Engineering Work Integrated Learning: a case study in problem-based research and development projects

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ABSTRACT

The case study presented in this paper is based on an internship program at a company located in Johannesburg South Africa. It aims to show an innovative problem-based research and development approach through an engineering work-integrated learning programme with technologist engineering interns. Through the case study, theoretical, practical and proper decision making have emphasized the understanding of problem solving strategy in research and development with interns. A thorough follow-up of the processes described in this paper could potentially enable decision makers to develop the skills of more engineers. A working model is presented to show how the system can be replicated.

Keywords: Work-Integrated Learning, Research and Development, Internship, Interns, systems engineering.

1. INTRODUCTION

Over the past two decades, a considerable number of people have moved to South Africa for diverse reasons such as political and economic stability and advancement [1]. Similarly, the population growth has increased over the same period [2, 3]. The increasing number of people has created the need for infrastructure development, better life styles and commercial opportunities which stem from engineering activities. Engineering activities require specific competencies [4]. Many of these competencies, including infrastructural and industrial design as examples, must be addressed by engineers. Engineers are considered crucial to economic development, sustainability and national growth. The question that arises is whether adequate engineering skills are available to address the growing South African economy.

According to the Engineering Council of South Africa (ECSA), one engineer serves 3000 people in South Africa in comparison with 227 in Brazil and 543 in Malaysia. This statistic validates the shortage of skilled engineers in South Africa [5].

In order to address the shortage, the development of engineering skills can be achieved through normal tuition supported by work-integrated learning (WIL). Practically, most graduates lack industrial problem solving exposure and effective mentoring which may be attributed to the absence of industry placement. However, for certain companies, employing engineering interns shift them from their economic targets since the time of productive staff is absorbed to mentor future graduates. Due to the recursive nature of this situation, it becomes a problem for students to graduate with their National Diploma (ND) of which the Work Integrated Learning (WIL) component is an exit-level outcome as required by ECSA. Furthermore, the graduation certificate confirming a degree or an ND in engineering technology does not automatically translate to experience, expertise and resultant employment. Consequently, recent graduates seeking their first job opportunity may lack realistic expectations and experience relevant to the kinds of challenges and responsibilities encountered in the work place [6]. According to Leinhardt *et al*. (1995) and Entwistle and Entwistle (1997), the theoretical learning from universities has been of huge criticism for focusing much effort on 'declarative knowledge' and unsatisfactory efforts on relevant professional understanding [7, 8]. In response, the combination of theoretical knowledge and industrial exposure could be seen as the bridge to link graduates with industry for the development of skills and value-adding engineers.

In this paper, the case study presented indicates how a well-managed ND engineering technicians' intern can be integrated into industrial projects to add value; maintaining budget and time constraints in a scenario where a new group of up to 300 interns is enrolled every 6 months.

2. BACKGROUND

The introduction of the practice for linking theory and practical work to enhance education is unclear. Historically, a practical program was introduced for engineering and architecture students in 1903 at Sunderland Technical Collage in Northern England [9]; and in1906, at the University of Cincinnati, Herman Schneider, an engineering lecturer believed that professional concepts and skills acquisition required more than just classroom lecturing. In order to master professional concepts and skills, he understood that students must undertake intense practical experience development. He suggested the key solution would be to alternate employment experiences on a work site with theoretical work on campus [10]. The notion of "learning by doing" has been in formal operation for over a century and from the late 1950s to mid-1980, led by the United States of America (USA), this notion has expanded globally [10].

Many papers have been published by a large spectrum of authors on the WACE International Conference portal to examine the effects of WIL on the students [11]. In 2009, Matsutaka *et al*. studied students' consciousness and its related effects on their academic and employment outcome by means of a sample of over 1300 students at a University in Japan [12]. Carlson and Kwan (2010) explored the effects of WIL on learning outcomes by means of 1040 students from a Hong-Kong University [13], and in 2009 and 2010, Green and Mendez focused smaller groups of engineering students to study the effects of work employment on academic performance in some Universities in Great Britain [14, 15].

In Australia, research has shown the importance and effectiveness of WIL in preparing university students for their work readiness on completion of their studies. From the employers' point of view, as revealed by the survey conducted for the Office of the Chief Scientist (OCS) in 2014, the key difficulties encountered when recruiting graduates were deficiencies in interpersonal skills, understanding of business and workplace experience [16]. As such, practical learning and critical thinking can be visualized as the two most important attributes a graduate should be equipped with on entry to the workplace [17]. According to the Australian Survey of Student Engagement (AUSSE), students who have experienced WIL are less likely to drop out of the University as compared to those who have no WIL experience [16]. The data retrieved from the AUSSE state that students who have experienced WIL have been learning things in their academic programme that 'improved knowledge and skills that contribute to employability' [18, 19].

Most of underdeveloped countries such as Uganda, Cameroon and Ivory Coast are agricultural-based economy countries with young and fast growing populations. Uganda, as an example, has a population estimated at 34 million people with a growth rate of 3.2% per annum, endowed with low industrialization and engineering value addition [20]. In spite of the economic structural transformation over the past two decades, it still faces huge challenges, which include high unemployment and inadequate skills development [21]. Due to the lack of organisational forecast, some efforts in addressing WIL are often not visible. Providing an answer to the skills development would definitely warrant economic growth through entrepreneurship and job creation. This applies to most of the underdeveloped countries worldwide.

In South Africa (RSA), the unemployment rate is in the range of 26.7% for the first quarter of 2016 [22]. Globally, the economies of first-world countries are recovering from recession whereas South Africa is entering one which may be attributed, to some extent, to the lack of a proper employment policies. In RSA, some opportunities aimed at contributing to the economic growth also lack specific engineering skills such as electrical, electronic, civil and chemical engineering as listed on the national scarce skills list [23]. Therefore, it is imperative and expected from the Universities to produce graduates who are job ready through WIL. But in reality, a large amount of students are not exposed to WIL due to a deficiency of opportunities offered in the local industrial environment. Additionally, the labor market fluctuates between skills scarceness and graduates without work. According to Coll and Zegward (2006), skills scarceness and graduates without work might arise because most students do not have behavioral or soft skills such as analytical and team work skills, and are therefore unable to organize and manage themselves [24]. The Resolution Circle (RC), a company based in Johannesburg, is a dedicated research and development environment with multi-disciplinary student teams. These teams are supported by internal technical experts. RC is an initiative of the University of Johannesburg (UJ) that aims to address specific technological challenges brought forward by industry partners. The RC internship WIL program was designed to address the lack of opportunity for engineering skills development in industry and to provide a platform for graduate employability skills development.

Previous studies conducted in first-world countries determined the technical and individual abilities required of engineers by today's industry [25, 26]. These studies have influenced countries like the United States of America [27], the United Kingdom [28] and Australia [29] to revise their national accreditation criteria for engineering programs. In these countries, the accreditation requirement has moved from what is being taught to what is being learned [30]. Therefore, current engineering programs must demonstrate that graduates achieve sets of learning outcomes but they have autonomy in implementation methodology [31]. Two concepts arise from the studies, including problem-based learning and project-based learning and in South Africa, these concepts are integrated in the WIL outcomes. Problem-based learning assists students to develop problem-solving, team and interpersonal skills; whilst project-based learning introduces methods for effective design and completion of projects.

Several universities that have introduced problem-based learning courses, including Monarch University, Curtin University and Griffith University in Australia. Project-based learning courses have been introduced at Hogskole Telemark in Norway, the Colorado School of Mines, Rose-Hulman University of Technology in the USA, Aalborg and Roskilde in Denmark, and TU Berlin in Germany [31]. In South Africa, the combination of problem-based and project-based learning is provided at RC under the umbrella of WIL.

3. A RESEARCH AND DEVELOPMENT WIL CASE STUDY

3.1. The Resolution Circle

In South Africa, universities receive subsidy from the government when students graduate. However, many students are unable to graduate since they have not received placement in companies to fulfil their WIL requirements. In order to overcome income loss and address this challenge, the University of Johannesburg (UJ), has invested in the Resolution Circle to recruit students for their WIL internship program. An on-site range of services is orchestrated in the company (RC) to support marketable projects throughout the commercialization life cycle, including research, development, prototyping, and incubation. Through commercialization, interns who have shown entrepreneurial skills and have developed product based ideas are selectively granted few sits to our incubation program.

RC attempts to close the gap between industry and academia by providing training opportunities and industrial support. The services offered by RC are presented in Figure 1.

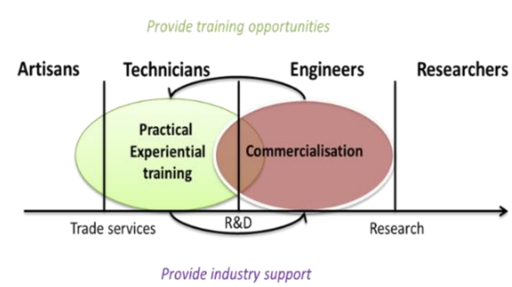

Figure 1. Services offered at the Resolution Circle

Figure 1 indicates that the services offered by RC lie between providing of training opportunities for students and industrial support. The interns, led by technicians and engineers, are exposed to experimental training and commercialization projects through the research and development (R&D) department. Another important focus of RC is research-based projects. The layout of the RC R&D WIL program with its functionality is presented in Figure 2.

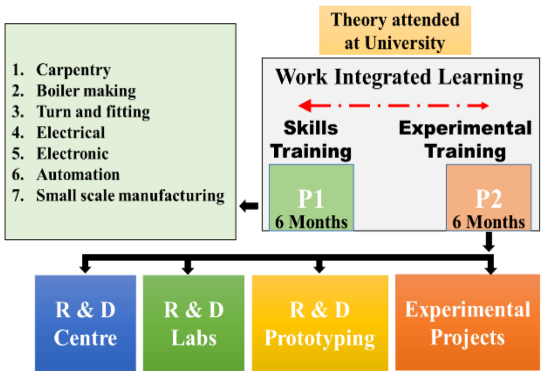

Figure 2. Resolution Circle R&D WIL program layout

Figure 2 displays the interaction between the main components of the company with respect to the WIL program. As required by ECSA, the ND WIL students must undertake practical training for a period of one year of which they do Practical 1 (P1) and Practical 2 (P2) for the first and second semester respectively in their final year of study. One hundred and fifty engineering technician interns from the electrical, mechanical, electronics and instrumentations disciplines are enrolled each semester to complete P1 training for a period of six months. The interns are exposed to six trades which include boiler making, carpentry, turn and fitting, automation, electronic and electrical skills. Exposure to the six trades trains the interns with the necessary hand skills required by the respective disciplines. When the R&D department is executing a project with a manufacturing component, the P1 interns may be involved as well. After completing the six trades, the P1 graduates receive certificates as proof of completion and then move to the P2 phase for another 6 month period.

During P2 the interns are mostly exposed to soft skills (technical report writing, formal presentation, interview readiness and engineering ethics), problem solving, team work and design. The WIL program includes students from other Universities as well.

3.2. Resolution Circle P2 WIL Layout

In the RC P2 WIL program layout, the interns are grouped per engineering discipline for a period of two months. They are exposed to individual stations for two weeks and then rotate to the next station. In mechanical engineering as example, the stations are: G-coding [32], Solidworks [33] and 3-D printing, small-scale manufacturing, and Revit mechanical-electrical-piping [34]. During the two week period, the interns are guided and monitored by trained instructors (senior and junior technicians). Relevant computer-assisted design (CAD) or other software packages are introduced to all the interns at the respective stations. The station arrangement for electrical engineering is presented in Figure 3.

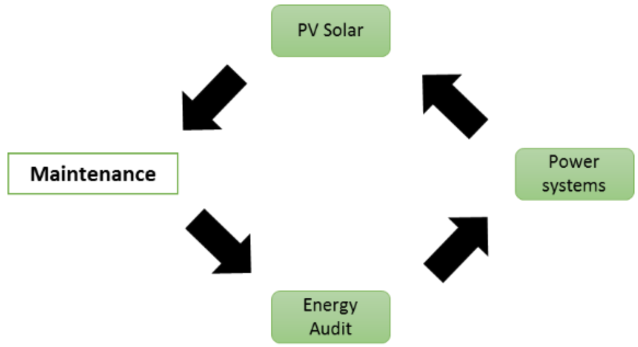

Figure 3. Station rotation layout for electrical engineering interns

Figure 3 indicates that the interns enrolled for electrical engineering are exposed to four stations where they learn relevant software packages such as ETAP [35] for power system, photo voltaic (PV) SOL [36] for solar PV systems and national instruments [37] programming packages. Professional report writing, presentation and entrepreneurial skills are introduced to each team. The interns enrolled for instrumentation and electronics are few and kept in small groups where they are introduced to programing using micro controllers such as Arduino [38], and conveyor belt control technologies using Allen Bradley Programmable Logic Controller (PLC) [39]. This last group is also introduced to electronic software for simulation and Printed Circuit Board (PCB) design.

Report writing is an important aspect of the WIL training program required by ECSA, and monitored weekly. At the end of each station period, the interns write group and individual reports aimed at providing personal and team work reflection and development. After the two month period rotation, all the interns are expected to use their skills to solve relevant problems from industry. The program is structured to satisfy the practical requirements set by the various universities, and to provide the interns with exposure to real-world problem solving. A minimum of 24 weeks must be completed by the interns per semester.

3.4. Resolution Circle P2 WIL R&D Problem Solving

After the initial two-month period, the interns are introduced to higher activity. During this time the P2 interns are placed in smaller groups per speciality. For diversity purposes, interns from different Universities are represented in each group.

The projects are multi-disciplinary including electrical, mechanical, instrumentation and electronic engineering. Some projects are engineering-based whilst others may not be. Clients range from government, the banking sector, industry and entrepreneurs. As projects are received, they are placed in a protocol pool and ranked by time and cost. The projects are then distributed to teams with the relevant discipline requirements; and managed by the Agile project management scheme [40]. Agile is employed since most customers are not fully aware of their requirements at the start of the project and the needs of the project cannot be clearly defined during inception. The project execution flow chart is presented in Figure 4.

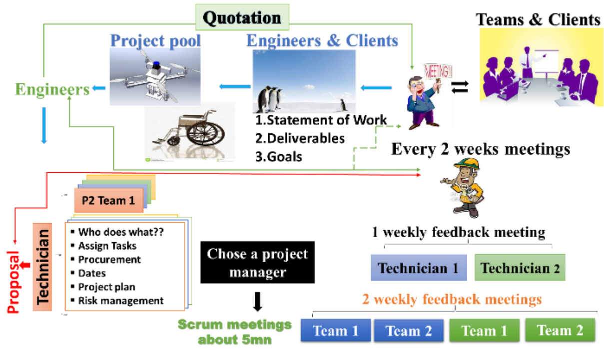

Figure 4. Project management WIL layout.

Projects are selected from the available projects pool and a meeting is organized between the clients and the engineering teams. The engineering teams consists of senior engineers as the project owner, the R&D P2 project manager, a team of four interns per group per speciality and a senior technician per project per speciality. A statement of work is drafted and a list of deliverables are drafted from the meeting including the project due dates. In preparation of the draft proposal, the teams meet to discuss the time needed for the project, the materials or components required, the risk involved, the remedies for risk, the schedule for the deliverables and the project plan. The project backlog is often used in the Agile project management scheme [40]. The project backlog provides a clear vision as an important factor. The backlog is converted into tasks and then assigned to each team respectively during execution. In order to execute the project, a specific time frame of not more than two weeks must be defined respectively. This time frame is known as the Run [40]. A run period is the time interval when teams come together to review the project's progress. When the teams are satisfied with their draft proposal, it is forwarded to the project manager who reviews, edits and forwards it to the senior engineer responsible of the specific project. The senior engineer is the project owner and the scrum master is someone in the execution team [40]. When the senior engineer is satisfied with the draft proposal, s/he sends it to the scrum master for pricing. If modifications are required, the senior engineer sends the files back to the teams and the process reiterates until consensus is reached. When this occurs, the scrum master discusses the proposal with the client and issues the project term sheets and the quotations. The term sheets clarify stakeholder expectations and the respective deliverable dates. The project commences officially once the term sheets are signed by all stakeholders.

A senior technician can work with up to four teams in his speciality on different projects. At commencement, each team selects its leader who holds a local scrum meeting every day on the progress of the project. The technicians hold informal meetings with the project manager twice a week. At the completion of the project, the scrum master and senior engineers hand over to the customer. The project and the client satisfaction is fed back to the teams after which the project is closed.
As an example, one of the projects that involved more than one team was the electric car which comprised of the electrical, mechanical and electronic engineering teams. At the commencement of the project, all the teams meet to discuss the project backlog and the assigned tasks. The project team elected one-week runs run for the project. Team leaders were chosen and procurement and communication issues were addressed. Project management was allocated to the interns as a learning experience. The interns held local scrum meetings every morning which were monitored by a senior technician. The mechanical team was assigned to design the car, the suspension, its road worthiness and the aerodynamics and suspension system.

The tasks assigned to the electrical team were to design the electric drive system, the battery size and the electrical wiring of the car. Through team consultation, cost effective and high performance parts were designed. The task allocated to the electronic team was to design a charger for the battery bank and the lighting of the car. The project was executed according to plan and is a showcase project for WIL development.

3.5. Challenges of WIL projects

A challenge in performing projects with a new groups of interns every six months makes management of the R&D P2 project a complicated task. A new group of interns introduces new personalities and new cultural dynamics. Placing the new group at the level where the previous P2 left becomes more difficult with unwilling interns. Human behavioural and cultural implications therefore make the program both exciting and challenging. This transition and human factor challenge necessitates the introduction of a systems engineering approach.

According to the International Council of Systems Engineering (INCOSE), Systems Engineering (SE) is an interdisciplinary approach that provides the means to enable the realization of successful and complex systems [6]. SE focuses on:

- Defining customer needs and required functionality early in the development cycle;
- Documentation requirements;
- Proceeding with design synthesis; and
- Structure validation and verification whilst considering the complete problem.

SE integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

Challenges experienced during the execution of WIL projects at RC include: interns with no industry experience; limited budgets; inefficient procurement processes; and cultural differences in the team composition (age, gender, religion, ethnic group and race). On the other hand, the computer labs, workshops and experienced senior engineers and technicians are available to support the intern teams. The systems engineering approach facilitates the execution of projects as follows:

- Clients' needs are defined as soon as possible in the project process as per project backlog;
- Drafting the statement of work clarifies team expectation and the project deliverables and dates,
- The teams involved in one project discuss, design, harmonize costs and optimize the human resources; and
- The system validation and verification are addressed using the systems engineering V-model.

The V-model works well with small projects where requirements are very well understood and where tasks are completed individually. The V-model is presented in Figure 5.

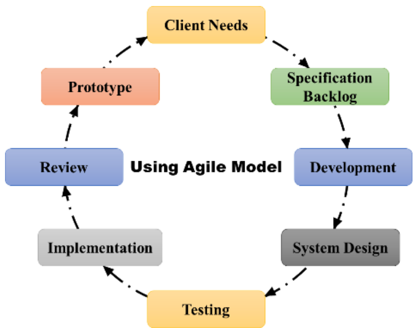

Figure 5. R&D Project Agile project management model.

From Figure 5, the life cycle of the project is implemented with the interaction with the client until completion.

4. RESULTS

A number of WIL projects at RC have been success stories. These include the circuit board project, the intelligent solar inverter, the electric car and the thin film solar modules testing project. The success of all the projects is ensured by a clear definition of the project scope, as well as the execution of project with the Agile project management techniques. Another important element of project success is communication amongst team members which is facilitated by the systems engineering approach.

5. CONCLUSION

The involvement of the Resolution Circle with the internship program of the ND interns has not been an easy task. The lessons learned have channeled the P2 program to important results in terms of a project's effectiveness, consistency, management and repeatability. The authors provide solutions to engineering skills development though WIL problem solving R&D at the Resolution Circle as a specific case study. The value added through the program was both shared by the interns and RC. The interns have specifically gained and earned their skills through the program whilst RC has contributed by providing a future strategy for engineering skills development in South Africa. Therefore, after their graduation at respective Universities, these former interns would possibly address the needs from clients and effectively contribute to the economy. As recommendation, decision makers and business owners may replicate the model presented in this paper for enhanced skills development to reduce technical skills shortage in South Africa and Africa.

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