Industry preferences of future engineering leadership education in South African tertiary education institutions

Kobashen Moodley & Cecile G. Proches

University of KwaZulu-Natal
Durban, South Africa

ABSTRACT: The engineering profession is vital to the health, safety and development of a country. It creates vision and shapes public policy. The Engineering Council of South Africa (ECSA) requires engineers to display *leadership* as a professional competency. South African engineering schools presently do not offer engineering leadership education (ELE) to undergraduates. The aim of the research was to investigate a preferred framework for future ELE, based on international best practices and the preferences of the ECSA membership. A review of international professional registration guidelines and ELE programmes was undertaken. More specifically, a focus was placed on the various programmes' approaches, goals, themes and the specific competencies developed. Theory around leadership competence development was also explored, including the skills approach and associated capability models. The recommendation from the study was that any future implementation of ELE should take place through well-structured engineering leadership coursework to provide theoretical knowledge and provide a baseline standardisation of programmes and an opportunity to monitor improvement.

INTRODUCTION

South African tertiary education institutions do not offer any explicit or non-explicit forms of engineering leadership education (ELE) to undergraduate engineers, as recognised by Graham et al at the time of their significant global study into the topic [1]. Upon a review of current South African engineering programmes and from the apparent absence of South African literature regarding the topic of ELE, it is evident that the situation has, to date, remained largely unchanged in this regard. This is in contrast to international trends to recognise and implement ELE in an effort to produce high performance engineers who are globally competitive [2]. The South African statutory engineering body, the Engineering Council of South Africa (ECSA), recognises leadership competency as a requirement for professional registration [3]. However, the Council does not currently detail the leadership competency required, relative to other international engineering regulators reviewed, thus ELE eludes the attention of South African engineering schools.

Engineers are predominantly rigorously trained in technical skills yet receive little to no explicit leadership development [1]. However, leadership development through ELE has been identified by international engineering authorities, such as the National Society of Professional Engineers (NSPE) in the United States of America, as being important to develop engineering leaders capable of rising to the challenges of the day and maintaining a competitive edge [4]. According to Paul and Falls, leadership capabilities, in addition to traditionally outlined engineering skills, such as technical aspects, are important for innovation in engineering [5]. These leadership skills are seen as valuable in a 21st Century workplace regardless of whether engineers are pursuing management roles or technical team member positions.

Hartmann explained that the American Society of Civil Engineers' (ASCE) Civil Engineering Body of Knowledge, which represents the knowledge, skills and attitudes necessary for entry into professional practice, stipulates that *leadership* is one of the twenty-four (24) outcomes required for professional registration [6]. Leadership is described here as the ability of an engineer to …*organise and direct the efforts of a group* [7]. The ASCE explains that leadership is the ability to influence others towards accomplishing shared goals and does not necessarily originate from an appointed position. Engineers are expected to …*lead when confronted with professional and/or ethical issues* [7]. Further, the ASCE highlights that engineers who, in addition to good design and analysis skills, possess high leadership skills, are increasingly sought after, because of the benefit they bring in especially in the early stages of new technologies, management models and organisational structures. Leadership is fortunately in itself also viewed as an outcome of engineering training, where strong analytical skills and rational decision-making skills are seen to be the very nature of the profession.

ENGINEERING LEADERSHIP DEVELOPMENT IN SOUTH AFRICA

Leadership competency is more obligatory and comprehensively described in the professional registration guidelines by the ASCE than by ECSA. The ASCE views leadership as one of its specific outcomes, which is well detailed for candidates and institutions to process, while ECSA currently vaguely explains its requirement of leadership to be one of a few desired competencies within a management role. Professional competencies are explained by the Candidate Academy's registration guide to comprise of communication, collaboration, management and business practice, and problem solving [8]. *Leadership* competency is highlighted early in the list of *management and business practices* among other skills, such as delegation, following-up, time management, stress management, decision-making, and so forth. The guide to the Council's registration guidelines allows a link to be made from a real-world challenge to an engineering leadership opportunity. This allows for a holistic view of the ECSA's *leadership* competency registration requirement. Figure 1 shows a summarised illustration of where leadership competency is described in this regard.

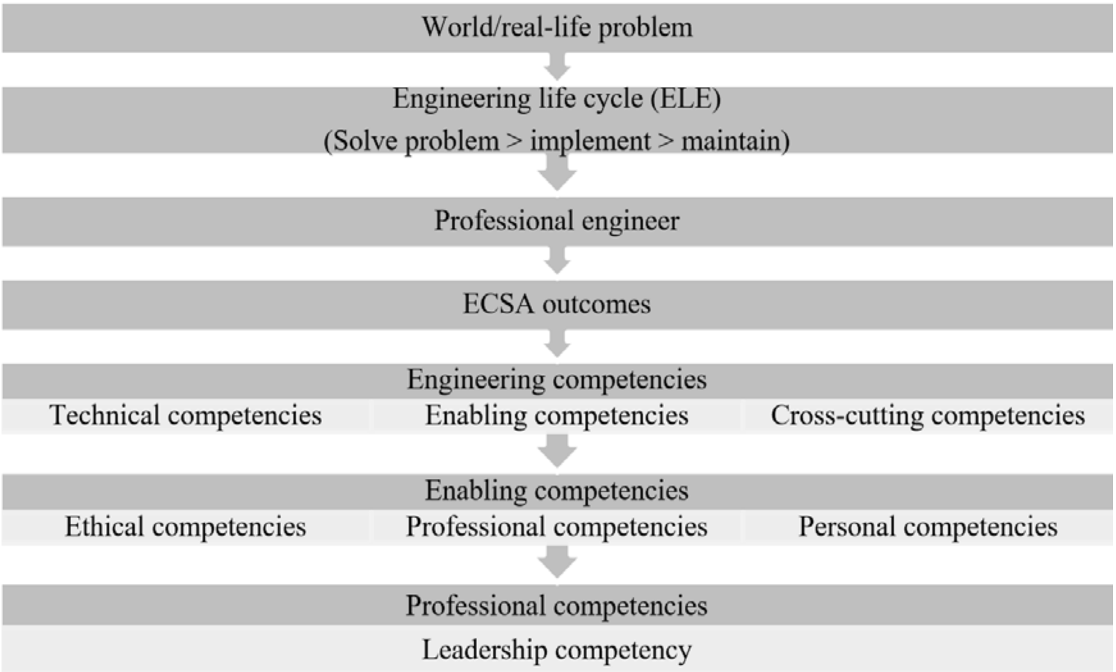

Figure 1: Illustration of where leadership is positioned by ECSA.

As mentioned, South African engineering tertiary education curricula are currently not structured to explicitly develop leadership competency (knowledge, skills and attributes) in undergraduate engineers. The Candidate Academy's registration guide explains where the present ECSA registration framework expects the development of these *enabling competencies* to occur. Leadership is expected to be developed as an engineer takes on more management duties, postgraduation, through work experience. The guide also mentions that some amount of competency may be enhanced by attending courses; however, it is suggested that competency is better developed in the workplace. Workplace development is anticipated to take place through coaching, shadowing, observation and practice [8].

Of specific concern is where a lack of knowledgeable mentorship with regards to leadership competency is available to a graduate engineer. Leadership is explained to be a diverse and important area of competence to a professional engineer, which extends beyond the gains that they may effectively receive by general observation and experience. Owen highlights this concern when he states that …*the problem with learning [leadership] from experience is that it is a random walk* [9].

RESEARCH METHODOLOGY

The aim of the research was to determine ECSA members' preferred framework for ELE within South African tertiary education institutions, based on international best practice. The research objectives were to:

1) identify what is meant by *leadership* competency as a requirement for professional registration of engineers, by ECSA;
2) identify what dimensions of leadership competency are delivered through international best practice of ELE;
3) determine what the perceived current level of leadership capabilities (or gaps) is in present graduate engineers from South African tertiary institutions, by members of ECSA;
4) determine what the consensus is among the ECSA membership about any possible implementation of ELE within South African tertiary institutions;
5) formulate and recommend ECSA members' preferred framework of ELE based on international best practice, which could be implemented in South African tertiary institutions.

The methodological choice adopted was that of a *mono method quantitative approach*. A descriptive, survey strategy was used to collect data via a questionnaire and the results were numerically analysed. The national multidisciplinary survey of ECSA's engineering practitioners was seen as a credible target population to gain relevant insight. ECSA comprises and regulates the majority of engineering disciplines in South Africa (SA) including aeronautical, agricultural, civil, chemical, computer, electrical, electronic, industrial and mechanical engineering [10]. The on-line questionnaire utilised was based on international best practices of ELE which were reviewed in the study. The survey was used to measure and collect predominantly insubstantial data including the preferences and opinions of respondents with regard to the research topic. The questionnaire was constructed using an Internet-based survey tool, Google Forms. It comprised of four sections which included 103 questions in total.

An invitation to participate in the study was e-mailed to members of South African engineering associations which comprise ECSA's membership. These associations consist of all the sub-groups of the target population including candidate engineers, professional engineers and student engineers. Furthermore, the associations covered most of the major engineering disciplines. Responses were captured in real time and completed submissions were tabulated by the on-line survey tool. All data collection took place between 21 August and 26 September 2019. Descriptive and inferential statistics were used to analysis the data and answer the core research questions being investigated in this study.

An official gatekeeper's letter was obtained from ECSA allowing the researchers to proceed with the study and for data to be collected from the volunteering and consenting ECSA membership. Further, ethical clearance was granted by the University of KwaZulu-Natal's Research Ethics Committee.

Limitations to the research existed and were moderated as best possible. The lack of awareness of ELE in SA translated to a scarcity of South African published literature and a reliance on international work on the topic. Due to financial and time constraints a decision to formulate a comprehensive survey using the literature on regulatory guidelines and best practice programmes was taken, instead of pioneering an interview process on the opinions of South African academics/specialists, which would have been too vast and time-consuming in nature due to the size and diversity of the field and the qualitative techniques which would have to be employed for reliable content. The study did, therefore, not directly engage specific stakeholder groups including ECSA's education specialist, the education department, tertiary education institutions, employers, clients and/or students. The research was confined to focusing on a general South African industry perspective on the topic.

RESULTS AND DISCUSSION

The overall response to the survey study was found to be positive and representative of the targeted population. An analysis and explanation of the survey results follows, including an exploration of specific links between it and the existing literature on the topic. The surveyed sections more specifically included:

1) demographics;
2) perceived value of specific leadership competencies;
3) perceived level of current leadership competency and shortfalls/gaps in SA;
4) consensus regarding the future implementation of ELE in SA and the preferred framework.

The various analysis methods and results were interpreted systematically, such that the collected data were able to yield as many useful deductions as possible, regarding the engineering industry's perspective of the topic of ELE. Additional inferential statistics including factor analysis, section analysis, cross-tabulations and correlations were carried out and discussed, but are not presented in this limited article.

Descriptive Statistics

A significant portion (66%) of responses was received from the civil engineering discipline followed by industrial and electrical. The remaining responses were from the other participating disciplines. These results were in line with ECSA's records which indicate that civil engineering is the most established and largest engineering discipline in SA. As all engineering disciplines have specific demands due to operating under varying circumstances, it must be noted that the general results here may be skewed towards the majority response base of civil engineering.

A majority 70% of respondents indicated that they were registered as professional engineers, technologists or technicians with ECSA. Over half of the respondents have worked within the engineering industry for more than 20 years. A further 22% have worked within the industry between 11 to 20 years. This assures that a mature and well-experienced industry viewpoint was derived from the results. This was supported in an another question were the respondents' age profile was found to be well distributed among the senior age groups with the majority 36% between 40 to 60 years of age and a further 29% over 60 years old. These were viewed as a positive outcome in that the majority of the sample had already had experience with the current and/or older registration systems, so they may be more able to critique aspects relating to them. A counter argument could be made that the senior response base may in some respects be out of touch with present and/or future needs.

Lastly, a majority (73%) of respondents indicated that they worked within the private sector, consisting of consulting engineering companies, mining, production, and so forth. This implies that the results may be skewed towards a production and business-centred approach, over an administrative and regulatory one.

Perceived Value of Specific Engineering Leadership Competencies

The value of specific engineering leadership competencies as perceived by members of ECSA are ranked and scored as per Table 1-Table 3. A numerical score for ranking items was used (1 = not important to 5 = very important). The original order of the listed items is also indicated. As tabulated in Table 1 respondents ranked the specific engineering leadership responsibilities. Of highest importance was *upholding and leading good ethical behaviour*. The result supported the ASCE's priority and call for *high ethical standards* to be demonstrated by professional engineers [7].

Table 1: Mean scoring of the perceived importance of engineering leadership responsibilities.

Item	Description (descending order)	Score
S2.1.8	Upholding and leading good ethical behaviour	4.68
S2.1.3	Developing and maintaining trust	4.49
S2.1.2	Clearly planning and organising resources	4.45
S2.1.1	Being able to develop and engage others in a common vision	4.32
S2.1.6	Heightening motivation	4.07
S2.1.5	Inspiring creativity	4.00
S2.1.4	Sharing perspectives	4.00
S2.1.7	Being sensitive to competing needs	3.91

Respondents ranked the specific engineering leadership principles as per Table 2. Of highest importance was *ensuring that a project is understood, supervised and accomplished*. While it may be assumed at first that such a principle may only be developed through real world projects, the ASCE specifically mentions that this development should begin at an undergraduate level through formal education [7].

Table 2: Mean scoring of the perceived importance of engineering leadership principles.

Item	Description (descending order)	Score
S2.2.7	Ensuring that a project is understood, supervised and accomplished	4.58
S2.2.5	Seeking responsibility and taking responsibility for one's actions	4.55
S2.2.1	Being technically competent	4.53
S2.2.3	Making sound and timely decisions	4.48
S2.2.4	Setting the example	4.41
S2.2.2	Knowing oneself (abilities) and seeking self-improvement	4.36
S2.2.6	Communicating with and developing subordinates both as	4.33

Respondents ranked the specific engineering leadership qualities/attributes as per Table 3. Of high importance was *engineering competence, high ethical standards, commitment, communication skills, discipline, initiative, adaptability'* and *persistence*. The ASCE [7] and Crumpton-Young et al [11] also maintain that proficient engineering knowledge, personal initiative and good communication skills, among others, are seen to be large contributing qualities and attributes to business and industry success [11].

Table 3: Mean scoring of the perceived importance of engineering leadership qualities/attributes.

Items	Descriptions (descending order)	Score
S2.3.5	Engineering competence	4.65
S2.3.8	High ethical standards	4.62
S2.3.6	Commitment	4.54
S2.3.10	Communication skills	4.39
S2.3.11	Discipline	4.32
S2.3.4	Initiative	4.28
S2.3.9	Adaptability	4.24
S2.3.15	Persistence	4.22
S2.3.12	Confidence	4.12
S2.3.2	Enthusiasm	4.12
S2.3.1	Vision	4.09
S2.3.3	Industriousness	3.99
S2.3.13	Courage	3.90
S2.3.14	Curiosity	3.84
S2.3.7	Selflessness	3.75

Perceived Level of Engineering Leadership Competency in SA at Present

Next, the perceived level of engineering leadership competence in SA was tested. Respondents provided an indication of their level of awareness about ELE and subsequently rated current graduate's leadership knowledge and competence. Further, more specific shortfalls/gaps were ranked by the respondents, as perceived to be present in graduates.

Firstly, when asked if respondents were aware that engineering leadership could be *taught and learned* at undergraduate level a relatively large percentage (44%) responded *no*, that they did not realise this. This result is in line with the findings of Graham et al who recognised that no ELE programmes have historically been implemented in SA, with the present circumstances remaining unchanged [1].

Internationally, one can expect that more engineers are aware of ELE as engineering statutory bodies, associations and tertiary institutions alike are promoting it, and there is a vast amount of research and literature available on the topic.

Secondly, when testing the perceived current level of *knowledge* of engineering leadership possessed by graduate engineers of South African universities a majority (59%) of respondents rated them to possess *little knowledge of engineering leadership*. Only 5% of respondents rated *fair (amount of) knowledge* and a low 1% rated *highly knowledgeable*. When testing further the perceived level of *competence* of these graduates, a majority (54%) of respondents similarly rated them to possess *little competence in engineering leadership*. Only 4% of respondents rated *fair (amount of) competence* and 0% rated *high competence*. The negative responses are concerning as they indicate a gap in the education and training system.

Perceived Engineering Leadership Competency Shortfalls in SA at Present

The value of specific engineering leadership competencies shortfalls/gaps in SA as perceived by members of ECSA are ranked and scored as per Table 4. A numerical score for ranking items was used (1 = no shortfall to 5 = major shortfall). The original order of the listed items is also indicated.

Table 4: Perceived shortfall in regard to specific engineering leadership competencies.

Items	Descriptions (descending order)	Score
S3.4.3	Client/customer relations skills	3.62
S3.4.9	Ability to assess risk	3.54
S3.4.5	Industry/organisational knowledge	3.52
S3.4.10	Sense of urgency and will to deliver on time	3.50
S3.4.2	Written and oral communication skills	3.47
S3.4.6	Decision making skills	3.41
S3.4.17	Planning skills	3.36
S3.4.4	Personal initiative	3.30
S3.4.7	Self-management	3.27
S3.4.15	Quality orientated	3.24
S3.4.11	Resourcefulness and flexibility	3.18
S3.4.14	General knowledge	3.09
S3.4.8	Problem-solving skills	3.07
S3.4.12	Trust and loyalty in a team setting	3.07
S3.4.16	Creativity and innovation	3.04
S3.4.1	Engineering knowledge	3.03
S3.4.13	Ability to relate to others	3.03

Preferred Framework for any Future ELE in SA

The last area tested was with regard to any preferred framework for future ELE in SA. Respondents firstly provided a consensus on whether they believed ELE should be incorporated into the curriculums of South African tertiary education institutions, and secondly to what level/extent any implementation should be carried out. Finally, respondents ranked their preferred level of focus with respect to aims/goals, themes and implementation methods for any future ELE programmes, in SA.

The consensus regarding the desire to include ELE within SA institutions was a 91% majority answering *yes* to inclusion, reaffirming that future consideration needs to be given to ELE as per the industry's own desire. When testing what level/extent of implementation is preferred, a marginal 52% supported a non-explicit approach, where engineering leadership is incorporated into other engineering programmes which have their own primary objectives. Since the result is marginal, further specific investigations would need to be carried out in future, or ECSA and universities may subjectively choose for themselves. The cross-tabulation of demographic details with the question indicated an association related to the employment sector of respondents.

The preferred level of focus for specific aims/goal, themes and implementation methods as perceived by members of ECSA were ranked and scored as per Table 5 - Table 7. A numerical score for ranking items was used (1 = no attention to 5 = considerable attention). The original order of the listed items is also indicated.

Respondents scored specific aims/goals which may be used for any newly developed ELE programmes implemented in SA as per Table 5. Of high preference was improving *ethical leadership*, *desire for demonstrating excellence*, *project management skills* and the *ability to engage others*.

Table 5: Preferred level of focus to specific aims/goals of ELE programmes.

Items	Descriptions (descending order)	Score
S4.3.8	Improve ethical leadership	4.38
S4.3.16	Develop desire for demonstrating excellence	4.17
S4.3.11	Improve project management skills	4.10
S4.3.14	Develop ability to engage others	4.02
S4.3.3	Improve understanding of business concepts	3.97
S4.3.13	Develop ability to obtain team effectiveness	3.96
S4.3.1	Development of leadership skills	3.96
S4.3.6	Improve ability to solve business challenges	3.95
S4.3.7	Improve interpersonal skills	3.94
S4.3.15	Develop personal awareness and growth	3.93
S4.3.5	Improve skills in current technology	3.90
S4.3.4	Development of entrepreneurial skills	3.88
S4.3.9	Improve visionary leadership	3.86
S4.3.10	Improve industry leadership	3.78
S4.3.12	Develop desire for a positive impact on world challenges	3.75
S4.3.2	Development of managerial (administrative) skills	3.67

Respondents scored specific themes which may be used within any newly developed ELE programmes implemented in SA as per Table 6.

Of high preference was training and development in *ethics in engineering*, *communication skills*, *conflict management knowledge and skills* and *project management knowledge and skills*.

Table 6: Preferred level of focus to specific themes of ELE programmes.

Items	Descriptions (descending order)	Score
S4.4.11	Training in ethics in engineering	4.30
S4.4.13	Training in communication skills	4.03
S4.4.9	Development of conflict management knowledge and skills	4.00
S4.4.3	Development of project management knowledge and skills	4.00
S4.4.18	Training in working effectively with others	3.98
S4.4.7	Development of teamwork knowledge and skills	3.95
S4.4.2	Understanding of business fundamentals	3.93
S4.4.6	Development of presentation knowledge and skills	3.93
S4.4.10	Training in how to effectively lead and motivate	3.91
S4.4.8	Development of self-awareness and emotional intelligence knowledge and skills	3.89
S4.4.14	Training in managing interdisciplinary engineering teams	3.86
S4.4.4	Development of negotiation knowledge and skills	3.85
S4.4.15	Development of innovation knowledge and skills	3.77
S4.4.5	Development of career management knowledge and skills	3.76
S4.4.1	Understanding of leadership theory and practice	3.73
S4.4.17	Training in finance, marketing and investment	3.62
S4.4.12	Development of public relations knowledge and skills	3.55
S4.4.16	Development of public policy knowledge and skills	3.45

Respondents scored specific methods/approaches which may be used in any newly developed ELE programmes implemented in SA as per Table 7.

Of high preference was improving *peer/faculty/industry mentoring programmes*, *industry vacation work experience*, *personal leadership development plan(s) with mentor* and *coordinated networking opportunities with leaders*.

Table 7: Preferred level of focus to specific methods/approaches of ELE programmes.

Items	Descriptions (descending order)	Score
S4.5.5	Peer/faculty/industry mentoring programmes	4.01
S4.5.4	Industry vacation work experience	3.99
S4.5.7	Personal leadership development plan(s) with mentor	3.96
S4.5.8	Coordinated networking opportunities with leaders	3.73
S4.5.3	Team learning/scale projects	3.67
S4.5.1	Leadership coursework/modules	3.60
S4.5.2	Leadership workshops/seminars	3.58
S4.5.9	On campus/community leadership opportunities	3.53
S4.5.6	Leadership reflection journals/personal portfolios	3.37

CONCLUSIONS AND RECOMMENDATIONS

An engineering industry that offers visionary leadership, in addition to sound technical competence, is SA's best chance of moving forward to a healthier and safer society than the present one. An important understanding developed through the study is that this leadership can and should be developed at the grassroots level of engineering. This research was a baseline study into what needs to be achieved to bring ELE into a South African context.

The specific areas of focus preferred by the South African industry for any future ELE programmes, based on international best practice, included ethics in engineering, communication skills, conflict management skills, project management skills, effective teamwork skills and business fundamental skills. There is a preference for future ELE programmes in SA to primarily adopt *conventional implementation methods*, such as mentoring programmes, work experience and development plans. It is, however, recommended that this must be accompanied with well-structured theoretical knowledge, delivered through specific engineering leadership coursework, given the current shortcomings. Further, such an approach must keep sight of achieved outcomes for baseline standardisation and improvement.

A baseline conceptual framework of ELE which is based on international best practices and the preferences of ECSA members was developed, and is presented in Figure 2.

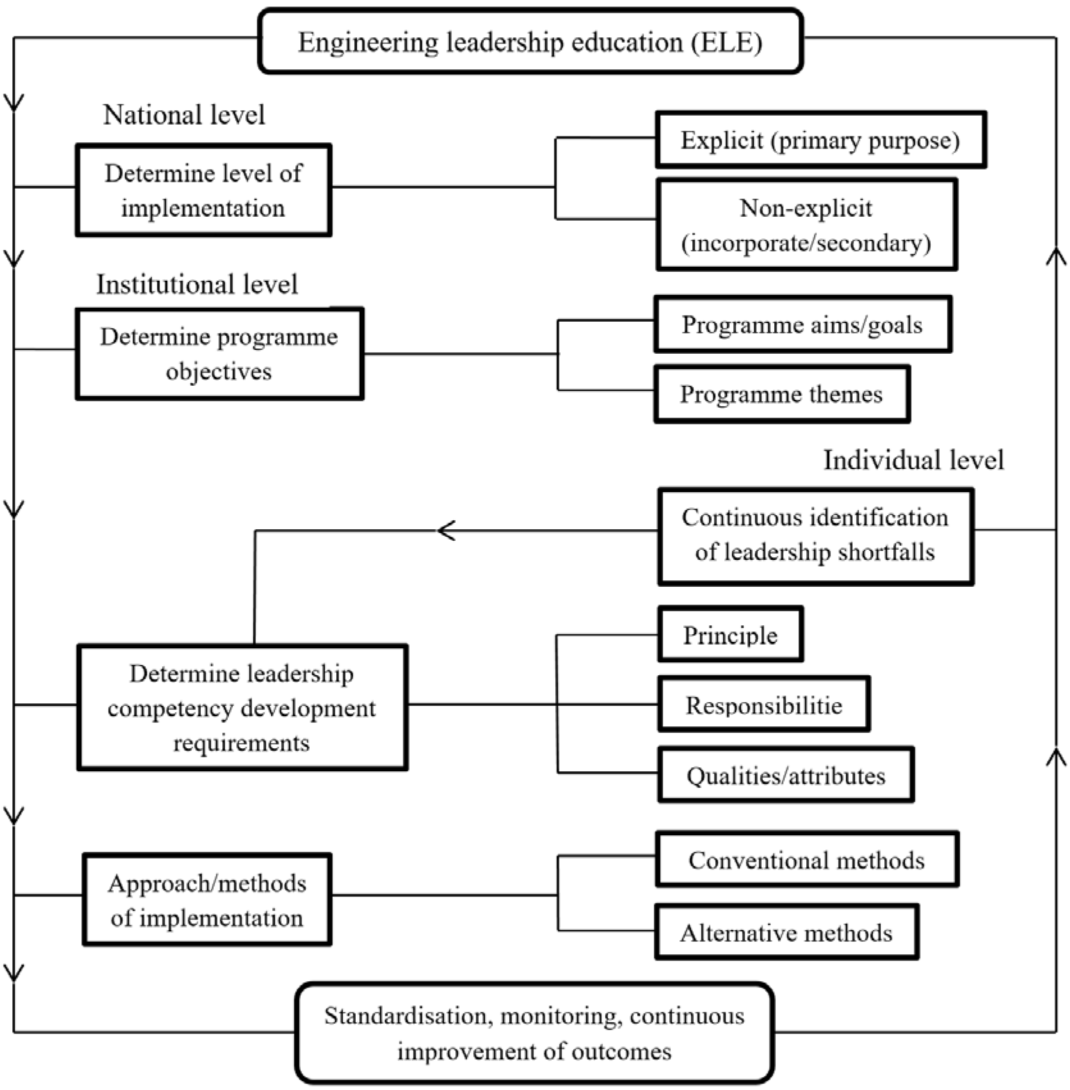

Figure 2: Summarised illustration of the conceptual framework of ELE.

Engineering leadership development efforts in SA have been found to be lagging behind other international engineering schools. ECSA's current *leadership competency* professional registration requirements were found to be too narrow and vague in comparison to other international statutory bodies. The registration requirements in terms of leadership competency must primarily be reviewed and improved in line with international best practices. More awareness regarding ELE needs to take place in SA as a large percentage of the industry is unfamiliar with the topic.

The opportunity cost of doing nothing to change the situation is that international engineering graduates of the future may offer better performance or be perceived in such a manner by employers and society, over South African engineering graduates. This study has confirmed that there is a great desire from the South African engineering industry and more specifically, ECSA members, for ELE to be incorporated into the South African tertiary education system. Further, when looking at how poorly experienced South African industry professionals rate current engineering graduates' leadership knowledge and competency, the recommendation follows that ELE implementation should be prioritised.

ECSA and the Department of Higher Education and Training need to further investigate and decide on the approach the country should take (explicit, non-explicit or none) to incorporate ELE in SA. This could also be left optional to engineering schools; however, they need to consider future professional registration requirements with ECSA in such regard.

Much work and research opportunity exists in the South African context to develop and implement ELE within SA. At a national level, work needs to be done to enhance the registration guidelines for engineering leadership competency. More clear guidelines as to its definition, development and assessment need to be specified by ECSA, in line with efforts made by other leading accreditation bodies. Also, the various tertiary education institutions need to examine how best to incorporate ELE into their curriculums.

REFERENCES

1. Graham, R., Crawley, E. and Mendelsohn, B.R., Engineering Leadership Education: a Snapshot Review of International Good Practice. Massachusetts: Gordon - MIT Engineering Leadership Program [Whitepaper], 1-36, 12 (2009).
2. Kotnour, T., Hoekstra, R., Reilly, C., Knight, R. and Selter, J., Infusing leadership education in the undergraduate engineering experience: a framework from UFC's eli^2. *J. of Leadership Studies*, 7, **4**, 48-57 (2014).
3. Engineering Council of South Africa (ECSA). Ensuring the Expertise to grow South Africa: Guide to the Competency Standards for Registration as a Professional Engineer. Johannesburg: ECSA, 15 (2018).
4. National Society of Professional Engineers (NSPE*).* National Position Statement No. 1752 - Engineering Education Outcomes. Alexandria: NSPE, 1-5, 2 (2010).
5. Paul, R. and Falls, L.G., Engineering leadership education: a review of best practices. *Proc. ASEE Annual Conf. and Expo*., Seattle, Washington, 1-9, 1 (2015).
6. Hartmann, B.L., Engineering Leadership: Important Themes Identified by Recruiters of Entry-Level Engineers. Ames: Iowa State University Graduate Theses and Dissertations, Paper 14987 (2016).
7. American Society of Civil Engineers (ASCE). Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future. Reston: ASCE, 17, 145 (2008).
8. Candidate Academy (CA). Road to Registration for Candidate Engineers, Technologists and Technicians. Johannesburg: CA, 13-50 (2013).
9. Owen, J., *The Leadership Skills Handbook: 50 Essential Skills You Need to be a Leader*. (3rd Edn), London: Kogan Page Limited, 1 (2014).
10. Engineering Council of South Africa (ECSA). Recognised Voluntary Associations Search (2021). 21 September 2021, https://www.ecsa.co.za/stakeholders/SitePages/Voluntary%20Associations.aspx
11. Crumpton-Young, L., McCauley-Bush, P., Rabelo, L., Meza, K., Ferreras, A., Rodriguez, B., Millan, A., Miranda, D. and Kelarestani, M., Engineering leadership development programs: a look at what is needed and what is being done. *J. of STEM Educ.: Innovations and Research,* 11, **3**, 10-21 (2010).