Capstone Design: A Vehicle to Explore Landscapes of Practice in Engineering Education

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***Abstract*—Engineering design as capstone course creates an opportunity for practitioners to demonstrate their familiarity with the particular landscape of practice of their chosen field. This research follows a team of seven final-year Mechanical Engineering students as they complete a capstone design project to design and build an energy efficient vehicle to be entered into an international race. A qualitative, ethnographic study was conducted, collecting data through observation, reflection, and interviews with each of the student-participants and their academic supervisor. Landscapes of practice are defined through patterns of interaction within and between the various communities occupying the landscape. How we design the landscape of practice determines the opportunities we create for student development. The research demonstrates how the institutional and technological backdrop of capstone design introduces pressures that can both hinder student learning and create space and opportunity for deep learning to occur. It is concluded that the engineering curricula should include a series of design projects which allows for conceptualization to operation of the final product, challenging students learning both with respect to technical and social skills**

Keywords—engineering education; landscapes of practice; communities of practice; capstone design courses; curriculum design

I. Introduction: Engineering Design, Landscapes of Practice and Higher Education

The expectations placed on the engineering graduate are not minimal. Reading of the literature reveals that engineering students “must learn how to merge the physical, life, and information sciences at the nano-, meso-, micro- and macro-scales; embrace professional ethics and social responsibility, be creative and innovative, and write and communicate well. Our students should be prepared to live and work as global citizens, [and] understand how engineers contribute to society” [1]. These lofty goals are further embodied in the Exit Level Outcomes that the Engineering Council of South Africa (ECSA) defines for all engineering graduates and diplomats in the country. These outcomes, or expectations, are met within a landscape of practice [2], and the role of the higher education institution is one of facilitating students’ exploration of this landscape.

This paper examines the potential for such exploration resident in the capstone design courses that most final year engineering students in South Africa, and internationally, undertake. Design is that part of engineering activity where individuals (whether expert or novice practitioners) demonstrate their familiarity with the particular landscape of practice of their chosen field. This is because “design has unique ways of developing cognitive and situated skills that require the ability to work with materials, work collaboratively, and become part of a community of practice” [3]. More importantly, it is also because the engineering practitioner, in the act of design, is both constrained and enabled by the institutions, and the technologies, that have a stake in her design work and in which her designs have a stake.

This study follows seven final year Mechanical Engineering students as they complete a capstone design project. This project, which is described in detail in the following section, required the student-participants to collaborate on the design of an ultra-energy efficient vehicle to be entered into an international eco-challenge, sponsored by a prominent oil company. A qualitative, ethnographic research design was deployed, so as to embrace the ‘messy’ nature of the social world [4], through which landscapes of practice are constituted. Data was collected through observation of the design students during formal engagements they had with their design supervisor, reflection on the part of the design supervisor, and interviews conducted with each of the student-participants.

However, this study was also informed by a critical agenda, in that it is concerned with how the institutions and technologies that inhabit the landscape of practice in which the student-participants operate both help and hinder their design. To this end, the notion of landscapes of practice is useful due to its embedded concern with the boundaries between communities of practice [5]. This allowed the researchers to examine where and how institutions and technologies either construct or dismantle boundaries, and how the student-participants navigated these boundaries and, indeed, constructed their own during the course of their design work.

II. Context: Capstone Projects, Regulatory Bodies and the Shell Eco-Marathon

The design project reported on herein was undertaken by seven final-year Mechanical Engineering students as part of a capstone module in engineering design. Engineering design is a situated event: this means that it is actuated within micro-contexts, that is, the contexts that immediately define the situation, as well as macro-contexts, including various social, cultural, historical, institutional and technological factors [6].

The focus of this paper is on these macro-contexts rather than the micro-contexts.

The particular design project that the participants undertook formed part of an educational program which deploys cooperative learning and facilitates students' participation in technology challenges such as, in this particular case, the Shell Eco-Marathon [7]. The Eco-Marathon requires student participants to design, build and race alternative energy vehicles, competing against local and international teams. The project had both pedagogical and practical aims: it sought to deliver graduates who are equipped with the necessary abilities and attributes to deal with real-world energy challenges while promoting science, engineering and technology innovation in a green economy, ultimately supplying skills in global demand [8]. Furthermore, the vehicle would be used as a platform to promote research, the University, careers in science and technology and alternative energy solutions. The objective being to develop a pipeline that supplies the necessary skills base to support global demand [8]. This is achieved through engagement with schools, teachers, students and industry partners nationally. Fig. 1 shows the envisaged pedagogical outcomes of the project. As can be seen, there was a strong focus on building a network of communities, where the various communities interact in service of multi-directional skills development and knowledge transfer. Together, these various communities constitute a landscape of practice for the student design team [2]. This landscape is a multidisciplinary network of communities that includes sponsors, industry, academics, students and others, as is illustrated in Fig. 2.

Fig. 2 shows the various communities directly involved in completion of the design task facing the student participants. However, it does not illustrate the institutional and technological constraints within which the design task is undertaken. In addition to the project aims described above, the project also requires that the student design team meet the institutional requirements laid out by the University, as governed by the Engineering Council. To this end, the student participants are registered in the final year of study of a four-year Bachelor's degree in Mechanical Engineering. The capstone design project contributes significantly towards the award of the qualification: 24 credits, where one credit is equal to ten notional study hours. As a whole, the qualification is meant to develop 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 [9]. The knowledge and skills reflected in the qualification are seen as building blocks upon which graduates can move from being candidate engineers towards becoming competent professionally registered engineers. The degree program is internationally accredited by the Engineering Council of South Africa (ECSA) and, therefore, complies with the quality assurance processes of the Washington Accord [10].

The capstone design project is an important component of achieving the aims of the program. It is designed to assess learning in a student-centered and student-directed manner, and requires the command, analysis and synthesis of knowledge and competencies. Assessment includes criteria such as professional and general communication; impact of engineering activity on society and the environment; individual, team and multi-disciplinary working; lifelong learning; and professional ethics and practice. As part of the capstone design requirement, several hybrid and solar powered vehicles have been designed and constructed since 2010, which saw students compete in 3 locally-hosted, but FIA-regulated, races. In 2014, a second technology challenge was taken up in the form of the Shell Eco-Marathon (SEM) where students are expected to design and build ultra-energy efficient vehicles also to compete against local and international teams.

Through participation in these challenges, undergraduate students become part of a community of specialists designing and manufacturing vehicles. The SEM design team consisted of seven students. Each student was responsible for a specific aspect of the design: the vehicle was modular in design where the different design components had to be integrated for the students to have successfully completed the project. The student-participants also had to fulfil auxiliary roles in terms of project management, coordination of marketing efforts and public relations, interaction with sponsors and industry partners,

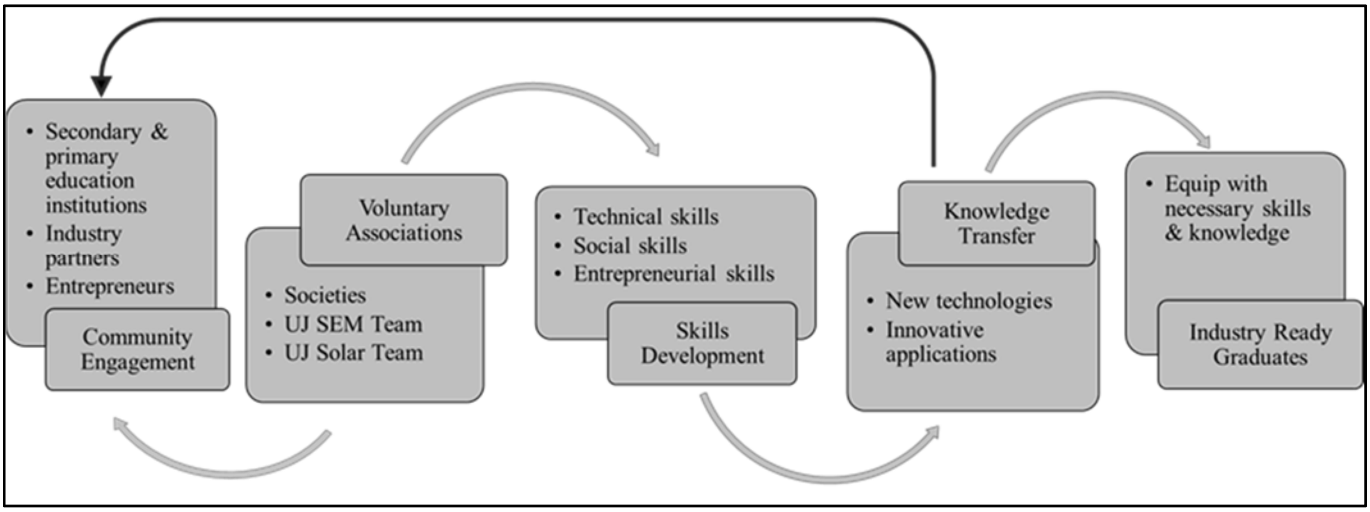

Fig. 1. Skills development and knowledge transfer across and between communities

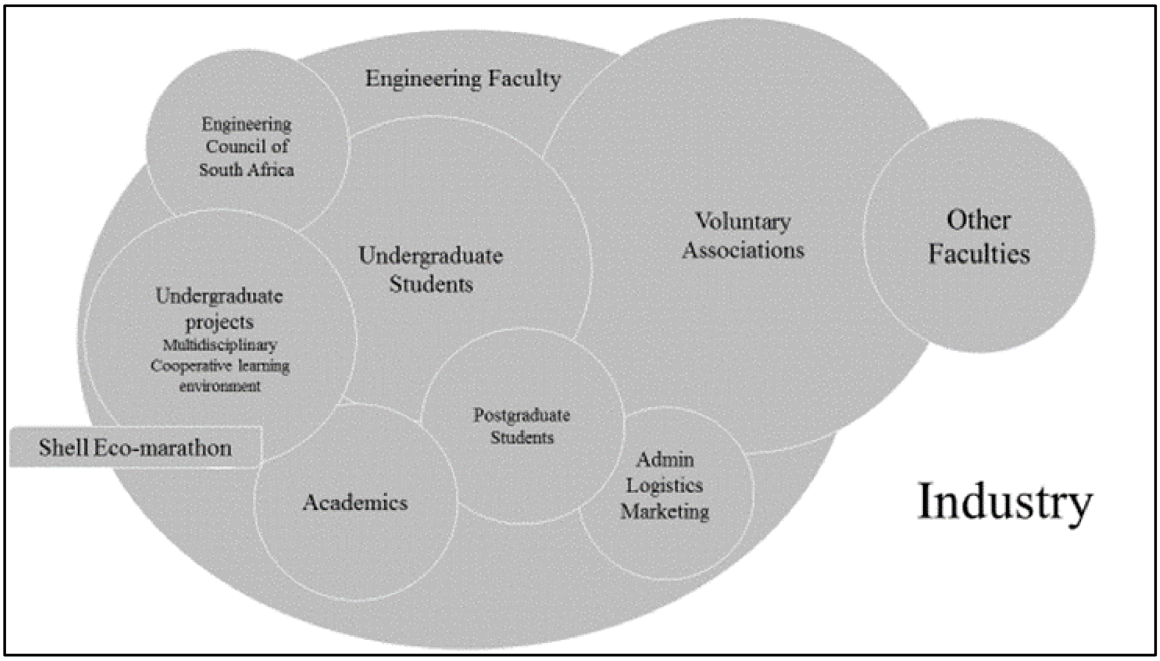

Fig. 2. The landscape of practice for participation in technology challenges

race strategy development, health and safety, and logistics management.

III. Methodology: Observation, Interviewing and Reflection

The empirical component of this study adopts a three-pronged, qualitative, ethnographic methodological framework. Although the methods used are characteristic of ethnography, particularly in educational settings, ethnography is deployed in this study as a perspective on the social world and the people within it. This has been informed by the argument presented by Blommaert and Jie [6], who contend that ethnography places communities at the center of attention and focuses that attention on "the complexity of separate social units, [and] the intricate relations between small features of a single system" [6]. Ethnography, as employed here, is not aimed at uncovering a body of representative facts and findings about the population under study; instead, it is fundamentally subjective, aimed at demonstrating the complexity of the landscape of practice that characterizes capstone design courses in South Africa, and around the world.

The ethnographic lens adopted in this study also facilitates the critical stance adopted by the researchers. This is because ethnography "has the potential and capacity of challenging established views" and because it provides accounts of the "social dimensions of meaningful behavior which differs strongly from established norms and expectations, indeed takes the concrete functioning of these norms and expectations as starting points for questioning them, in other words, it takes them as problems rather than as facts" [6]. Because the ethnographic lens is concerned with how people define themselves, and with the symbolic forms, including the institutions and behaviors, with which they identify themselves [11], it is able to place emphasis on the ways in which individuals, in communities, resist and/or adopt the behaviors and other symbolic entities of specific institutions.

Within this over-arching perspective, three specific, qualitative methods were employed. These were observation, reflection and interviewing. The participants of the study (who are described later in this section) were required to attend weekly design meetings that were also attended by their design supervisor. The team's design supervisor, a co-author of this paper, also occupies a position of participant in this study in that her reflections constitute data employed herein and she was also an active participant in the meetings, often dictating the direction and focus of the discussion therein. The other co-author of this paper also attended these meetings, but acted primarily as an observer and participated very little in the discussions that ensued therein. Such observation is the basis of much qualitative research [12] and is one of the most oft-cited methods employed within ethnographic research (see [13], for example, but there are countless others). In line with the recommendation of Blommaert and Jie [6], observation was initially undertaken "indiscriminately in an attempt to get an overall image". This overall image subsequently informed later observations, as well as the other data collection methods employed.

Reflection was also undertaken in the study, specifically on the part of the design supervisor. In some cases, this reflection was made manifest through discussion between the authors, where the 'outsider' observer would question the 'insider' supervisor as to her thoughts and observations of the student-participants. In other instances, the design supervisor would engage in 'introspection', which Saville-Troike [13] argues can lead to valuable insight into the phenomenon or group being studied. Indeed, reflection was also a driving point for this study as both authors believed in the need, as Biggs [14] argues, for educators to engage in reflective practice, so as to make implicit one's theories about teaching and learning generally, and design practice and design teaching, specifically.

Finally, all the participants were interviewed during the course of completion of the design project. Semi-structured interviews were deployed where an interview schedule was designed, but where some leeway was provided for deviation on the part of the interviewer where interesting points were made. Again, the 'outsider' author acted as interviewer in this study. The interviews were audio-recorded, and transcribed by a research assistant.

The participants in the study were seven final-year Mechanical Engineering students. The seven students were friends prior to the advent of the project and had put themselves forward to undertake the design (and construction, though this was not required by the prevailing formalized curriculum structure) of an eco-friendly vehicle that could be entered into the Shell Eco-Marathon. The seven student-participants do not represent the diversity of the South African population, or the body of students that constituted the final year Mechanical Engineering cohort at the time this study was undertaken. All the participants are male, and the majority of them are white. All of them come from middle-class backgrounds. The group has a reputation for including some of the strongest candidates amongst their year group, and includes the two valedictorians for their graduating cohort.

This group of participants, therefore, are largely homogenous and do not represent any marginalized groups. This adds to the strength of this study, as it demonstrates that even the strongest students, drawn from dominant social and economic groups, with sufficient cultural, financial and social resources are locked into relations of institutional power within the engineering education environment. This study, therefore, is able to demonstrate the monolithic nature of the landscape of practice in which capstone design courses play out. It should be borne in mind, however, that the findings discussed in this paper are made even more significant, and the consequences made particularly dire, when they are coupled with the systematic inequalities along race, class and gender lines evident within South African society.

Three further methodological concerns related to this study warrant discussion here. The first of these relates to the notion of insiders and outsiders. From an ethnographic perspective, the different roles that the researchers play constitute a strength of this study. This is because the ethnographer must "grasp an insider's position… while being able to find the boundaries" of their interpretations [15]. Researchers, as Everhart [16] argues, have to be both stranger and friend to their research participants. That is to say, they have to be involved enough so as to learn about and describe a phenomenon under study, but detached enough so as to identify aspects that are taken for granted. Because of this, the different roles and perspectives adopted by the co-authors became a productive resource in the study, as the findings point to those moments where the "relative outsider could come to agree with an insider" and vice versa [15].

A second, and related, issue pertains to the fact that qualitative data, and one could argue all data, is co-constructed. The methods deployed herein are not neutral tools. Instead, interviews and observations are contested and negotiated, shaped by social dynamics [17]. The success of these methods relies on an ability to foster mutually supportive relationships with research participants [18]. Data, whether interview data, observational or even statistics, is thus socially constructed through interaction. This manifests in this study in the fact that one of the co-authors is an active participant in the study, directing observed events and reflecting on these events throughout the process of the study. Data emerges out of her interactions with student-participants, from her interaction with the 'outsider' researcher, and from interactions between the student-participants and the 'outsider' researcher.

A third, and again-related issue pertains to the question of ethics. The orientation to this study adopted by the authors was a developmental one. It was envisaged that the participants as well as the researchers would benefit from their mutual engagement in the process of designing and building an eco-vehicle, as well as their mutual engagement in the research process. To this end, care was taken not to overload the student-participants with extraneous, time-consuming tasks and, besides the interviews, the participants were required to do little more than what was already required of them. All participants gave permission for the research to be undertaken, and were able at any point to share concerns, ask questions or withdraw from the study, without any form of censure or sanction.

Finally, collected data was analyzed in line with the ethnographic perspective adopted herein. A characteristic of such a perspective is that data collection and analysis occur simultaneously [19]. That is to say, data collected through observation and reflection was analyzed and used to inform subsequent data collection, whether in the form of further observation and reflection, or in the interviewing undertaken. The authors agreed that "there is no right way of organizing data – whatever the approach, authenticity and credibility is key" [20]. Bearing this in mind, the authors followed the process outlined by Titscher et al. [19], which moved from reading through data, generating explanatory concepts, coding, and detailed analysis of central categories, their meanings and their interrelationships.

IV. Design Landscapes

Design is central to engineering activity and is one of the key criteria for evaluating and accrediting engineering programs. It is an integral part of the skill set required to become a successful engineer who is able to conceive, design, implement and operate complex, value-added engineering products, processes and systems in a modern team-based environment [1]. Students should be afforded opportunities to develop technical expertise, social awareness and a bias towards innovation in a sustainable manner as they are initiated into this community of practice.

Engineering design is defined as the creation of a plan or convention for the construction of an object or system [21]. It is the creative process of identifying needs and devising products or processes to fill those needs. It is the specification of an object, manifested by an agent, intended to accomplish goals, in a particular environment, using a set of components, satisfying a set of requirements, subject to constraints. Furthermore, the engineering design landscape is defined through the process of devising a system, component, or process to meet desired needs and the interaction of the practitioners and stakeholders in the design community of practice. The participants engage in this landscape through an often iterative decision-making process, in

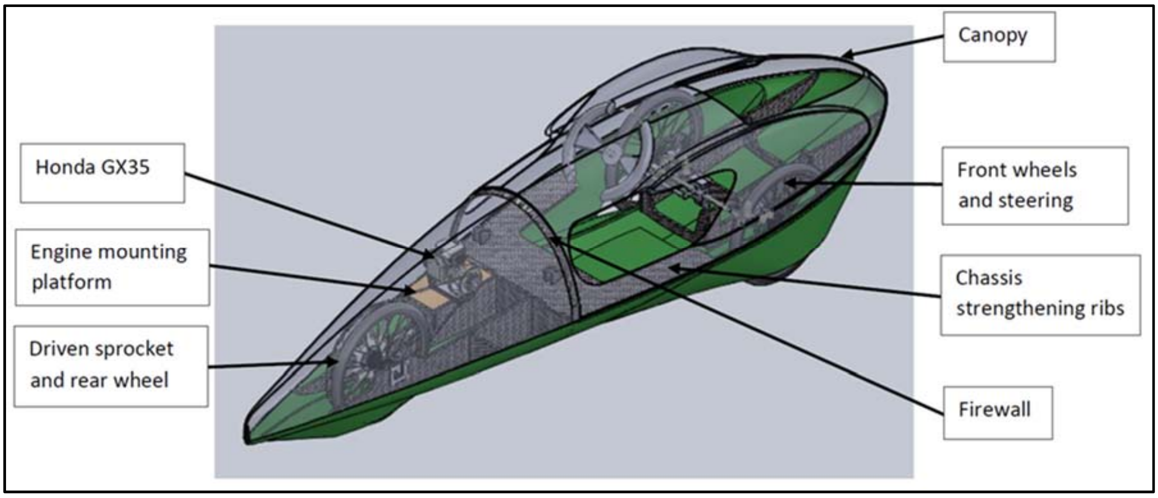

Fig. 3. Render of the SEM vehicle designed by the student-participants

which basic science and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation [22]. The engineering design component of a degree program should include features such as: the development of student creativity, use of open-ended problems, development and use of modern design theory and methodology, formulation of design problem statements and specifications, consideration of alternative solutions, feasibility considerations, production processes, and so on. It is also considered essential to include a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics and social impact [23].

The Eco-Marathon project requires students to design, build and race energy efficient vehicles in an international competition. Teams compete to travel the furthest on one liter of fuel or one kilowatt hour of electricity. The Eco-Marathon project brings together many engineering disciplines such as aerodynamics analyses, heat transfer considerations, dynamics and mechanics, drive considerations, material selection, design methodology and principles, and manufacturing methods. The Eco-Marathon project also requires consideration of safety, reliability, ergonomics, aesthetics, efficiency, creativity, project planning, resource management and team work. The design tasks on the project are modular and interlinked. Seven different individual projects were identified in collaboration with the design team. Each of the seven individual projects focus on a key aspect of the vehicle which is critical to its overall performance.

The SEM project was, first and foremost, a detailed design task. To this end, the student participants strongly located themselves within a modular design landscape. When students were asked to describe their role within the team, all but one of the students identified their individual design contributions. Only one, the project manager, identified his auxiliary role as project manager as superseding his design contribution. The participants also had a generally good, albeit incomplete (in the researchers' opinion), view of the activity of design. The majority of the team equated engineering design with problem solving. They recognized that engineering design is a creative, iterative process aimed at fulfilling certain design criteria and that constraints regarding cost and safety, for example, had to be considered. The participants felt that novel, simple, effective, efficient, and innovative solutions were required to solve design problems.

However, the project was also product-oriented in that the outcome was a manufactured vehicle that could compete in an international event. To this end, none of the participants made specific reference to the outcome of their design work: creating an object/artefact. Furthermore, little reference was made to identifying and addressing social need or to deploying scientific knowledge to solve design problems. There was general understanding amongst the participants that design solutions need to be communicated to specific audiences using engineering drawings but only some gave consideration to how engineering designs impact on society or the environment. Overall, the student-participants viewed the design task as an exercise in problem solving, and considered the outcome of design work to be computer-aided design drawings. There was very little focus on design as a series of decisions or on the outcomes and impacts thereof.

Observation of and discussion with the Eco-Marathon design team thus highlighted a potential institutional failing regarding engineering design in the program structure. Because the landscape of higher education is primarily academic in nature, problem solving, in the theoretical and abstract sense, is often privileged over practical experience with and physical manufacture of products. This accords with the argument of Juhl and Lindegaard [24] that although the technical, scientific content of engineering curricula is improving, this often comes at the expense of students' ability to put that knowledge to use in design and product development. Too often, the design process ends at the point of simulation and there is thus a disjunction between the activities of design and manufacturing. Although curricula include modules on manufacturing, these are seldom integrated with design or positioned as corollary to design activity. This translates into the kind of responses and behaviors evident amongst the student-participants here.

The design aspects of the project were not without difficulty for the student-participants. Felder [25] points out that the modern engineering workplace requires designers capable of creating products that are functional and attractive and, the authors would argue, cost-effective and 'green'. As such, it is unsurprising that inexperience, self-doubt and uncertainty were challenges that most of the design team faced. Integrating and working as a team were also a challenge and there were a number of conflict situations regarding division of labor and work load. Time management, the pace of the team's progress, and interdependence between team members were also issues that the participants had to deal with. The design students admitted to a lack of effective planning and acknowledged that they lacked the interpersonal skills to function as an effective team, particularly as this regards effective communication. The participants argued that functioning in a team provides greater challenge than individual work. This is because lack of skills and experience become more apparent in a group where everyone has unique abilities. These challenges are returned to later in this discussion.

V. Learning Landscapes

The Eco-Marathon project is structured so as to address the requirements prescribed by the Engineering Council of South Africa's exit level learning outcomes. Participation in the project affords students the opportunity to solve an engineering problem (in a real life situation) and to develop the skills required to do so. In so doing, it exemplifies an inductive approach to teaching and learning [26]. The project is seen as a practical exercise in interdisciplinary project management and modular, concurrent engineering design. Students are required to work effectively as individuals, in a team and in multidisciplinary environments. Apart from innovatively solving the engineering problem by creatively applying scientific and mathematic principles and methods, students also have to apply their people and project management abilities in managing budgets and logistics, and dealing with suppliers, manufacturers and sponsors. The project thus provides students with an invaluable learning experience and prepares them for the ultimate expectations of industry. As such, the student-participants are also, crucially, part of a learning landscape, as well as a design landscape.

Looming large within this learning landscape is ECSA: the regulatory body that accredits engineering programs and engineering professionals in South Africa. When asked to reflect on the role of ECSA, it became clear that the student-participants perceived ECSA to be on the periphery of their learning landscape. The students focused extensively on the body's role in accrediting degrees and setting and maintaining standards for degree programs, but gave far less attention to its role in validating practitioners as professionals. That is to say, ECSA is seen as a regulatory body only insofar as it regulates the Faculty and not individual students. Furthermore, although the exit level outcomes were used as a guideline to prepare their design reports, the expectations implicit in these outcomes were seen as padding for the actual engineering work, which was seen only to include design drawings and calculations. In particular, discussion with the design team focused extensively on environmental issues and the impact of engineering, as the students found it particularly difficult to conceive of, find, and filter relevant information in this regard.

The tensions evident in the students' responses and behaviors are indicative of tensions that exist in the institutional landscape of engineering education. On the one hand, the traditional academic landscape of the university locks students and lecturers alike into a particular, modular approach to education (though this has been roundly critiqued for many decades – see [27] and [28], for example). On the other hand, regulatory bodies and industry expect graduates to be able to deal with the complexity that characterizes the digital information age. Academic faculty have struggled to come to grips with this disjunction. Engineering educators tell students that the social landscape of engineering matters but what actually matters in their landscape are academic, largely technical, requirements. Indeed, the inductive learning approach of the capstone design project is undermined by the curriculum structure, as inductive teaching and learning is an alternative to simply telling students they need to know certain information [26]. The result is that many of the learning outcomes expected by ECSA are given only token attention in the curriculum, as traditional curricula do not readily lend themselves to meaningful engagement therewith. Academic exercises teach academic skills: the engineering student today is pulled between an academic landscape and a professional landscape that are at odds, each locked into its own set of ways of doing things. This may explain why there is resistance on the part of student-participants to engage with the requirements of ECSA, and why they view ECSA's requirements as *padding for* rather than *integral to* engineering activity.

Discussion was also entered into with the student-participants as to what learning resources they drew upon during the completion of the Eco-Marathon design task. To this end, the student participants relied on self-study, but input from fellow team members was also regarded as an important learning resource. This may be unique to this set of participants as they existed as a study group prior to the advent of the design challenge and were therefore accustomed to supporting each other's learning. However, there were two resources that the bulk of the participants singled out as particularly important.

On the one hand, the student-participants emphasized that the design project served to bring their existing knowledge into context by creating an improved understanding of previous modules undertaken within the program. They took up their previous academic experiences as particularly important because of the clear connections that they could identify between their prior academic activities and the current project. They applied the technical skills and theoretical knowledge gleaned from previous modules in their design work and commented that this made that knowledge more practical. This highlights design as an important learning activity, in which students begin to migrate from an academic landscape to a landscape of engineering practice.

On the other hand, the students also drew significant benefit from the experiences of postgraduate students and lecturers: this input gave direction to the project but also served to motivate the team to do better. These more senior mentors introduced the student-participants to various communities within the larger landscape of practice: manufacturers, suppliers, sponsors and so on. In so doing, these mentors acted as gatekeepers to the landscape of practice, teaching the social discourses of engineering as practice, rather than as academic exercise. That is to say, this allowed the students to make links to their careers and introduced them to different skills that technical, academic modules, as representative of the academic landscape could not.

VI. Organisational Landscapes

When asked to evaluate the group as an organization, the members generally described the process as involving significant initial stress, with this stress decreasing as roles became better defined and easier to manage. Typical group dynamics, as described by Tuckman and Jensen [29] were evident within the group. Two leaders emerged within the group: one with technical expertise, experience and a general "know how", and one with responsibility for engaging with stakeholders and overall project management. Furthermore, when asked to evaluate the strengths and weaknesses of the team, various group members argued that working in parallel complicated the task at hand. They found it difficult to schedule times where they could work together and to share information. They identified the fact that time management was a challenge, further exacerbated by delays and problems of integration between the discrete components. In terms of strengths, the team members argued that each member offered unique and complementary skills that strengthened their overall efforts and that their own skills were enhanced through their interaction with the rest of the team.

As is to be expected, there were some communication issues, especially during the inception phase of the project. The participants had to develop new lines of communication, relying on online solutions to share information, stay in contact and track the progress of the project. The participants communicated with each other via the following media:

- Separate mobile chat groups were created using WhatsApp, one including the postgraduate mentors and the design supervisors, one only including the team members themselves, and some sub-groups within the team, organized either around technical topics or social issues. The 'open' chat group, that included mentors and the supervisor, was largely used by the supervisor to broadcast information, announcements, reminders and instructions, and there was very little discussion undertaken through this media.
- Weekly team meetings were scheduled where progress on individual design tasks and the project as a whole were presented and discussed, allowing for peer review of designs and input from mentors and the supervisor.
- Minutes of meetings were irregularly kept and, when kept, were often ignored by the team members.
- Email was mostly used only with the design supervisor.
- MS Project: although a detailed plan was developed using MS Project (as a curricular requirement), this plan was not subsequently used as a tool to organize and track design activities. Ultimately, the project diverted significantly from the project plan and the project plan was not subsequently updated.
- Shared electronic cloud storage was used to share information and reports and to collaborate on designs. This was only used within the group: mentors and the supervisor did not have access to these folders.
- Computer-aided design (CAD) software was available in open computer laboratories and stand-alone licenses were made available to the participants. The students did not have any prior experience with the specific CAD application used, and they all underwent introductory training related to this software. The members experienced significant difficulty with the software, both in terms of its use and in terms of licensing and so on.
- The students applied some programming and engineering tools to evaluate and validate their design concepts. Computational fluid dynamics (CFD) and strength analysis using finite element modelling (FEM) were applied.

It emerged in analysis of the data that the student-participants used one set of technologies for communication with each other (cloud storage, private mobile chat groups) and an altogether different set of technologies for communication with the supervisor (e-mail, face-to-face meetings and, to a lesser extent, an 'open' mobile chat group). It was thus evident that the technologies deployed exist within landscapes of practice, where these technologies both coordinate what individuals can do, and are coordinated so as to delineate boundaries within the landscape. The decision, for example, to learn and use an altogether new CAD application was informed by the fact that the students experienced the capabilities of the applications with which they were already familiar as limiting. However, their lack of expertise in the new application was itself limiting as well. Indeed, the constraining influence of these design technologies was a theme often returned to in discussion during meetings. It also became a major source of conflict within the group: although the entire group were inexperienced in using the specific CAD software, some developed the necessary skills quicker which led to frustration with those who remained less proficient.

Also important for consideration in this paper is the fact that the use of technology mirrored the various competing communities within the larger landscape of the capstone design project. It was important to the team members that they had private avenues for communication, away from the academic gaze of the supervisor and mentors. To this end, the team actively deployed technological communication media to create boundaries with the broader community, and reserved particular channels for communication across these boundaries. Furthermore, those media that primarily served an organizational function (as opposed to a design, or academic function) were largely neglected, including the project plan on MS Project and meeting minutes. This reflects the fact that the organizational aspects of the design task were largely neglected. For example, even by the end of the process, there was little common understanding the of SEM race regulations, with each designer primarily focused on his own design task and little attention given to the overall design product (except on the part of the two 'leaders').

Ultimately, from an organizational perspective, the group collapsed, despite the fact that their individual designs were of a high standard. Some team members felt that lines of communication were often broken, that they did not have access to the necessary information, and that there was significant room for improvement. Much of the information they required of each other was easily available, but they were generally poor with regard to sharing information with each other. Throughout the process, participants displayed a level of ignorance regarding what their teammates were doing and the particular design criteria they were supposed to meet. These design integration issues were fueled, at least in part, by poor communication. The team members also noted that aggressive leadership hindered communication and split loyalties within the group, a fact reflected in the prevalence of smaller mobile chat groups within the design team. The members completed their individual designs, but the integration was left to the leaders, and the team opted not to continue into the manufacturing process, despite all being keen to do so at the beginning of the process.

VII. Conclusion

Competitive markets and the advanced needs of modern societies demand successful design of increasingly complex products and systems in environments where design, engineering and business is integrated [30]. This paper has demonstrated, in a fine-grained, qualitative manner, how the institutional and technological backdrop of capstone design introduces pressures that can both hinder student learning and create space and opportunity for deep learning to occur. The capstone design module might very well be the most valuable opportunity to develop students' ability to become successful engineering practitioners. However, participation in these modules is colored by the nature of the curricula which precedes the capstone module, as well as the ways in which learning is designed so as to integrate and synthesize engineering content. Put more simply: how we design the landscape of practice determines the opportunities we create for students.

Of course, landscapes of practice are defined through patterns of interaction within and between the various communities within the landscape. On a macro-level, therefore, universities and regulatory bodies need to engage more fruitfully with one another so that their respective demands on students are better synchronized, rather than at odds with one another. On a micro-level, this paper reiterates calls for curricula that are designed so as to integrate and synthesize engineering content, rather than isolate it into discrete silos [24, 27, 28]. Juhl and Lindegaard [24] also argue that improved design practice can be achieved through assisting students in undertaking effective knowledge-sharing routines. This paper reinforces this suggestion by showing how technologies both help and hinder knowledge-sharing. More research needs to be undertaken into the technologies of design (its teaching, learning, practice and communication).

Three points can be made by way of conclusion.

i) Engineering curricula need to include "a series of design projects that provide progressive challenges to the students' learning", in which the design context is integral so that better teamwork can be achieved [24].

ii) The link between design and the manufacture of a working system, process or product can be better emphasized.

iii) The development and maintenance of communities of practice, that operate within the broader landscape of engineering practice, including its technological dimensions, is critical in order to develop not only technical expertise but also social and environmental awareness and creativity.

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