Preparing for the Solar Challenge: Critical competences acquired in undergraduate engineering education

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***Abstract*—Engineers are expected to function in a highly competitive environment, which demands that projects are developed in increasingly efficient and cost-effective ways, across various disciplines. This trend necessitates multidisciplinary collaboration which requires both traditional engineering skills and so called 'soft skills', such as good communicative competences and working cooperatively in teams. In this paper it is described how these skills were developed in the course of the University of Johannesburg's preparation for participation in the biannual Solar Challenge.**

Keywords - communicative competence; multidiciplinary teamwork; project-based learning; multidisciplinary teaching; cooperative learning; Solar Challenge

I. INTRODUCTION

Engineering students have to learn how to merge physical, life, and information sciences at different levels, embrace professional ethics and social responsibilities, be creative and innovative, and communicate effectively [1]. The undergraduate curriculum should prepare students to live and work competently as global citizens in a multidisciplinary environment, while demonstrating awareness of how engineers contribute to society and impact on the environment.

In line with international trends, project-based learning is increasingly being viewed as an important instrument in engineering education, used to facilitate learning that is conducive to producing graduates that become productive engineers. According to Papanikolaou and Boubouka [2], project-based learning is based on the idea that a problem or question drives learning activities toward the construction of a concrete artifact in an authentic context. Project-based learning can be instrumental in facilitating peer learning in a collaborative, multidisciplinary environment, developing competences, and linking teaching with the professional environment. This learning strategy, based on cooperation and active student participation in an inductive learning environment, offers multiple possibilities for developing technical, contextual and behavioral competences.

Collaboration between the Electrical & Electronic Engineering Science, Mechanical Engineering Science and Industrial Design Departments has provided an opportunity to implement multidisciplinary and cooperative learning strategies at undergraduate and postgraduate level at the University of Johannesburg (UJ) in South Africa. Both the final year capstone courses and the third year Systems Engineering and Design courses in the Mechanical Engineering Science and the Electrical & Electronic Science Departments respectively, were adapted to incorporate multidisciplinary, cooperative learning strategies by participating in the Solar Challenge project. The Solar Challenge calls for the design and manufacture of solar powered vehicles. Through the efforts of students from the Faculty of Engineering and the Built Environment (FEBE) in cooperation with the Faculty of Art, Design and Architecture (FADA) this goal was achieved. Ultimately, these vehicles will take part in a 4000km race throughout South Africa, competing against local and international entries.

Against the background of the diverse requirements and quality assurance in engineering education as recognized by the Engineering Council of South Africa (ECSA) and the Washington Accord [3], it is an ongoing challenge for Faculty to optimize engineering education programs. Not all exit level outcomes fit comfortably into traditional engineering curricula, but are often well suited to inclusion in cooperative learning projects, such as the Solar Challenge.

The objective of this paper is to describe how a number of critical engineering competences were developed in the course of the UJ's preparation for participation in the 2012 Solar Challenge. This qualitative research study was aimed at investigating the imparting of skills that contribute to the development of engineering graduates who are equipped to lead complex engineering activities and solve complex engineering problems in a multidisciplinary environment.

This paper is focused on two key outcomes that have featured prominently in the results of this investigation, i.e. multidisciplinary team work and communication skills. The research population consisted of third year, fourth year and master's degree engineering students at UJ. In this paper the authors will present a theoretical overview of the research context, including an introduction to the Solar Challenge as a project in FEBE and FADA, and an engineering educational perspective on the project-based, cooperative learning environment that characterized the preparations for the Solar Challenge. The research design will be described briefly, followed by a discussion of the results of this study and recommendations for future projects

II. THEORETICAL OVERVIEW OF THE RESEARCH CONTEXT

Implementing the Solar Challenge project created an opportunity to incorporate cooperative teaching strategies in a multidisciplinary, project-based learning environment. A discussion of the background and rationale for the project is presented and the advantage of implementing the Solar Challenge project is explored. The authors will also investigate to what extent a cooperative, multidisciplinary, project-based learning environment (in the form of the Solar Challenge project) effectively develop the competences specified by the ECSA exit level outcomes.

A. Background to and rationale for the project

South African universities rely mainly on lecture-based teaching, supplemented with laboratory work, tutorials, seminars, and projects where appropriate. Capstone courses are implemented at final year level and provide an opportunity for students to demonstrate that they have achieved the outcomes set in the degree by successfully completing design and research based projects. The capstone courses are designed to assess cognitive, affective and psychomotor learning in a student-centered and student-directed manner. This requires the command, analysis and synthesis of knowledge and competences. Also included in the assessment criteria are professional and general communication; impact of engineering activity on society and the environment; individual, team and multidisciplinary working; lifelong learning; and professional ethics and practice. Previously, engineering students at UJ engaged in individual design and research projects in their final year capstone courses. A disadvantage of an individual project of this nature is that it does not promote the development of a professional identity. Furthermore, students are not necessarily afforded the opportunity to develop effective communicative competences to work effectively in teams and in multidisciplinary environments.

The research and design courses used as case studies in this investigation are presented in the final year of study, of a four-year Bachelor's degree in the Mechanical and Electrical Engineering programs at UJ. These capstone courses contribute towards the engineering sciences, design and synthesis, and complementary studies knowledge areas of the qualification, and accounts for 60 credits of the degree, where one credit is equal to ten notional study hours. The purpose of the BIng qualification is to develop mechanical and electrical engineers who can identify, assess and respond to the needs of society (and the economy) and to address these needs innovatively through the creative application of scientific and mathematic principles and methods [4]. The knowledge and skills reflected in the qualification are seen to be building blocks for the development of candidate engineers towards becoming competent engineers. These engineers will ultimately lead complex engineering activities and solve complex engineering problems in a multidisciplinary environment. The degrees are internationally accredited by the ECSA and comply with the quality assurance processes of the Washington Accord [3]. Signatories of the Washington Accord include the USA (Accreditation Board for Engineering and Technology) and the UK (Engineering Council).

The Solar Challenge necessitated that an integrated project between the engineering departments and industrial design department be implemented. This enabled students to design, build and test their individual projects in a collaborative, multidisciplinary, project-based learning environment. Students who applied to participate on the Solar Challenge were given a design brief with strictly enforced deadlines. Students were provided with individual research and design tasks, as well as tasks beyond the expected capability of any individual team member, requiring team work to successfully complete these tasks. One of the 2011 Solar Challenge vehicles was a solar car, designed and manufactured by a team of eight undergraduate (six final year engineering students and two industrial design students), mentored by a mechanical engineering and an electrical engineering postgraduate student, as well as an academic staff member from each department. Six third year engineering students from the Systems Engineering and Design courses in Electrical Engineering Science Department were also involved in the wiring design, logistics and marketing of the solar car, although third year student solutions were not implemented in the final design of the vehicle. A unique feature of the Solar Challenge project is that a thirteen part television documentary on the development of the solar powered vehicle was broadcast. The documentary detailed the student efforts throughout the construction phase of the vehicle and subsequent races and events of the solar car [5].

B. Advantages of implementing the Solar Challenge project

According to [6], learning is not only knowledge acquisition or participation in established social practice. It is also a process of creating new knowledge collaboratively when addressing complex problems which involve interdisciplinary knowledge and innovative thinking. This pertains to the purpose of the BIng qualification. The Solar Challenge presented a learning opportunity to prepare engineering students for an increasingly complex professional environment, equipping them with the ability to acquire competences of collaboration, management and innovation as well as awareness of knowledge creation, with a focus on efficient energy usage and sustainable engineering design. The intended benefit of implementing a project of this nature was twofold. Firstly, the authors anticipated the benefits of an enhanced learning environment created through the students' participation in the Solar Challenge which will be presented in the following sections. Secondly, the marketing potential of the Solar Challenge was evident from the start of the project. By luck, rather than grand design, these benefits materialized through the evolution of the project and the efforts of faculty management to get buy-in from university management and industry partners.

The Solar Challenge was designed to run on an overlapping three year cycle. This implies that a team of students participates on the project over a three year period from undergraduate to postgraduate level, encouraging knowledge transfer, peer mentoring and apprentice style training. Each vehicle is raced in a Solar Challenge event, and then modified and refined by the next generation of students, mentored by the previous generation of students (enrolled as postgraduates). Students have the opportunity to work alongside engineers and technologists in a multidisciplinary environment, experiencing the challenges faced by engineers in terms of project and resource management, procurement systems, managing personalities in a diverse team, solving complex technical problems and communicating their solutions to a variety of audiences.

The Solar Challenge project was initiated to serve as a promotional vehicle to (amongst others) attract undergraduate students to pursue postgraduate studies focused on efficient energy usage and sustainable engineering design. Students from the BIng programs take up research and design projects on the Solar Challenge and continue these studies at postgraduate level. Students are initiated in the field at undergraduate level, develop an interest in it and become potential contributors to progress in these fields. With a rigorous academic background and commitment to the subject, these students will most likely enter the engineering environment with a unique focus on energy innovation and sustainable engineering design. The proven success of postgraduate student intake in the Mechanical and Electrical and Electronic Engineering Science Departments has made this project an essential research and marketing tool in FEBE.

Furthermore, FEBE place an emphasis on community engagement and industry involvement to support and develop current and future students. Through the Solar Challenge and similar events, FEBE brings awareness of engineering, energy issues, and technology innovation to a wide audience across South Africa. Plans for road testing the vehicles include visiting schools and community events, as well as industry showcases and conferences. The project demonstrates the creative application of mathematics, science, engineering science and technology – and ultimately promotes these subjects to learners, making it an amazing platform to promote engineering and technology careers to learners. The Solar Challenge also provide an opportunity for industry to collaborate with UJ on developing and showcasing green technology and innovative products used in energy efficient design. Through industry's participation in the Solar Challenge, students, future engineers, technologists and industrial designers become acquainted with the problems facing current industry leaders.

C. Developing critical competences through cooperative, multidisciplinary project-based learning

Institutions of higher education have an obligation to address changes in social climates using relevant teaching strategies that provide students with the necessary competences to participate in the real world. McLeod and Reynolds [7] argue that we are teaching and learning in times of overwhelming change in the way we know, the way we teach and in what is expected of us as educators and learners. Engineering educators in South Africa are faced with changing student demographics, changing student attributes, a shift in student preparedness, as well as ever changing engineering practice. With diminishing numbers of graduates that complete engineering degrees [8], the demand for effective training of engineering students has become a national priority calling for effective teaching and learning strategies in engineering education.

A key attribute of engineers is that they are problem solvers [9]. These problems occur in a world which – in simple terms – is characterized by three conditions [10,11,12]. These are rapid change; complexity of both technical and non-technical considerations; and information, more readily accessible, communicated to a wider audience in a multidisciplinary environment. With rapid changes in technology, the boundaries of professions become progressively more difficult to identify as problems become increasingly ill-defined and complex, relying on multidisciplinary solutions [6]. Teaching professional competences in technology-related fields such as engineering are gaining importance since problems cannot be solved through traditional technical solutions alone. Rapid change continually presents new situations to respond to. Existing approaches and procedures must be reassessed and adjusted or even discarded and replaced. Complexity demands consideration of multiple criteria, viewpoints, solutions and pathways – often interacting with one another. More information, more readily accessible, presents new possibilities, but also requires that we differentiate between what is more important and what is less important. When the content increases, we therefore need to spend time, learning new skills to acquire, understand, and evaluate this information [13], rather than learning more information.

Outcomes-based program accreditation necessitates change to the traditional model of engineering education design and delivery. Equipping engineering students with the competences for specified outcomes such as effective communication and teamwork requires teaching and assessment methods not traditionally found in engineering education and unfamiliar to most engineering educators [14]. This is also true in the case of the Solar Challenge project. Due to the multidisciplinary nature of the field of engineering, students are faced with the challenge of developing multidisciplinary competences and knowledge in an environment that is constantly changing.

According to [7], students should demonstrate competence to communicate effectively both orally and in writing, with engineering audiences and the community at large. Students should demonstrate their ability to use the appropriate structure, style and language for the intended purpose and to the intended audience. Students should also be comfortable to communicate their ideas and solutions by using appropriate graphical support and visual materials, applying methods of providing information for use by others involved in the associated engineering activity. Students should also develop competence to deliver ideas fluently and meet the requirements of the target audience.

In terms of teamwork, ECSA prescribes that students demonstrate competence to work effectively as individuals, in teams and in multidisciplinary environments. In terms of working effectively, a student should demonstrate the ability to identify and focus on the objectives of the project, work strategically, and execute tasks effectively and on time. Working effectively in a multidisciplinary team requires that students make individual contributions to the team activity and perform critical functions in the team. Students should enhance the work of fellow team members and should also benefit from the support of team members. Effective communication with team members should also be developed and assessed. Project-based learning in a cooperative learning environment has attracted particular interest in the international engineering education community because of its potential to increase student engagement and facilitate development of critical competences [15,16,17,18].

According to [19] success in professional life requires one to be able to work independently and as part of a team, always being ready to take the initiative, and to acquire new knowledge. Acquiring these professional competences requires good social skills and learning abilities. No single teaching strategy can enable the development of all the competences required by students entering the engineering realm. However, a combination of two or more learning strategies can put together the most favorable conditions for developing these competences. The Solar Challenge combined project-based learning in a cooperative, multidisciplinary environment in the pursuit of developing these critical engineering competences.

Bransford, Brown, and Cocding [20], argue that the likelihood that knowledge and skills acquired in one course will transfer to real work settings is a function of the similarity of the two environments. Traditional lecture-based teaching that focus on individual work differs from most work environments which usually involve collaboration in a multidisciplinary environment. Assigning teams to perform tasks thus further promotes transfer, provided that the students are helped to develop competences to work in teams and the work is organized in a way that assures individual accountability for all of the learning that takes place [21].

According to the Johnson and Johnson model [22], cooperative learning is instruction that involves students working in teams to accomplish a common goal, under conditions that include elements like positive interdependence, individual accountability and face-to-face promotive interaction. Appropriate use of collaborative skills where students are encouraged and helped to develop and practice trust-building, leadership, decision-making, communication, and conflict management skills is also a characteristic of collaborative learning. Group processing is the final element described by the Johnson and Johnson model. In a collaborative learning environment team members set group goals, periodically assess what they are doing well as a team, and identify changes they will have make to function more effectively in the future.

The multidisciplinary nature of the Solar Challenge required that students from different disciplines depended on their colleagues to perform the tasks outside of their field of expertise and that they ensure an interface where these technologies interact. The appointed mentors played an important role in face-to-face promotive interaction, facilitated weekly supervised meetings and provided a common workspace. Students had individual and shared tasks that required working together, with group members providing one another with feedback, challenging reasoning and conclusions, in effect teaching and encouraging one another. In the Solar Challenge project, the role of the mentors and supervisors was to assist students in adopting the strategies and reflective processes that would enable them to define, plan, and self-monitor their thinking and progress. Participating in the Solar Challenge project gave students the opportunity to develop competence to work effectively as individuals and in a multidisciplinary group, as prescribed by ECSA.

According to Felder and Brent [23], when the principles of cooperative learning are observed – including holding all team members individually accountable for the entire project content and facilitating their acquisition of teamwork skills – students tend to exhibit improved academic achievement, greater persistence through graduation, better high-level reasoning and critical thinking skills, deeper understanding of learned material, greater time on task and less disruptive behavior in class, lower levels of anxiety and stress, greater intrinsic motivation to learn and achieve, greater ability to view situations from others' perspectives, more positive and supportive relationships with peers, more positive attitudes toward subject areas, and higher self-esteem. Studies also suggest that student participation and interaction in a group learning process is critical to effective learning [24]. Another nontrivial benefit for instructors is that when assignments are done cooperatively, consultation time and the number of papers to grade can also decrease.

Project-based learning is rooted in constructivist theories of learning, implying that individuals actively construct and reconstruct their own reality in an effort to make sense of their experience [21]. The teaching strategies based on constructivism focus on providing students with authentic experiences that induce cognitive conflict and encourage students to develop new knowledge schemes [25]. In cognitive constructivism, an individual's reactions to experiences lead to (or fail to lead to) learning. In social constructivism, language and interactions with others – peers, mentors, and instructors – play a primary role in the construction of meaning from experience. Meaning is not simply constructed, it is co-constructed. Team work, considered desirable in all forms of constructivism and essential in social constructivism, supports the use of collaborative and cooperative learning. Therefore, according to the constructivist philosophy, learners construct their own knowledge both individually and collectively

In their proposal of a knowledge-creation metaphor for learning, Paavola, Lipponen and Hakkarainen [26] describes that learning can be seen as a collaborative effort to enhance a certain subject matter, and fundamentally it relies on the interaction between individual and communal processes. The main features of this approach are described as a pursuit of new knowledge by combining cognitive aspects and affective aspects of learning. It includes highlighting social processes and stressing individual efforts. It also requires going beyond conceptual knowledge as the only form of knowledge and stresses the importance of conceptual artifacts to develop, evaluate, and modify conceptual artifacts collaboratively. Furthermore, interaction through shared objects and reflection stimulate learning. Through the students' participation in the Solar Challenge, these features occurred naturally.

The emphasis in project-based learning is on applying or integrating knowledge rather than acquiring it. According to Felder and Prince [21] project-based learning is centered around one or more tasks that lead to the production of a final product – in this case the design and manufacture of a solar powered vehicle. The culmination of the project is a written and oral report summarizing the procedure used to produce the product. Project-based learning incorporates a range of inductive instructional methods where the focus is on a fixed deliverable. Inductive teaching and learning strategies are student-centered, supported by research findings that students learn by fitting new information into existing cognitive structures. [16]. Inductive instructional methods almost always involve students discussing questions and solving problems, with much of the work in and out of classroom being done by students working in cooperative learning environments [21].

Research has shown that project based learning can be used as an efficient method for students to achieve process skills such as collaboration, project management, innovation, creativity, and communication [6,27]. Compared to traditionally-taught students, students who participate in project-based learning are likely to be more motivated, demonstrate better communication and teamwork skills, and have a better understanding of issues of professional practice and how to apply their learning to realistic problems [27,28]. These are all attributes well suited to engineers and expected by prospective employers. Studies also suggest that project-based learning may effectively reach students whose learning styles are poorly suited to a traditional lecture-based classroom environment [29]. Students participating in project-based learning environments site that they received more support from their instructors, saw more connections between theory and practice, were more inclined to use autonomous learning strategies and were less reliant on rote learning. The perceived benefits of project-based learning could be attributed in part to the perception of greater support from educators, a factor known to have a positive impact on both performance and attitudes.

Although the benefits of project based and cooperative learning is supported by theory and well established by classroom research, there are obstacles to address. Disadvantages associated with project-based, collaborative learning strategies include incomplete mastery of engineering fundamentals, frustration over the time and effort required by projects and the interpersonal conflicts students experience in team work, particularly with teammates who fail to pull their weight [30]. Students often fail to succeed in working effectively in a collaborative environment. A common problem with collaborative learning is "freeloading", whereby one or more leaners do not contribute to their full potential and instead rely on others to carry them through. Another drawback/failure faced by learning teams is where an individual "highjacks" a situation and takes complete control of an assignment and aggressively/assertively directs the activities of the other students [31]. In addition, if the project work is done entirely in groups, the students may be less equipped to work independently. There are however several practical tips and strategies that can be incorporated to curb dysfunctional behavior in teams [23].

III. Research Design and Methodology

The research design of this study was qualitative, exploratory, descriptive and contextual [32]. A functional approach to research was followed [33], which means that the research was aimed at improving practice, in this case engineering education practice. Research was conducted on the basis of the scientific principles of logic and justification [33]. An important aspect of justification involves establishing trustworthiness, in this case by applying the strategies for the achievement of rigor in qualitative research, as based on Lincoln and Guba's [34] criteria for trustworthiness in qualitative research. Of the criteria for establishing trustworthiness – credibility, transferability, dependability and confirmability – credibility was most significant in the research process in question.

Credibility is related to establishing how confident the researchers are with the truth of the findings, based on the research design, research participants and the context of the study [35]. This was achieved through the description of experiences as they were lived and perceived by the research participants. Krefting [35] suggests some strategies to ensure credibility, of which triangulation was a key aspect in this study. Triangulation of data sources involved maximizing the range of data sources that might contribute to the researchers' understanding of the way that participants had developed important engineering skills.

The research took the form of a contextual, specific and descriptive case study of the impact that the preparation for the Solar Challenge has had on engineering education at UJ. Case study research is an in-depth qualitative investigation of a bounded system or current phenomenon – the development of skills during the Solar Challenge project, in this case – by means of detailed data collection and utilizing multiple sources of information. It then results in a case description and case-based themes, concerned with generating knowledge of the particular [36,37,34].

A purposive sample was drawn, consisting of potential research participants who seemed to be most likely to make a specific, unique contribution to this study and from whom the researchers were likely to learn the most, given that the opportunity to learn is the most important in case selection [37,38]. This sample consisted of a number of third year, fourth year and master's degree students from both the Departments of Electrical and Electronic Engineering Science, and the Department of Mechanical Engineering Science, who were involved in the Solar Challenge project.

Data collection took place through a number of conversational, semi-structured interviews with the selected participants, with the aim of eliciting accounts of the interviewees' experiences during the Solar Challenge project. The empirical data in this study consisted of the video recordings and subsequent transcriptions of the interviews, along with field notes made by the interviewer during the research period.

Interviewing as a process of human interaction may pose certain risks to interviewees, such as potential embarrassment, violation of privacy, misunderstandings, and conflicts in opinions and values. Certain ethical measures related to informed consent were taken to prevent the potential risks implicit to the research interview: Participants were invited to take part in the research voluntarily and were told why they were singled out for participation. Background information about the study was provided. Participants were informed of the competence and background of the researcher who conducted the interviews. Information obtained during the data collection process remained confidential, unless otherwise agreed upon in advance. They were also informed of their right to withdraw from the research without penalty.

The process of data analysis consisted of the coding of the empirical data, with the emphasis on interpreting for understanding. The texts and video footage were revisited as needed in order to continue the process of identifying themes. Based on a detailed description of the case, certain key issues or themes were focused on, so as to better understand the complexity of the case [36]. These themes were then compared to determine how they were related to each other. Finally, the researchers can attempt to portray the relevant aspects of the case and the lessons learnt from the Solar Challenge project in this paper [37].

IV. Discussion of results

The capabilities of cooperation, communication, and project management in diverse social contexts are primary qualities required of engineering graduates upon entering industry. Competences that are highly valued by employers include engineering graduates' communication skills, problem-solving abilities, and the ability to work as effective members of a team. Collaborative learning activities have proven to be effective in developing and improving qualities such as the above [31]. Although Engineering educators are responsible for assessing these outcomes, they need to create a learning environment where the skills in question are nurtured.

Creating such a learning environment has been successfully attempted by in preparation for the Solar Challenge project as described above. The results of this study have revealed the successful development of a number of non-technical skills in addition to the research participants' reported increased technical competence and engineering related knowledge, such as problem solving skills. Of these non-technical skills, we have elected to discuss only two main competences that have emerged as predominant themes during the data analysis phase of the study in this paper. These competences were also selected because they are exit level outcomes that are required by ECSA for the qualification BIng. The two competences in question are *professional and technical communication* (ECSA Exit Level Outcome 6), and *individual, team and multidisciplinary working* (ECSA Exit Level Outcome 8). The research results that are relevant to these two competences will subsequently be discussed.

A. Professional and technical communication

There is increasing international recognition of the need for communicative competence in virtually all fields of industry [39]. This is also the case in engineering, where much of an engineer's time is spent communicating technical details to various audiences [40]. The growing recognition of the importance of communicative competences is widely demonstrated. One example is the World Chemical Engineering Council's [1] development of lists of engineering graduates' most significant shortcomings and most important abilities. Effective communication is the only ability to feature prominently on both of these lists.

Ironically, while communicative competence is considered one of the most important abilities with respect to employment, it is often neglected in engineering education. The Massachusetts Institute of Technology [1] conducted a survey of lecturers, professionals and alumni aimed at ascertaining the relative importance of a number of skills for engineering graduates. Again, these results placed communication among the most important skills required (along with reasoning, analysis and teamwork). In another study (reported on by [39], effective communication was rated as the second most important skill in engineering after problem solving. On home turf the importance of communication is recognized by the fact that it has been identified as one of 10 exit level outcomes for engineering graduates. According to [41], engineering graduates should be competent in effective oral and written communication, aimed both at engineering audiences and the community at large.

Based on the results of this study, many of the participants in the Solar Challenge project have gained considerably in terms of communicative competence. The significance of communication in this project has been evident in the research data gathered from the four groups of research participants that were interviewed, i.e. 3rd year undergraduates, 4th year undergraduates, master's degree postgraduates, and academic staff. The central position of communication in this project was by and large the result of a rather unusual media component associated with this project. The preparation for the Solar Challenge was the subject of a nationally televised reality television show named Fuelduel, and everyone who was involved in the project was likely to have at least some television exposure. The focus was, of course, on the student participants in the Solar Challenge. Students were filmed informally while working on the project and formally in television interviews. Hence they became well aware of the way their oral communication might be perceived. Their awareness was generally followed by a need for assistance in improving their oral communication, amplified by the realization that their progress might be highly visible. (Much debate has taken place regarding the complex ethical issues related to this project [42]).

In response to the need for improved oral communication skills, the undergraduate students attended a workshop on presentation skills, presented by a professional television presenter. The research participants reported that this training enhanced the undergraduate students' confidence and oral presentation competence, not only when doing formal presentations, but also in front of the camera.

Across the four groups of participants, the initial reactions to the media presence on the project were characterized by surprise and unease by a number of research participants. Participants report having gradually grown accustomed to the presence of the camera, followed by one of mainly three reactions: Accepting and ignoring the camera while attempting to act as usual; accepting and avoiding the camera; and utilizing the camera to achieve conscious or subconscious personal and/or team objectives.

As mentioned in the introduction and discussed in section II, the third year Electrical and Electronic Engineering students were involved in the Solar Challenge project as part of the requirements for the subject Systems Engineering and Design. One outcome of this subject pertained to written and oral technical communication. Besides the written communicative competences that were successfully acquired in the lectured section of the course and applied in the learning environment of the Solar Challenge project, the third year students were faced with an increased number (in comparison to the course in previous years) of diverse communication situations that required effective oral communication. Their oral communicative interactions included informal exchanges with peers, regular informal meetings with their teams, mentoring conversations with the master's degree students to whom they reported, formal oral presentations of their work, formal communication (both written and oral) with suppliers, sponsors and other service providers outside the context of the university. Not only the students in question, but also the mentors and the academic staff responsible for the course, reported student growth in this regard. This was also evident from improved achievement of these learning outcomes, in comparison to previous years.

An almost predictable communication related theme that emerged clearly during data analysis, was the issue of interpersonal conflict and the challenge to resolve said conflict professionally and constructively. The main reasons for conflict pertained to a team member not meeting the expectations of other team members in terms of quality of work, work ethic, and unequal work load. The words "he doesn't pull his weight" were often heard during the research interviews. These conflicts were not always resolved through professional communication, but rather through avoidance of the underperforming team member, excluding the team member from future tasks and indirectly from the team, as well as occasional direct confrontation. On occasion lecturers who served as monitors for one of the teams played a moderating role by intervening on an individual basis. Given the fact that students had no formal instruction to help them address conflict and relied mainly on existing responses to conflict, it has become clear that basic skills in conflict management would have contributed to the students' professional development.

B. Individual, team and multidisciplinary working

ECSA [41] requires that engineering graduates are competent to work effectively individually, in teams and in multidisciplinary environments. During the analysis of the research data, it was confirmed that these approaches to working were indeed critical skills required for the success in the Solar Challenge project.

A general theme related to both individual and team work which emerged across the four groups that were involved in the project pertains to the conflict between individual priorities and project or team responsibilities, alternatively described as conflict between personal interests and those of the team. Although some participants attempted to achieve some form of balance in terms of their responsibilities, they seemed to have been faced with a conscious or sub-conscious choice in response to this mostly internal conflict. This choice might have been a deliberate and once-off decision, or it might have been an ongoing internal struggle. The response to this dilemma often resulted in trade-offs based on the implicit or explicit priorities of the individual. This had personal and academic implications, some of which the participants in the project might not have foreseen initially.

On undergraduate level students had to balance their project responsibilities with their other academic demands. Some prioritized their individual academic performance, often resulting in a dissonance with the teams they were part of. Others became passionate about the project, often accompanied by a strong sense of responsibility towards the team. The latter students mostly experienced the impact of their choices in the form of less satisfying results in their other academic subjects or in the documentation aspect of their final year capstone projects. Even in the case of the master's degree students, it was evident that their work on the project had to be weighed against their individual research projects. Some master's degree students chose to immerse in the all-consuming work demanded by the project, but had to face the consequences of delays in their research output.

Among the third year undergraduates there were distinct differences in skill and ability to perform technical tasks individually. Some undergraduates surprised their mentors by the proficiency with which they performed technical tasks, while others reportedly had inadequate technical experience and skill. While the onus was on each student to take responsibility for his/her own learning and the acquisition of the necessary new skills, it seems that most students preferred to take a more passive role or perform less challenging technical tasks.

The students who were willing to immerse themselves in the project regardless of prior ability, were notably also the ones who seemed to have had the richest learning experience. It was therefore not surprising that the latter individuals were more likely to indicate an interest in postgraduate studies and were most keen to have an active part in the following year's phase of preparation for the Solar Challenge. Similarly, they displayed a strong sense of belonging and loyalty to their team, and took pride in the product of the team effort. These team oriented students forged the ability to establish working relationships in the form of networks and partnerships among peers and other role players with whom they needed to cooperate. They emerged from the project with a clear understanding of what they as teams require of prospective team members, in terms of engineering expertise, work ethic and likelihood of being compatible with the team culture.

Regarding multidisciplinary work, the most successful examples were found among the final year undergraduates and the postgraduate students. Data analysis revealed an emphasis on effective and productive multidisciplinary work. This mainly involved students from Mechanical Engineering Science and Electrical and Electronic Science departments, although students from FADA initially played an important role in designing the cars for the Solar Challenge in cooperation with the engineering students. There was an openness to learn from peers who studied in a different discipline, contributing to students acquiring a working knowledge of the other discipline/s. This fostered a spirit of collegiality and an enriched learning experience. With reference to the key result of improved communication discussed above, it was found that team members communicated more effectively and confidently across disciplines. Some research participants report having discovered new interests and talents within themselves in the process of working alongside a team member from a different discipline.

V. STRATEGIES FOR FUTURE PROJECTS

The pitfalls and challenges of taking on cooperative, problem-based teaching strategies are well documented [43,23]. The following guidelines outline key elements that were found to support the implementation of a cooperative, multidisciplinary project [44] and are suggested for future projects at FEBE. It is a structure that was followed by the authors, not initially and not intentionally, but evolved towards providing a better management structure for the Solar Challenge.

In terms of working cooperatively in a team:

- Explain the purpose and outcomes of a cooperative, multidisciplinary project-based learning environment and the reasons for implementing this teaching strategy.
- Assess individual personality and learning profiles and equip team members with strategies to optimize their own learning.
- Provide basic training in team work and conflict management, with reference to individual personality profiles.
- Establish team dynamics and define the roles. Assign different responsibilities to each team member in terms of project management, logistics and finances.
- Assign mentors and lecturers in the roles of coaches or facilitators.
- Create a physical environment where the team can work together during scheduled class time and after hours.
- Develop an action plan and utilize project management tools to track the progress of the design project.
- Schedule routine meetings, minute discussions and action the decisions made.
- Schedule routine document brainstorming sessions.
- Encourage peer editing when students have to submit reports or present work orally.
- Provide for regular assessment of team functioning by team members.
- Train students in basic conflict management skills.

In terms of the overall project and individual projects

- Clearly identify the design problem and ensure that students develop enough background knowledge to understand the application.
- Specify detailed parameters required to solve the problem, along with relevant tolerances.
- Encourage students to brainstorm with teammates and formulate ideas or hypotheses for conceptual solutions to the design problem before they settle on a final design solution.
- Stipulate total system integration from each team member as a requirement Summarize the results in both written document that is regularly evaluated.

VI. CONCLUSIONS

The research described how a number of critical engineering competences were developed in the course of the UJ's preparation to participate in the 2012 South African Solar Challenge. Firstly, the perceived advantages of implementing the Solar Challenge project were presented, highlighting the teaching, learning and marketing potential of the project. The project proved to be a platform to promote engineering and technology careers, to engage with industry and to attract students towards pursuing postgraduate studies. A unique feature of the Solar Challenge project is the fact that students' efforts were televised in a reality television show.

A qualitative study explored and described how implementing cooperative, multidisciplinary learning strategies through the construction of a concrete artifact in an authentic context, led to enhanced learning and development of core competences. The two competences in question are professional, technical communication and individual, team and multidisciplinary working. These competences are required exit level outcomes of the degree and consideration was given to the research results relevant to these two competences.

The unusual media component of the project enhanced awareness of the importance of communication skills, fostering a need to improve these skills. The project presented diverse communication situations which required effective written and oral communication. Findings from this study show that participants reported greater development in terms of communicative competence in comparison with that found in previous years. A second theme that emerged was the issue of interpersonal conflict and the challenge to resolve conflict in a professional and constructive manner. Conflict stemmed from the perception that some team members failed to meet the team's expectations in terms of quality of work, work ethic, and unequal work load. It emerged from the interviews that basic skills in conflict management would have contributed to the students' professional development.

Engineering graduates are required to do effective work as individuals, in teams and in multidisciplinary environments. The research confirmed the necessity of these approaches to work for the ultimate success of the project. Central emerging themes relate to conflict between personal interests and those of the team. Team-oriented students developed the ability to forge working relationships and showed a clear understanding of what was required of a team player in this team. The multidisciplinary component of the project appeared to have fostered an openness to learn from peers, while it was also found that students communicated more effectively and confidently across disciplines.

A cooperative, multidisciplinary learning environment proved to be a more efficient way in which to introduce undergraduate novices into engineering research communities, allowing them greater scope in developing the knowledge, competences and behaviors necessary to become successful engineers. This proved especially effective in terms of developing communicative competences, and for effective individual and team work within multidisciplinary environments. It became clear from this study that project-based learning can be an effective teaching strategy that permits students to learn both the fundamental principles of science, while also cultivating a better understanding of how these principles should be utilized in applied engineering.

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