Keynote Address: Importance of the capstone mine design and planning project in addressing graduate attributes for accreditation of mining engineering programmes in South Africa

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There are four universities in South Africa that currently offer programmes in mining engineering. The Engineering Council of South Africa (ECSA) is the professional statutory body that accredits these programmes. It undertakes this important role by deriving guidance from international accords for the accreditation of engineering programmes. The International Engineering Alliance (IEA) is the custodian of these accords, which are namely, the Washington Accord, Sydney Accord, and Dublin Accord. The accords set international benchmark standards for the education of engineering graduates and the standards must be satisfied for accreditation to be awarded. One of the benchmark standards pertains to Graduate Attributes (GAs), which are descriptions of the professional and technical competencies that graduates must demonstrate at the Exit Level of an engineering programme. The four mining engineering schools in South Africa offer a final-year capstone mine design and planning project which is structured to satisfy several GAs at the Exit Level. The project also acts as an integrative assessment of competencies developed during the entire programme and is an avenue for students to demonstrate most of the competencies described in the range statements of respective GAs. The experiences of the four South African mining engineering schools suggest that it is critical to have a capstone mine design and planning project as a bridge for graduates to enter the world of work. This observation is particularly important for educational institutions considering the introduction of new mining engineering curriculums or re-designing existing ones.

INTRODUCTION

Four universities in South Africa offer programmes in mining engineering. These universities are the University of the Witwatersrand (Wits), University of Pretoria (UP), University of Johannesburg (UJ) and University of South Africa (UNISA). As noted by Nel (2014), the mining engineering programmes offered by these four universities constitute pathways or articulation routes for compliance with the educational requirements for eventual registration in any of the professional categories specified by the Engineering Council of South Africa (ECSA). ECSA is the statutory body responsible for the registration of engineering professionals in specific registration categories. The registration categories include the professional engineer (Pr. Eng.), professional engineering technologist (Pr. Tech. Eng.), professional engineering technician (Pr. Eng. Techni.), and professional certificated engineer (Pr. Cert. Eng.) categories. To be eligible for professional registration, an applicant should have:

- an accredited engineering qualification (or alternatively, an engineering qualification recognised as substantially equivalent to an accredited one).
- a minimum number of years of relevant engineering training and working experience obtained after graduating, as prescribed for each category of professional registration.
- experience or demonstrable ability to design in one's specific engineering field at the appropriate level descriptor of engineering activities.

Level descriptors for engineering activities exist generally in three main contexts namely, complex, broadly defined, and well-defined engineering activities. Complex engineering contexts are characteristically ill-defined, high-level (i.e., abstract) multidisciplinary contexts that typically require consideration of, among other factors, incomplete information, and judgement in decision-making within uncertain contexts to generate a wide range of acceptable solutions that show originality by applying from first principles, specialised engineering knowledge (ECSA, 2020a). Broadly defined contexts are characteristically ill-posed multidisciplinary contexts that require consideration of, among other factors, the identification and interpretation of contexts related to technology for which solutions are usually obtained by applying well-accepted and structured detailed engineering knowledge and techniques underpinning the applicable technology area (ECSA, 2020a). Well-defined engineering contexts are characteristically focused on the application of practical engineering knowledge by following standard prescribed ways to tasks that are mostly routine and discrete and occurring in familiar settings which are usually encompassed by standards, established codes, and documented procedures (ECSA, 2020a).

The requirement for an accredited engineering qualification to be eligible for professional registration underpins the importance of accreditation of engineering programmes. In South Africa, ECSA is the statutory body responsible for accrediting engineering programmes. ECSA undertakes the accreditation process based on guidance available from international accords for the accreditation of engineering programmes. These accords are the Washington Accord, Sydney Accord, and Dublin Accord and are under the custodianship of the International Engineering Alliance (IEA). The IEA comprises member countries which are signatories to the different engineering accords. The IEA establishes and enforces international benchmark standards for engineering education (i.e., academic standards) and professional engineering competence to facilitate reciprocal recognition by signatory countries. One of the benchmark standards pertains to Graduate Attributes (GAs) which are statements describing the professional and technical competencies expected from graduates at the Exit Level of an engineering programme. The Exit Level is the point in an engineering programme where a GA is assessed, and this is typically at the final (or fourth) year of study or penultimate (third) year of study for typical four-year engineering programmes. The four mining engineering schools in South Africa offer a final-year capstone mine design and planning project which is structured to satisfy several GAs at the Exit Level for the appropriate level descriptors for each programme's qualification. The overarching principle of including a final-year capstone mine design and planning project to assess several GAs is useful to other institutions considering the introduction of new mining engineering curriculums or re-designing existing ones. Musiyarira *et al* (2018) emphasised the importance of the ad-hoc re-design of mining education programmes to avoid extinction and remain sustainable under global threats to the viability of the mining industry which absorbs graduates from mining education programmes. Table 1 summarises the 12 GAs within the ECSA accreditation framework.

Table 1. Overview of Graduate Attributes in the ECSA accreditation framework (adapted from ECSA, 2020b)

Graduate Attribute	**Broad description of competencies that graduates must demonstrate**
GA1: Problem solving	Identify, formulate, analyse, and solve engineering problems that are in either complex, broad, or well-defined engineering contexts, depending on the nature of the engineering programme.
GA2: Application of scientific and engineering knowledge	Apply knowledge of mathematical, natural, and engineering sciences to solve engineering problems that are in either complex, broad, or well-defined engineering contexts, depending on the nature of the engineering programme.
GA3: Engineering design	Undertake engineering designs and syntheses which can be described as creative, procedural, and non-procedural to produce techno-economic solutions such as useful components, systems, processes, or tangible and intangible products.

GA4: Investigations, experiments, and data analysis	Design and conduct investigations and experiments by undertaking tasks that can include relevant literature reviews and choice of appropriate research methodologies.
GA5: Engineering methods, skills, and tools, including information technology (IT)	Use appropriate engineering methods, skills, and tools, including those based on information technology (IT) to solve engineering problems.
GA6: Professional and technical communication	Communicate effectively, both orally and in writing, to various audiences which can include peers, engineering, and non-engineering audiences
GA7: Impact of engineering activity	Display critical awareness and recognition of the sustainability and impact of engineering activities on the social, industrial, and bio-physical environment.
GA8: Individual, team and multidisciplinary working	Work effectively as an individual, in teams and in multidisciplinary environments, including those that transcend engineering boundaries.
GA9: Independent learning ability	Undertake self-directed learning which indicates that the graduate has well-developed learning skills, such as lateral thinking and creative thinking (i.e., 'thinking out-of-the-box') that can include showing abilities in research and critical thinking.
GA10: Engineering professionalism	Display critical awareness and recognition of the importance of acting professionally and ethically, and to exercise judgment and take responsibility within own limits of competence.
GA11: Engineering management	Possess knowledge and understanding of engineering management principles such as time management, self-management, managing teams, and economic decision making.
GA12: Workplace practices (where required) i.e., work integrated learning (WIL)	Possess good understanding of workplace practices for solving engineering problems consistent with academic learning by participating in appropriate work environments.

The mine design and planning project affords students the opportunity to demonstrate several of the competencies described in the range statements of respective GAs. The range statement of a GA specifies the situations, activities, tasks, methods, and forms of evidence through which assessments address the broad outcomes of the GA. The next section outlines the way the mine design and planning project is structured and presented in each of the four mining engineering schools to address some of the GAs.

Mine design project process and assessment of some Graduate Attributes

The mine design and planning project course is a 'capstone' course because it is structured as a culmination project-based course that addresses the integrative synthesis and demonstration of competencies developed throughout the programme. Table 2 indicates a summary of how the four South African mining schools conduct the final-year mine design and planning project. It also illustrates how the schools use the project to assess some of the GAs. The ECSA accreditation process allows for flexibility in the assessment of GAs so that no single assessment instrument is used to assess all the GAs. It is therefore expected that the mine design and planning project cannot be used to assess all GAs.

Table 2. Summarised depiction of the mine design and planning project in the four South African mining schools

Project detail	Wits	UP	UJ	UNISA
Engineering programme	BSc (Eng) (Mining Engineering)	BEng (Mining Engineering)	BET (Mining Engineering)	Advanced Diploma in Mining Engineering
Course code and name	MINN4006A/MINN4014A (Mine Design)	PMZ422 (Mine Design)	SSPMNB3 (Mine Design and Planning Project)	MIN3704 (Mine Design Project)
Year offered	Final Year NQF Level 8 (Exit Level)	Final Year NQF Level 8 (Exit Level)	Final Year NQF Level 7 (Exit Level)	Final Year NQF Level 7 (Exit Level)
General structure	The mine design and planning project is structured to mimic the mining value chain but within a Scoping Study/Pre-Feasibility (PFS) context and addressing a complex engineering activities context.	The mine design and planning project is structured to mimic the mining value chain but within a Scoping Study/Pre-Feasibility (PFS) context and addressing a complex engineering activities context.	The mine design and planning project is structured to mimic the mining value chain but within a Scoping Study/Pre-Feasibility (PFS) context and addressing a broadly defined engineering activities context.	The mine design and planning project course has a principles-based structure to mimic the mining value chain and addresses a broadly defined engineering activities context
General principles	1. Groups are randomly selected. 2. Individuals work on sections of the project allocated to them by the group and the group works as a team. 3. Regular feedback group meetings are held to assess progress and address any challenges. 4. Students are expected to undertake a mine design project by integrating knowledge and skills obtained during the programme and work exposure gained during vacation work.	1. Groups are carefully selected using the Myers Briggs selection criteria to fairly balance different student capabilities. 2. Participation is crucial since fellow students are dependent on the inputs of the other students. 3. Each student should at the end be able to plan and execute a mine design with a team of other students.	1. Students are allocated to groups at course coordinator discretion. 2. Each student works as a member of the project team and is responsible for specific sections of the project. 3. Mid-term progress presentations held. 4. Each student is expected to utilise knowledge gained during the programme	1. Blended learning lecture-based course. 2. Students work as individuals on individual assignments and each student is responsible for specific sections of a group-based final mine design project portfolio. Students also work as a team (group) on the mine design project portfolio.

			and experience gained during vacation work to carry out a mine design exercise.	3. Submission of assignments is used to track progress of students. 4. Students are expected to holistically demonstrate skills and tools necessary for the design of mining projects.
Assessment instruments	Written group reports and oral group presentations.	Written group reports and oral group presentations	Written group reports and oral mid-term presentations regarding progress.	Three assignments and a portfolio-based examination.
GAs assessed	GA3, GA4, GA5, GA6, GA7, GA8, GA9, GA10.	GA3, GA5, GA6, GA11.	GA1, GA3, GA5, GA6, GA8.	GAs not specified, but GA3 and GA6 inferred from course structure and assessment.

Some observations from the approaches by the four South African mining schools

Table 2 indicated a summary of the general principles and contexts for the mine design and planning project exercise in each of the four different mining engineering schools in South Africa. Two course codes are indicated in Table 2 for the Wits Mine Design project because the school introduced a re-designed curriculum while the old curriculum is being phased out, tentatively by the end of 2023. Details of the curriculum re-design were discussed in Mitra *et al* (2018). It is discernible from Table 2 that:

- Universities have autonomy in deciding on the structure of curriculum components.
- The mine design and planning capstone project should serve as an instrument for demonstrating in an integrative way, the competencies developed during an entire mining engineering programme through coursework and practical mining exposure obtained during vacation work. This principle is highlighted in Genc and Mitra (2018).
- Graduate Attributes 3 and 6 on engineering design and communication, respectively, are common to all programmes.
- GA12 is not applicable to the mining engineering programmes. Where a WIL component is required, it must be assessed and allocated credits.
- Not all GAs are addressed by the mine design and planning project. This aligns with an ECSA accreditation principle that an integrated assessment strategy should be used so that major work or multiple instances of limited scale work when taken together, collectively demonstrate that GAs have been satisfied at the Exit Level as described in each range statement for each applicable GA (ECSA, 2020c).
- The engineering programmes are offered at different NQF levels. The National Qualifications Framework (NQF) is a South African system for defining demonstrated competencies (i.e., skills that students possess). A student at a higher NQF level is judged to possess higher level academic skills, wherein the high school leaving qualification or Matric is at NQF Level 4, the first year of a tertiary qualification is at NQF Level 5, with the highest NQF Level 10 being for a doctoral qualification.

The student experience with the mine design and planning project is wide and varied. Students often find that the mine design and planning project exercise prepares them for the world of work because they do not get to choose team members, which is an experience encountered by anyone joining an organisation or company. In addition, the mine design and planning project develops the ability of students to manage group dynamics because each individual in a group brings unique strengths that each group must enhance and unique weaknesses that each group must mitigate to effectively operate as a team. The teamwork requirement for the mine design and planning project also enables students to sharpen their interpersonal skills because throughout the project exercise, students must engage within the group, with lecturers and with external industry people to obtain additional information required for the successful execution of the project. Some of the schools invite industry professionals to act as external examiners for both the written reports and oral presentations. Some of the industry professionals are usually from the mining companies that will have provided the mine design and planning project, and sometimes find useful perspectives from the evaluations undertaken by the students, which they can plough back into their respective mines.

Limitations of this paper

This paper focused on South African mining engineering programmes, but the principles covered have a global relevance. In addition, it was limited to the assessment of GAs which form part of the criteria used in the accreditation of engineering programmes. This paper also does not delve into the importance or benefits of accreditation as this is discussed more comprehensively in other publications such as Mohd Said *et al* (2013). This paper also only focuses on the final-year mine design and planning capstone project within any mining engineering programme.

Concluding remarks

It is possible to note some key principles regarding the role of the capstone final-year mine design and planning project in mining engineering programmes satisfying most of the GAs for accreditation purposes. These overarching principles, though not exhaustive, are:

- The mine design and planning project should mimic the mining value chain so that it creates an opportunity for competencies developed throughout a mining engineering programme and skills obtained by students during practical mining exposure gained during vacation work to be brought to bear in an integrative way.
- Ideally, the mine design and planning course should be at the Exit Level and structured such that students undertaking the course work in groups and learn the value of teamwork.
- In the world of work, people do not get to choose who they work with in any organisation. It is essential that students realise early on in their academic training that they should manage group dynamics so that a group can work collaboratively as a team. The mine design and planning project prepares students for this eventuality in their careers.

The above principles indicate that the mine design and planning project should be structured to play a pivotal role in mining engineering programmes to satisfy most of the GAs required for accreditation. It is essential that the mine design and planning project is at the Exit Level, is team-based, and has both written and oral assessment components. In this way, the mine design and planning project can ensure that mining engineering programmes have an integrative assessment tool that also acts as a bridge to funnel graduates into the future world of work. These lessons are important for mining academics considering introducing new mining engineering curriculums or re-designing existing ones.

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