Reflective Learning in Engineering Education: A Case Study of Shell Eco-Marathon

S. von Solms[1], H. Nel[2]
[1]Department of Electrical Engineering, University of Johannesburg, Johannesburg, South Africa
[2]Postgraduate School of Engineering Management, University of Johannesburg, Johannesburg, South Africa
(svonsolms@uj.ac.za)

Abstract - **Globally, universities are reinventing STEM education where traditional classroom methods are substituted or supplemented with practical learning methods such as problem-based learning and project-based learning. Another method, not often employed in STEM, is learning through reflection. This paper presents a case study where a group of engineering students participated in an international competition, the Shell Eco-Marathon, and partook in reflective learning before and after the event. The results indicate that students who learn through reflection value the inclusion of project-based learning in their curricula, which emphasizes the importance of this study for the future of engineering education.**

Keywords - **Reflective learning, STEM education, project-based learning**

I. INTRODUCTION

In recent years, South African businesses have indicated that they cannot find sufficient engineering graduates who can fill all their available professional vacancies. This shortfall in Science, Technology, Engineering and Mathematics (STEM) graduates can be partly attributed to the fact that university graduates generally lack the graduate attributes, or complementary skills, which supplements their technical abilities. This includes skills such as problem solving, adaption to changing environments, team work and critical thinking [1][2]. Due to this mismatch in skills taught at university and those required in industry, universities are revising and adapting their teaching and assessment methods to deliver graduates who are not only technically competent, but also who possess the graduate attributes required by industry [3].

One of the methods employed by universities is to motivate students to participate in practical design projects and competitions [4]. These real-world experiences can assist students to develop their knowledge, to apply skills in real situations, and to learn about project management. Students can also see the impact of their work and decisions through experiences. This promote innovative thinking and creativity as well as team building and communication skills.

The participation of students in these learning activities proves to be invaluable, as students learn skills such as team work, communication skills and self-directed learning skills [5][6]. Additionally, it can be beneficial to guide students to reflect on their experiences throughout and after these activities as reflection has been proven to assist students to learn from their experiences and to teach skills such as problem-solving and cognitive flexibility [7].

This paper presents a case study of such a project, where a group of engineering students from the Faculty of Engineering and the Built Environment at the University of Johannesburg participated in the Shell Eco- Marathon event in London in 2016. The students were guided through reflection before and after their participation. The outline of the paper is as follows: Section II provides an overview of engineering education in South Africa, and Section III a precis on reflective learning in engineering education. Section IV discusses the case study, and Section V the methodology followed by the results in Section VI. Section VII concludes this paper with presentation of the student team's reflective learning.

II. ENGINEERING EDUCATION IN SA

A. *STEM Education in South Africa*

According to the Future of Jobs Study report by The World Economic Forum [1], the growing demand of STEM specialists in South Africa is unable to be satisfied by the country's universities. The poor quality of science and mathematics education in South African schools are seen as one of the main limiting factors [3][8][9]. Another limiting factor is that STEM graduates generally lack a range of skills a business would require of the graduate. These skills are often not technical in nature, but seen as complementary skills, or graduate attributes, such as complex problem solving skills, good communication skills, critical thinking and cognitive flexibility [10][11]. South African universities are therefore re-evaluating their teaching and learning methods in order to ensure that their STEM graduates are technically skilled and also has the graduate attributes required by industry.

B. *Project-Based Learning*

Several engineering faculties at South African universities have started to introduce more practical learning methods into their curriculum. These practical teaching methods aim to expose engineering students to practical, real-life engineering projects in order to develop a range of complementary skills in graduates.

The use of projects through project-based learning (PBL), is a teaching and learning approach where students are required to gain and apply theoretical principles to solve open ended problems in real-world applications [5][6]. Engineering management and the understanding of systems thinking can be introduced to students through exposure to practical design projects. Critical awareness of sustainability and impact of their engineering activities can be fostered when students gain experience in real-world projects outside of the university. Innovative thinking and creativity as well as communication skills can be improved when students are given the opportunity to work in multidisciplinary teams to solve real-life problems [5][6][12][13]. In addition to PBL, the process of learning from reflection is also considered a valuable approach in engineering education [14]. Reflective learning is viewed as an important strategy for individuals to acquire the ability of lifelong learning [15].

Reflective learning involves students to consider their own experiences and actions in certain situations to make a connection between knowledge and practice [15]. Historically, reflective learning has been used to train professionals in the fields of teaching, health and social work; but it has not been fully explored in science and engineering [15]. However, recent application of reflective learning methods in engineering education has demonstrated that it can be employed as a learning methodology to enhance students' ability to solve problems and deal with uncertainty [16]. Reference [17] showed that reflective learning integrated in engineering education can improve the student's recall and transfer of information and help them to understand their successes and failures within an experience.

III. Reflective Learning in Engineering Education

The practice of reflective learning is when an individual explores an experience to determine what happened and what his/her role was within the experience. This includes evaluating behaviour, thinking and related emotions. The act of reflection enables the person to identify possible changes in his/her approach when faced with similar events in the future which can lead to improved performance [18].

A. *Requirements in Engineering Education*

According to the Engineering Council of South Africa's Qualification Standard for Bachelor of Engineering (BEng) degree, the core and specialist requirements for the qualification can be divided into three categories, namely (1) core of mathematics, basic sciences and fundamental engineering sciences; (2) specialist engineering knowledge; and (3) complementary skills to support practice [19].

ECSA motivates that complementary studies, which cover the disciplines outside of engineering sciences, basic sciences and mathematics, are essential to the practice of engineering, including engineering economics, the impact of technology on society and effective communication; and that it is necessary in order to broaden the student's perspective in the humanities or social sciences to support an understanding of the world [18]. The importance of complementary studies is supported by various studies in literature [7][11][19][21].

Reference [7] argues that professional engineers are seldom presented with well-defined technical problems in the real world. Manageable, well defined problems can be solved through the application of research-based theory and application if static knowledge found in textbooks, but engineers in practice are hardly faced with well-defined problems which can be solved in this manner. Real-world engineering problems do not come in well-defined packages, but are rather presented as "messy, interdeterminate situations" [7]. Professional engineers are required to not only consider the technical aspects of a project; but also the social, environmental and economic aspects thereof. Engineers cannot rely on only their technical knowledge to solve these problems, they must consider factors outside of the technical scope, which requires dynamic and adaptive knowledge. The requirement of this "professional artistry" can be taught through the process of reflection [7].

B. *Models of Reflection*

Literature presents two principal types of reflection: reflection-in-action where the individual reflects while engaged in an experience, and reflection-on-action where reflection happens after an experience [7][23]. Reflection-in-action aims to help the individual gain a new perspective, rather than just allowing him/her to simply solve the problem. Reflection-on-action aims to let the individual step back from the situation and challenge their assumptions, ideas and beliefs regarding their experience [23].

It is argued that reflective learning can be improved when the act of reflection is guided by a predetermined framework or structural process [20]. Several reflective processes exist which can be applied to suit the learning situation at hand. Although these models differ, they share common features [23]: description of the situation; relating to what you know; making sense of what was learnt; and reflection of change. These key elements ensure that the reflection process is able to create a gain in knowledge and a change in conceptual perspective as it should challenge the individual's concepts and theories by which they make sense of knowledge. Reflection should prompt the individual to not simple see more, but to see differently [21].

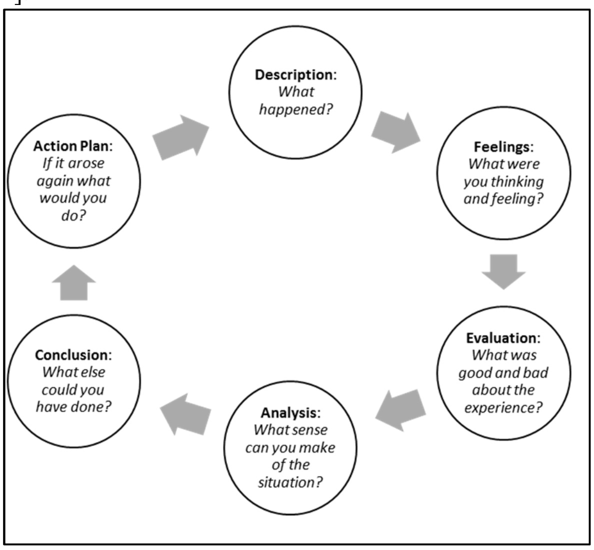

Fig. 1: Gibbs Reflective Cycle

The Gibbs reflective cycle encourages an individual to provide a clear description of the situation, describe their feelings, evaluate the experience, analyse the experience to try and make sense of it, draw a conclusion to consider other possible actions and examine how you would react if faced with a similar situation [24]. The process is described in Fig. 1.

Reference [25] proposed a model for structured reflection which requires a student to work with a supervisor throughout the experience to provide guidance. The authors argue that a greater understanding of the learning experience can be gained when sharing reflections than when done alone. The model proposes 5 steps in the reflection process, namely Description, Reflection, Influencing factors and Learning [25]. The model, originally created for the field of nursing was adapted in the case study described subsequently and is briefly summarised in Table 1. Johns model and the Gibbs reflective cycle were utilised in the case study and the learning discussed subsequently.

TABLE 1: JOHNS MODEL OF REFLECTION ADAPTED FOR ENGINEERING

The following cues are offered to help practitioners to access, make sense of, and learn through experience:
Description: • Write a description of the experience • What are the key issues that I need to pay attention to?
Reflection • What was I trying to achieve? • Why did I act as I did? • What are the consequences of my actions? • How did I feel about this experience when it was happening?
Influencing factors • What internal factors influenced my decision-making and actions? • What external factors influenced my decision-making and actions? • What sources of knowledge did or should have influenced my decision making and actions?
Learning • How do I NOW feel about this experience? • How has this experience changed my way of knowing in practice?

IV. CASE STUDY: SHELL ECO-MARATHON

Shell Eco-Marathon is an international competition which was started in 1939 amongst employees of the Shell oil company. The aim of the competition was to determine which car could achieve the furthest distance using a single litre of fuel [26]. This competition has grown globally to three main competitions in America, Asia and Europe with smaller events hosted in Turkey, Brazil and South Africa. The aim of the competition is for student teams to build a safe, energy efficient car that must reach the furthest distance on an equivalent litre of fuel or on a kilo-watt hour of electrical energy. Energy sources allowed for these cars include gasoline, diesel, compressed natural gas, methanol battery electric and hydrogen fuel cells. Cars are subject to the global set of rules contained in the Shell Eco-Marathon Chapter 1 rule guide [26]. The Shell Eco-Marathon challenge allows for two types of car entries: prototype class for experimental cars, and urban concept class for more traditional car designs.

The Shell Eco-Marathon event held in South Africa was launched in 2014. The Faculty of Engineering and the Built Environment at the University of Johannesburg (UJ) utilises this competition as a PBL event for their students as the third year electrical engineering students participate in teams in this event.

After competing in the event as third-year engineering students in 2014, a group of students continued to participate as a team in 2015. Upon completion of their second Shell Eco-Marathon in 2015, they decided to aim for participation the seven day Shell Eco-Marathon event in London in 2016. Researchers at the University of Johannesburg identified the participation in the international event as an opportunity for reflective learning.

V. METHODOLOGY

The research methodology is qualitative and the approach followed for the reflective learning exercise was created from the model proposed by [25] as described in Section III.

A. *Reflection before Event*

Before the team departed to London to participate in the competition, they were presented with a reflection exercise. Team members were guided by the specific questions in the documents which they were required to complete prior to departure; the questions are presented in Table 2. The questions posed to the students emulated the first two sections of the Johns Model of Reflection, namely Description and Reflection; and the students were required to complete the questionnaires individually. Their individual feedback is presented in Section VI.

B. *Reflection after Event*

After the team arrived in South Africa after the event, a debriefing session was held with seven members of the team; as well as the academic who had joined the team during the event.

TABLE 2: SEM REFLECTION BEFORE EVENT

Before you start the next level of the journey, reflect on the following questions.	
1	How did being a team member participating in the Shell Eco-Marathon change your understanding of engineering?
2	How did being a team member participating in the Shell Eco-Marathon change your understanding of teamwork?
3	Should team projects such as the Shell-Eco-Marathon be part of undergraduate engineering curricula?
4	Did you develop business skills as a team member?
5	Did your culture play a role in the performance of your team?
6	Did your gender play a role in the performance of the team?
7	Did you contribute innovation to your team?
8	How were decisions made in your team?
9	What is the marketing contribution you made to your team?
10	What value did you receive from being a member of a team participating in an international competition?

The session was guided by senior researchers and addressed the third and fourth sections of the Johns Model, namely Influencing Factors and Learning. In support of the finding that "a greater understanding of the learning experience can be gained when sharing reflections than when done alone" by [25], the reflection-on-action exercise was conducted with all the team members in one room. The session was managed as a brainstorming session with minimum scaffolding and the results are discussed in Section IV.

VI. Results

A. Reflection before Event

Considering the significance and potential insight of Questions 1 for engineering educators, the results of the students' reflection is presented per student. Thereafter, the reflection feedback from the team members is merged and discussed collectively. *Question 1: How did being a team member participating in the Shell Eco-Marathon change your understanding of engineering?*

Student One: It gave a better understanding of how to develop parts and how much time, effort and cost is involved with such things. Student Two: When working in a team, I found that gaps in my engineering knowledge were quickly filled by being around a diverse set of population of team members. Student Three: Organising an engineering process step-by-step to do it right the first time. Student Four: It gave me an appreciation of what goes into a project regarding funding, designing, planning, logistics, the need to able to adapt designs/costs according to what is available. Student 5: Being part of the team allowed for theoretical knowledge about engineering to be put into practice. It enabled the team to observe and perform real world engineering practices, as well as to increase our knowledge on engineering concepts previously unknown such as motor controllers. Student 6: There is more to doing technical work to get the work done on a good technical level. Student 7: Gave me a very good idea of how real world engineering and design is done.

Feedback to Question 2 indicated that students considered the selection of the right team members as very important and a significant contributor to project success. Also, role allocation and defining expectations were important. Six of the seven students agreed that team projects such as the Shell Eco-Marathon should be part of undergraduate engineering curricula (Question 3). The students suggested, however, that the project must be led by a postgraduate student and executed in conjunction with industry. In response to Question 4, the students listed the following business skills as important: marketing; fund sourcing; the role of risk and contingency in project planning; the importance of multiple quotations; appreciation for the value of money; improved communication with industry; and knowledge of the financial and governance structures of the university. Two students indicated that they did not acquire business skills through execution of the project.

The team was comprised of five men and two women of different cultures; and Questions 5 and 6 interrogated whether culture and gender affected the performance of the team. The team members indicated that these constructs did not influence their performance, but it did allow them to work with people of different cultures and language. Five of the seven team members listed individual innovation that they had brought to the design of the car as per Question 7. Interestingly, the students only listed technical innovation and did not consider innovation in business or project planning. This was confirmed by their responses to Question 9 on whether they had contributed to marketing – only two students responded that they had contributed by marketing the project on social media.

Decisions were made as a team and submitted to the team leader to implement (Question 8). In response to the final question as to the value that the student gained as a member of the team, the following feedback was received: students considered their participation as valuable for inclusion on their curriculum vitae; they had the opportunity to work with other team members and to develop their interaction skills; the competition presented an opportunity for international travel; and the practical application of theoretical knowledge deepened their understanding of key engineering concepts.

B. Reflection after Event

Once the students had returned from competing in Shell-Eco-Marathon in London, the researchers invited them for a brainstorming session to conduct reflection-on-action. The third and fourth sections of Johns Model of Reflection were addressed and the session was deliberately planned to be unstructured.

Internal influencing factors were discussed and identified as project planning; the UJ procurement procedures; engineering discipline integration; mentorship; teamwork and the selection of team members; role allocation within the team; organization of an international trip; funding and sponsorship; technical competence and alternate design solutions. The team stated emphatically that six months was not enough time to effectively plan for the competition, and suggested that the planning, design and build of the car take place over a two-year period. However, this remains a challenge since the academic semesters occur in six-month cycles and students change modules; hence, the team members change as well. The students also felt that they did not have enough time in the academic programme to commit to the project fully and recommended that the project be executed by post-graduate students. They confirmed that the appointment of a lecturer as mentor and senior engineer was highly beneficial to their success and learning.

Another internal influencing factor was the allocation of roles in the team, and the students felt that the sourcing of funding and sponsorship would have been more effective had they appointed dedicated marketing and accounting roles. Business benefit gained by the students included a better understanding of the value of effective marketing, management of funds and skill in sourcing sponsorship. The students did not anticipate the rigorous internal procurement system of UJ, nor the length of time required for payment of suppliers. This impacted on the project plan as a whole, and delayed the building of the car.

An unanticipated yet positive effect of delayed payments was that the students were required to create temporary solutions by building certain parts of the vehicle themselves. It also demanded of them to integrate their engineering disciplines and to learn from one another in creating solutions to technical challenges. Finally, the team realized that they had not tested the car sufficiently prior to departure given their time constraints. They recommended that students who participate in future competitions build a simulator and track in South Africa for testing the vehicle performance prior to participating in the competition.

With regard to external influencing factors, the Shell Eco-Marathon presented an opportunity to travel overseas for the first time. They experienced several challenges with regard to travel, including not receiving visas in time; not having sufficient subsistence money; and challenges in clearing the car through customs.

VII. Conclusion

Encouraging third year electrical engineering students to participate in an event such as Shell Eco-Marathon is aimed at implementing project-based learning in engineering education. Reflection-on-action learning from the student team indicates that this objective was successfully achieved and that the students gained insight and knowledge in technical, business and human aspects of engineering. This fundamentally supports the exit-level outcome required by ECSA for complementary skills in the education and preparation of engineers for industry. In response to the final section of the Johns Model, the learning reflected by the students included the following: to compare the South African team with other global teams; to gain practical experience to supplement theoretical education; to innovate; to work with team members of other engineering disciplines; to contribute towards a sustainable future; to demonstrate passion in engineering; and to be the first South African team to participate in a global competition.

The practice of reflection as a methodology for learning highlighted the value received by engineering educators and students from participation in Shell Eco-marathon; and continues to be employed by the Department of Electrical Engineering for project-based learning.

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