-systems for use in energy efficiency vehicles.
- **MechCo**: a Mechanical Engineering Company specialising in the design and manufacture of light weight vehicle chassis for use as in energy efficient vehicles.
- **LogCo**: a Logistics Company (LogCo) specializing in marketing, media, fund raising and logistical support. This company offers audit services for demonstration of safety compliance requirements.
- **ClientCo**: a Client Company defined as the project client who is represented by the lecturer for the module.

TABLE 2. ALLOCATION OF RESPONSIBLITIES FOR THE SYSTEM LIFE CYCLE

Life Cycle Process	**Responsibility**
Agreement Processes	
Acquisition	CEO and CSE
Supply	CEO and CSE
Project Processes	
Planning	CEO and CSE
Assessment and Control	SE
Decision management	CEO
Risk management	CEO and CSE
Configuration management	SE
Information management	CEO and CSE
Measurement management	SE
Organizational Processes	
Life cycle management	CEO
Infrastructure management	CEO
Project portfolio management	CEO
Human resources management	CEO
Quality management	CEO
Technical Processes	
Requirement analysis	CSE, E
Architectural design	CSE, E
Implementation	CSE, E
Integration	CSE ,E
Verification	CSE, E
Transition	CSE
Validation	CSE
Operation	CSE, E
Maintenance	CSE, E
Disposal	CSE, E

SYSTEMS ENGINEERING PROCESSES

The Client, represented as ClientCo, provided the specification structure for the project and contracted each of the Systems Engineering companies to meet and satisfy its' capability requirements.

A. SPECIFICATIONS STRUCTURE

The Client capability need was expressed through the Client Requirements Specification; alternatively understood to be the User Requirements Specification (URS) and expressed in the learner guide of the module. The Client Requirements Specification was inexplicit, thereby imitating reality in that most clients do not fully understand the detail of the work required at the beginning of a project. ClientCo was not the subject matter expert and required SysCo to realize the client needs and subsequent URS.

The next step in the process was for each SysCo to define the Systems Engineering Management Plan (SEMP) which details the planning activities required for execution of the project. Mil-Std-499B was used as basis for the SEMP. The Requirements Management process was followed to express the system capability through the System Development Specification, including required and relevant subsystems. Similarly, the focus of the section *Engineering Systems Modeling* covered in the systems engineering course developed by Yurtseven and Buchanan (2002) is on subsystem design; and includes design validation, manufacture, distribution and sales, liability and disposal [1, p.439]

The Systems Development Specification was based on Mil-Std-490A; and the sub-system development companies were contracted through SysCo. This occurred by drafting sub-system development specifications for the (1) development of the chassis sub-system by MechCo; (2) the propulsion sub-system by EnergyCo; and (3) the project logistics by LogCo. The design and implementation of subsystems in the course develops the student's understanding of one of the primary roles of systems engineers in industry: "Systems engineers are concerned with the translation of the functional architecture (in this case the Client Requirements Specification) into a physical architecture which describes the logical breakdown of the system into various subsystems. This physical architecture, or logical design description of the system, is next translated into an implementation architecture that provides guidance for implementation contractors to bring about the various subsystems, which comprise the system" [2, p.165].

Sage (2000) also recommends that each subsystem exists and operates as independently as possible, and that their integration is straightforward and feasible. Consequently, an agreement and acquisition process is initiated between SysCo and each sub-system company. On acceptance of the SysCo sub-system development specifications each sub-system company produces its' own SEMP. Upon completion of each sub-system, the relevant company is responsible to draft a product specification detailing its product. Requirements traceability is maintained from the URS through to the sub-system product specifications with applicable traceability matrices in each document.

B. CONFIGURATION MANAGEMENT

The purpose of the Configuration Management (CM) process was to establish and maintain the integrity of all identified outputs of a project or process and to make them available to relevant stakeholders. The principles of Configuration Management were applied by each company and changes to the specifications were controlled through a change control process subject to version control. A Configuration Control Board was established to control changes to the sub-systems of the project, consisting of the systems engineer and CEO from each company. Baseline control was established by the implementation of a functional baseline requirements specifications and an implementation baseline developed for the developed system with subsystems.

C. VERIFICATION AND VALIDATION

The principles of verification were applied by each subsystem company through acceptance testing. Each sub-system was evaluated according to an acceptance test procedure utilizing the four basic verification methods of test, demonstration, analysis and inspection. Results from the acceptance test were captured and a report issued for each implementation baseline. The purpose of the validation process was to provide objective evidence that the services given by a system complied with stakeholders' requirements, achieving its intended use in its operational environment. Validation demonstrated that the product was developed fit for purpose in meeting the capability needs of the Client. Validation was implemented as a two-step process and was accomplished by (1) obtaining the safety and track access pass from the Shell Eco-Marathon inspection officials; and (2) by completing the challenge and obtaining a performance result on the leaderboard during the event.

D. TRANSITION PROCESS

The transition process was implemented through a review process and its purpose was to establish a capability to provide services specified by stakeholder requirements in the operational environment. A Preliminary Design Review was conducted after the subsystem specifications were released and each subsystems company had drafted its' product specification. During the Preliminary Design Review the capability of the system to meet the requirements of the Client was presented by SysCo and reviewed by an independent external review panel consisting of two to three subject experts ideally registered as professional engineers. Each subsystem design capability was presented to the review panel by each company. Compliance to the design rules as specified in the Shell Eco-Marathon Chapter One were demonstrated [9]. The desired outcome of the review process was a set of comments on the adequacy of the design and the decision to continue to the implementation stage. After implementation a Critical Design Review assessed the adequacy of the implementation to meet the Client capability needs. The main focus area of the Critical Design Review was the presentation of evidence supporting the design claims. The outcome of the review were corrections to the implemented system as well as the decision whether the system was ready for final validation by participation in the Shell Eco-Marathon. The Critical Design Review was conducted with the same review panel used to evaluate the Preliminary Design Review.

E. RISK MANAGEMENT

Risk management was established during each of the design reviews by determining the risk status of the system and subsystems. For the purpose of the specified project safety management was categorized as a part of risk management. Safety rules and regulations are contained in Chapter One of the Shell Eco-Marathon documentation [9]; and compliance to the safety regulations were demonstrated in each design review. Before participation in the final validation event the systems engineer of each company drafted and signed a Declaration of Design and Performance confirming compliance of the implemented design to the design documentation.

CATME SOFTWARE

The Comprehensive Assessment for Team-Member Effectiveness (CATME) software tool was developed by Purdue University [10, 11]. CATME creates teams using a number of predetermined criteria for diversifying or homogenizing the team compositions. Teams were established based on the results from the team maker survey submitted by each student participating in the module. The team maker survey question "Rate your preference for fulfilling a leadership role in the company" was used to ensure similar management ability in each company. The question "Rate your ability in workshop skills" was employed to ensure each company had equal hand skills. CATME was configured to create eight company teams from the students enrolled for the module and team criteria were selected to promote homogeneity in terms of race, gender and skills ability. The eight teams were grouped into two containing four companies each. The two primary groups were labeled Alpha-group and Beta-group. The students were allowed to assign the roles of SysCo, MechCo, EnergyCo and LogCo to the individual four companies in each group. Each company appointed its own CEO and CSE; and assigned specialist skills to each engineer employed by the company. The end result was the two main Alpha and Beta groups consisting of a systems engineering company and three specialist subsystem engineering companies.

CATME was subsequently used to obtain results from the peer evaluations of the contribution from each company member to determine the module assessment mark for each student for each module outcome.

ASSESSMENT STRATEGY

The assessment strategy employed by the systems engineering course was peer review and the assessment of the module outcomes was facilitated using the results from the peer evaluations conducted through the CATME tool. In the paper *Engineering Education for a Changing World* published by the American Society for Engineering Education and cited by Sage (2000) [2], open competition amongst students based on assessment by peer review was identified as a key component of a relevant, attractive and connected engineering education curriculum.

The assessment was conducted on the deliverable for each module outcome from each company; and the assessment mark was distributed according to the individual contribution from each company member according to the CATME contribution survey. As an example: the external assessment panel allocated a score value of 60 % to the Critical Design Review outcome of a specific company. The CATME tool survey results list the contribution of each student as evaluated by their company peers on a scale of 1 to 5 as shown in Table 3. The total student effort (34.4) is obtained from the sum of all the individual student contributions which is then equated to 60% value for the total effort. Each student's mark is obtained from the portion of his or her contribution to the value of the total effort.

TABLE 3. PEER ASSESSMENT OF STUDENT CONTRIBUTION AS OBTAINED FROM CATME

Student	CATME Assessment	Final Mark	CATME Feedback
A	4.4	69	High: high performer
B	3	47	
C	4	63	
D	2.9	46	Low: low performer
E	4	63	
F	3.8	60	Under: the student rated him/herself lower than peers
G	3.6	57	
H	4.2	66	
I	4.4	69	
Total	34.4		

Feedback from the CATME tool was available to each student regarding his or her performance as assessed by peers. The "High" indicator suggested high effort as rated by the student and his/her peers. Similarly, a "Low" indicator proposed a lower comparative rating. The "Under" indicators implied that the student is underestimating his or her contribution to the team effort.

ACCREDITATION STANDARD

Worldwide engineering programs are subject to accreditation in terms of educational quality, standard and engineering content. The accreditation authority in the United States is the Accreditation Board for Engineering and Technology (ABET) [12] and the equivalent authority in South Africa is the Engineering Council of South Africa (ECSA) [13]. Both are affiliated under the Washington Accord. Accredited undergraduate engineering programs in South Africa must demonstrate compliance to the Qualification Standard for Bachelor of Science in Engineering by fulfillment of the eleven exit level outcomes defined in the standard [14, 13].

ACCREDITATION OF EXIT LEVEL OUTCOMES

Table 4 presents the criteria for accrediting engineering programs as required by ABET and ECSA under the Washington Accord. The criteria for each exit level outcome (ELO) is defined by a *Description* and a *Range Statement* detailing the extent of demonstration which is required for acceptable compliance to the outcome. Table 4 indicates how the application of the systems engineering process to the Shell Eco-Marathon demonstrates compliance to each exit level outcome.

TABLE 4. ACCREDITATION STANDARDS FOR UNDERGRADUATE ENGINEERING PROGRAMS

Accreditation Standard ELO	Description of the ELO
ABET (e)	An ability to identify, formulate and solve engineering problems.
ECSA ELO 1	Problem solving.
Description: Identify, formulate, analyse and solve complex engineering problems creatively and innovatively.	
The Shell Eco Marathon provides the students with an international challenge where the solution requires the solving a number of complex problems with many potential iterations. A student's creativity and innovation are stretched by nature of the challenge since the results from each challenge set the benchmark requiring novel and more innovative solutions for consequent problems. The student's ability to solve the problem and successfully compete is challenged in every competition since the students not only compete against the score set by their own institution but also challenge the best score achieved globally. This promotes a moving baseline as technology progresses. The student's ability to work individually and as a member of an engineering team is developed.	
ABET (a)	An ability to apply knowledge of mathematics, science, and engineering.
ECSA ELO 2	Application of scientific and engineering knowledge
Description: Apply knowledge of mathematics, natural sciences, engineering fundamentals and an engineering specialty to solve complex engineering problems.	
Range statement: Mathematics, natural science and engineering sciences are applied in formal analysis and modelling of engineering situations, and for reasoning about and conceptualizing engineering problems.	
By designing an energy efficient vehicle students are required to demonstrate their ability to apply fundamental science and engineering knowledge. Knowledge from physics such as non-linear energy conversion and system dynamics are applied during design of the vehicle. A broad range of engineering science concepts from aerodynamics, vehicle dynamics and propulsion systems are utilized. Various aspects of the vehicle design are modeled to ensure achievement of the design requirements for design verification. Students use their models in a study of alternative solutions to determine the best solution for implementation. The student's ability to apply basic scientific knowledge individually and as a member of an engineering team is developed.	
ABET (c)	An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
ECSA ELO 3	Engineering design
Description: Perform creative, procedural and non-procedural design and synthesis of components, systems, engineering works, products or processes.	
Range Statement: Design problems used in exit-level assessment must conform to the definition of a complex engineering problem.	
In order to participate in the Shell Eco Marathon students are required to design and build an energy efficient vehicle. Students follow the Systems Engineering process during the design of the vehicle. A vehicle is an excellent design platform as it requires multi-disciplinary design from the disciplines of mechanical and electrical engineering. Students demonstrate the design of engineering processes during manufacturing and testing of their vehicle. Business processes are designed for utilization during marketing and media campaigns for sponsorship solicitation and fund raising. The imposed company structures force the students to design processes for Human Resource and Employee Relationship management. The student's ability to perform engineering design individually and as a team member is developed.	
ABET (b)	An ability to design and conduct experiments, as well as analyze and interpret data.
ECSA ELO 4	Investigations, experiments and data analysis.
Description: Design and conduct investigations and experiments.	
Range Statement: The balance of investigation and experiment should be appropriate to the discipline. Research methodology to be applied in research or investigation where the student engages with selected knowledge in the research literature of the discipline.	
The Systems Engineering process requires verification and validation of components and systems. Students are required to verify the design of the components for their vehicles utilizing a component acceptance test procedure. The final vehicle is subject to a system acceptance procedure. Specific experimental processes must be designed and conducted; and the results thereof interpreted for selecting new innovative components.	
ABET (k)	An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.
ECSA ELO 5	Engineering methods, skills and tools, including information technology.
Description: Use appropriate engineering methods, skills and tools, including those based on information technology.	
Range Statement: A range of methods, skills and tools appropriate to the disciplinary designation of the program including: 1. Discipline-specific tools, processes or procedures; 2. Computer packages for computation, modelling, simulation, and information handling; 3. Computers and networks and information infrastructures for accessing, processing, managing, and storing information to enhance personal productivity and teamwork.	
Students use various computer simulation packages during the design process for verification of design performance. The design of a vehicle forces students to utilize multi-disciplinary software design tools. The Systems Engineering process requires rigorous documentation which in turn demands that the students use document configuration systems. Social media is mostly used for coordinating purposes such as setting meeting dates and times. Presentation software such as Microsoft PowerPoint or Prezi is used for presentation of results during design reviews. Often video editing software tools are employed for developing short video clips presented during fund raising campaigns. In some cases the students realized a telemetry system with an extensive remote station which were used during the challenge to provide the pit crew with real time vehicle performance data enabling adaptive racing strategies. By using the Systems Engineering process students are applying a recognized engineering methodology to the design process. The student's ability to use appropriate engineering tools, methods, and processes are individually and as a team member is developed.	
ABET (g)	An ability to communicate effectively.
ECSA ELO 6	Professional and technical communication.
Description: Communicate effectively, both orally and in writing, with engineering audiences and the community at large.	
Range Statement: Material to be communicated is in an academic or simulated professional context. Audiences range from engineering peers, management and lay persons, using appropriate academic or professional discourse.	
By nature the Systems Engineering process is a documented effort. Students are required to write system level specifications, sub-system development specifications, component specifications, acceptance test procedures and acceptance test reports. Verbal communication is demonstrated during the Preliminary and Critical Design Reviews conducted in front of an external panel consisting of subject experts and professional engineers. During the critique by experts from Shell students must communicate design ideas and concepts successfully to obtain an inspection pass. Communication to a general audience is demonstrated during the fundraising campaigns where the design is presented to different financing instruments. The effectiveness of the communication is measured by sourcing sponsorship. The student's ability to communicate effectively as an individually and as part of a team is developed.	
ABET (h)	The broad education necessary to understand the impact of engineering solutions in a global, economic, Environmental, and societal context.
ECSA ELO 7	Sustainability and impact of engineering activity.
Description: An awareness of the sustainability and impact of engineering activity on the social, industrial and physical environment.	
Range Statement: The combination of social, workplace (industrial) and	

Accreditation Standard ELO	Description of the ELO
physical environmental factors must be appropriate to the discipline or other designation of the qualification. Comprehension of the role of engineering in society and identified issues in engineering practice in the discipline: health, safety and environmental protection; risk assessment and management and the impacts of engineering activity: economic, social, cultural, environmental and sustainability.	
The Shell Eco Marathon is a challenge that highlights sustainability and energy efficiency. Rigorous safety practices and rules are enforced by Shell [Shell Chapter One]. A student's comprehension of - and compliance to - health and safety standards is continually assessed during the Shell Eco Marathon event. Risk management is a component of Systems engineering demonstrated by the students at each design review. The student's awareness of the impact of the engineering activity are individually and as a team member is developed.	
ABET (d)	An ability to function on multidisciplinary teams
ECSA ELO 8	Individual, team and multidisciplinary working
Description: Work effectively as an individual, in teams and in multidisciplinary environments.	
Range Statement: Multidisciplinary tasks require co-operation across at least one disciplinary boundary. Co-operating disciplines may be engineering disciplines with different fundamental bases other than that of the program or may be outside engineering.	
Participation in the Shell Eco Marathon requires engineering work crossing at least electrical and mechanical engineering discipline boundaries. Activities outside the engineering discipline are encountered during the marketing and media drive of each team. The Systems Engineering approach resulted in small product teams represented by each company working towards the fulfillment of an overall project goal. Each student's contribution in the product team is assessed by his peers using the CATME software tool. Individual work in the context of an engineering team is assessed towards demonstration of achieving this outcome.	
ABET (i)	A recognition of the need for, and an ability to engage in life-long learning
ECSA ELO 9	Independent learning ability
Description: Engage in independent learning through well-developed learning skills	
Range Statement: Operate independently in complex, ill-defined contexts requiring personal responsibility and initiative, accurately self-evaluate and take responsibility for learning requirements; be aware of social and ethical implications of applying knowledge in particular contexts.	
The Shell Eco Marathon presents the students with an ill-defined problem which requires students to research possible solutions. The students are challenged by a problem which they have not encountered before. The need for obtaining additional skills for solving the challenge is encountered giving an introduction to the life-long learning process required by a practicing engineering professional. Students have to take personal responsibility for their learning and participation. Through CATME the students' self-evaluation of performance is assessed and comparative feedback given. Group dynamics and the nature of the challenge exposes students to the ethical implications of their behavior.	
ABET (f)	An understanding of professional and ethical responsibility.
ECSA ELO 10	Engineering professionalism
Description: Be critically aware of the need to act professionally and ethically and to exercise judgment and take responsibility within own limits of competence.	
Range Statement: Evidence includes case studies typical of engineering practice situations in which the graduate is likely to participate.	
Each student is personally responsible for his or her contribution as part of the company. Company peers assess each other's contribution towards the goals of the company. Ethical and professional behavior are required to ensure that components that are developed are functioning as designed and are delivered on time. The company group structures require significant professional human interaction. The intercompany relations are assessed by the CATME tool which gives students feedback regarding their own perceived ability and their ability as experienced by their peers. The team's performance is determined by a real	

Accreditation Standard ELO	Description of the ELO
world challenge where success depends on a number of factors and not solely on analytical ability. The financial element obtained through sponsorships requires students to act financially ethically and responsible. Individual expression of ethical and professional behavior in the context of an engineering team is developed and assessed by demonstration of achieving this outcome.	
ABET (j)	A knowledge of contemporary issues
ECSA ELO 11	Engineering management
Description: Apply knowledge and understanding of engineering management principles and economic decision-making.	
Range Statement: Basic techniques from economics, business management; project management applied to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.	
The applied Systems Engineering Process ensures engineering management through agreement processes, organizational processes and project processes: elements which are implemented by the students as part of the company structures. The project nature of the Shell Eco-Marathon requires a strong managerial component in the management of financial resources, human resources and available time. At the design reviews each company must report on the management status of the company.	

RESULTS

Sage (2000) offers a structural definition for systems engineering as follows [2, p.166]:

> "Systems engineering is management technology to assist and support policymaking, planning, decision-making, and associated resource allocation or action deployment. It accomplishes this by quantitative and qualitative formulation, analysis, and interpretation of the impacts of action alternatives upon the needs, perspectives, the institutional perspectives, and the value perspectives of clients to a systems engineering study."

Application of the systems engineering process allowed two student teams to successfully participate in the Shell Eco-Marathon event in South Africa, achieving second and third position respectively in the battery electric class. As part of the pedagogy of the module, the value perspectives of the students of the systems engineering study were determined to understand and evaluate their learning experience. Figure 1 presents a word cloud from the project reflection of the CEO of one of the SysCo companies.

The size of the words presented in Figure 1 indicates the number of times the word was used in the reflection. The focus of SysCo on systems engineering and management is evident from the words *project*, *work*, *group*, *documents*, *members*, *engineering* and *team*.

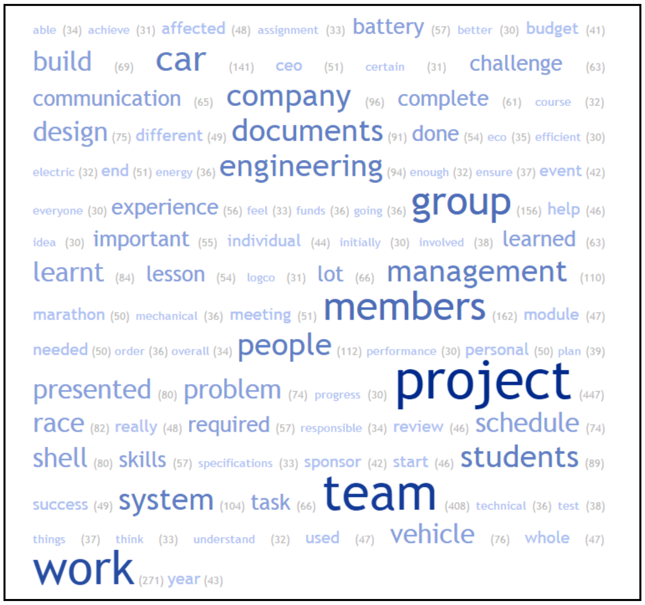

Fig.1. Word cloud from a SysCo Company

Figure 2 reflects the word cloud of the CEO of the logistics company LogCo. The marketing and engineering focus of LogCo is evident from the words *presentation*, *document*, *project*, *completed*, *specification* and *team*. Both these reflections strongly indicate project and team work.

Fig.2. Word cloud from a LogCo company

CONCLUSION

Engineering education is both an intellectual and a professional activity. It is therefore incumbent on the faculty and department responsible for educational delivery in engineering that they remain at the forefront of relevant and emerging technologies such as systems engineering [2].

Sage (2000) elaborates on why systems engineering is necessary and relevant in current engineering curricula: "We are witness to the emergence of new human activities that demand new processes and management strategies for the engineering of systems. The major need is for appropriate management of people, organizations, and technology as a social system. Systems engineering is basically concerned with finding integrated solutions to issues that are of large scale and scope. Educational programs in systems engineering need to be especially concerned with the emergence of systems engineers who can cope with these challenges" [2, p.172]

To date, however, the education and inclusion of systems engineering in engineering curricula is rare [4] and engineering students have little exposure to systems-related concepts, techniques and methodologies [1]. A finding from the 2015 academic forum held by the International Council on Systems Engineering found that "whilst there are some very good examples of SE Knowledge in wider education, its value is not accepted universally and there are practical issues in its inclusion in existing educational offerings" [15, p.502]. Students lack the ability to cope with interdisciplinary issues [7] and the lack of inclusion of systems engineering principles in engineering curricula becomes critical when students graduate as professional engineers and are expected to design, implement and manage complex socio-technical systems [1].

The Department of Electrical and Electronic Engineering Science in the Faculty of Engineering and the Built Environment at the University of Johannesburg aims to address these shortcomings in engineering education by introducing a framework for SE in its undergraduate engineering curricula. The challenge presented by the students' lack of practical experience is addressed by integrating the SE methodology with the international Shell Eco-Marathon competition; thereby ensuring the practical application of SE techniques within a socio-technical environment. The SE implementation framework presented by the paper was implemented successfully and as a result, students participated in the Shell Eco-Marathon South-Africa in 2014 and 2015. Students from the 2014 team entered a team in the following year's event and achieved overall best performance.

In May 2015, the International Council on Systems Engineering (INCOSE) brought together stakeholders in SE education, including people outside the existing INCOSE academic community, to discuss and explore ways of understanding, promoting and enhancing the value of Systems Engineering Knowledge in the education of all Engineers. A key outcome of the deliberation confirmed the need for continued focus of SE in the engineering curricula: "Engineers competent in both systematic and systemic approaches are better able to develop all kinds of systems, including complex and interconnected components/systems with predictable performance on schedule, quality, cost and alignment within a dynamic, uncertain system of systems environment" [15, p.505].

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