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Developing skills of graduate engineers to enable them to design mineral processing plants

A Minor Dissertation Submitted in Partial Fulfillment of the Degree of

MASTER OF PHILOSIPHAE

In

ENGINEERING MANAGEMENT

At the

FACULTY OF ENGINEERING AND THE BUILT ENVIRONMENT

Of the

UNIVERSITY of JOHANNESBURG

by

Tshepiso Banda

October 2017

SUPERVISOR: Dr A MARNEWICK
DECLARATION

I, Tshepiso Mompati Banda, declare that the contents of this Minor Dissertation represent my own work, and that the Minor Dissertation has not previously been submitted for academic examination towards a qualification anywhere else. It has not been taken from the work of others except that such work has been referenced and acknowledged according to legislation and internal regulations of University of Johannesburg.

Signed

Date

........................................

........................................
ABSTRACT

This study investigated the development of technical and non-technical skills required for graduate engineers to design mineral processing plants in an EPCM environment. The purpose is to provide the better way of developing the skills which are essential for graduates to be responsible in designing mineral processing plants. These skills then enable graduates to effectively and efficiently design mineral process plants with less supervisory directives from their superiors.

The research was inspired by what was recognised by the EPCM project delivery organisation involved in designing on mineral process plants, which placed a cognisance that graduate engineers need to build a combination set of skills, of which some is specialised, to become responsible for design of mineral processing plants. In addition, graduate engineers possess skills, which are not necessarily a prerequisite to design mineral processing plants. The investigation looked on the significant skills, activities for demonstrating possession of required skills, training and development methods imperative for upskilling graduates.

This research firstly focused on the theoretical background of skills and attributes of graduate students in processing plants designing, then activities demonstrating possession of such skills and training and development methods EPCM organisations should employ to ensure upskilling of graduates. To investigate a business problem, the study examined alternative solutions, and proposed the most effective solution using supporting evidence. A case study method was selected to provide the researcher with an in-depth knowledge of the phenomenon. A case study with questionnaire was conducted at an EPCM organisation which designs mineral processing plants, to compare the theoretical background with what the industry perceived as critical technical and non-technical skills, activities perceived significant to demonstrate possession of imperative skills and training and development methods significant to nurture the skills of graduates.

The findings of the study revealed that on non-technical skills, communication and interpersonal skills are the most critical to ensure that graduates communicate design information effectively. This finding signifies that organisations should nurture graduates’ communication and interpersonal skills. For technical, it was found that all the theoretical background skills were essential though the knowledge of thermodynamics and mechanics, were perceived to be less required by the mineral processing plant design environment. Furthermore, mentorship and job rotation system which ranges from test work, design, commissioning and optimisation, are
considered the most critical. Whilst the continuous training is also needed, it was not rated as the most important by the respondents.

This research is important for EPCM organisations dealing in mineral process plant design. It also identifies skills perceived essential for the designing of processing plants, activities which are critical for graduate engineers working in an EPCM environment, and the intermediate and senior engineers to implement the processes that will develop graduates’ skills.
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- Finally, my parents and siblings for their support throughout my studies.
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<th>Description</th>
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<tbody>
<tr>
<td>ABET</td>
<td>American Board of Engineers Training</td>
</tr>
<tr>
<td>ASCEND</td>
<td>Advanced System of Computations in Engineering Design</td>
</tr>
<tr>
<td>BFD</td>
<td>Block Flow Diagram</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer Aided Drawings</td>
</tr>
<tr>
<td>CPD</td>
<td>Continuous Professional Development</td>
</tr>
<tr>
<td>C&amp;I</td>
<td>Control and Instrumentation</td>
</tr>
<tr>
<td>ECSA</td>
<td>Engineering Council of South Africa</td>
</tr>
<tr>
<td>EPCM</td>
<td>Engineering Procurement and Construction Management</td>
</tr>
<tr>
<td>GA</td>
<td>General Arrangement</td>
</tr>
<tr>
<td>HAZOPS</td>
<td>Hazardous and operability study</td>
</tr>
<tr>
<td>HAZIDS</td>
<td>Hazard Identifications</td>
</tr>
<tr>
<td>HVAC</td>
<td>Heating, Ventilation, and Air Conditioning</td>
</tr>
<tr>
<td>SAIMM</td>
<td>South African Institute of Mining and Metallurgy</td>
</tr>
<tr>
<td>PFD</td>
<td>Process Flow Diagram</td>
</tr>
<tr>
<td>P&amp;ID</td>
<td>Piping and Instrumentation Diagram</td>
</tr>
<tr>
<td>REEP</td>
<td>Rotation Exposure Experience Program</td>
</tr>
<tr>
<td>3D</td>
<td>Three Dimension</td>
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CHAPTER 1: INTRODUCTION

The introductory chapter presents the topic of this research study; discusses the background which led to the research problem; followed by explanation of the rationale and research methodology. This research questions are identified, followed by information regarding the research limitations. The research’s purpose is to investigate a way for developing technical and non-technical competencies of graduate engineers to effectively and efficiently design mineral processing plants in context of EPCM project delivery organisation.

1.1 Engineering Graduate Program Background

Graduate engineers play a vital role in the EPCM project delivery organisation for the designing and execution of mineral processing plant’s projects. However, graduate engineers have the theory but lack the practical skills that enable them to design on their own and to complete projects deliverables on time, which results in projects schedule overruns and rework. This is the main reason why project delivery organisation must invest in developing a structured graduate development programme which will develop graduates to be more competent on designing mineral process plant projects responsibly by themselves with less supervision from their superiors (Bothma, 2012). Capelli (2014) argues that there is an insufficient investment by companies in relation to the ongoing training of graduate engineers as they have no structured training program.

Universities are criticised for developing and producing competent graduate engineers who find it difficult to effectively perform in a work environment, this occurrence is confirmed by (Cox, Berry and Smith, 2010) as most argue that universities’ curriculum do very little to ensure that engineers are on par with what work environment requires. Graduates belief that engineering faculty’s curricula teach them the theoretical information provided to engineering instead of training graduates about what the industry needs (Farr & Brazil, 2009).

Engineering graduates’ development structure should instill hard and soft skills which are relevant to what professional engineers are required to possess (Connor & Shaw, 2008). De Figuerredo (2008) argues that in a global competitive workplace engineers, just like other professionals, are required to possess a set of multidisciplinary and interpersonal skills to participate effectively as members of the said community of practice. Currently more and more of mineral processing plant design projects in EPCM context are currently halted due to economic downturn, and project delivery organisation’s profit margins are low. The tried and
tested method of learning from previous mistakes is not acceptable in the engineering industry (Edum-Fotwe & Mcaffe, 2000). Ayokanmbi (2011) argues that employees require globally competent engineers. The highly esteemed engineering competencies, by professors and engineers were analysed to be the following: basic engineering proficiency, problem solving and methodological skills and they also agreed on the following as the least valued competencies such as development of knowledge and practical experience in engineering, (Bodmer et al., 2002). Goel (2006) emphasises on design, problem solving, critical and creative thinking skills.

1.2 Problem Statement

Graduate engineers in EPCM project delivery organisations particularly on designing of mineral processing plants’ projects are struggling to take full responsibility of the design and must always be guided by senior engineers to complete project’s deliverables on time, within budget and quality. Graduates are quickly allocated task related to above-said projects with an expectation that they deliver work appropriately but without being thoroughly assessed if they are ready to design mineral processing plants on their own with less supervision.

- A lack of a structured graduate program is one of the reasons why graduate struggle to perform and more organisations are unwilling to invest in engineering graduate program because they tend to be academic and are likely to leave the organisation once they possess the required business skill (Hogarth et al, .2007).
- It is further stated by (Jaschik, 2015) that graduates think they are well trained with the skills and qualities needed for careers but organisations think they still need training.
- Olatunji (2010) argues that lack of technical and non-technical skills by graduate engineers is one of the reason projects fails as they delivery deliverables late and with poor quality.

Archer and Davison (2008) argue that organisations experience problems regarding graduates’ basic skills such as communication, problem solving and team work, as they are not on par with what the industry requires. Previous study conducted by (Preston and Goh,2013) indicated that graduates reported that they gained more technical skills as the graduate program consists of work experience and allow project exposure, nevertheless they felt that their tertiary education has failed to make them more competent for professional positions in commercial and industrial environments. It was emphasised by According to Felder (1982) institutions of higher learning teach technicalities, memorising and routine methods, synthetic reasoning, instead of reasoning techniques, independent thinking, investigation, evaluations and creativeness.
This research will explore this problem statement:

**Graduate engineers need to build a combination set of skills, of which some is specialised, to become responsible for design of mineral processing plants.**

### 1.3 Aim

This research identifies skills which should be developed through the engineering graduate development program in context of mineral processing plant design projects for graduates to complete their design work on time within budget whilst monitoring quality. It also identifies specialised skills to be developed through engineering graduate program which enables graduates to take responsibility when designing mineral processing plant’s projects as stated by (Preston & Goh, 2013) maintains that engineers are expected to take responsibility for engineering projects and program in the most far-reaching sense.

### 1.4 Research Questions

To explore the importance of a structured / tailor-made graduate program on career growth of engineers, the following questions were investigated:

**Research Question 1:** What skills do graduate engineers need to successfully design mineral processing plants as part of mining projects?

**Research Question 2:** What activities should be carried out as an indication that graduates possess mineral process design skills?

**Research Question 3:** How would the organisation implement strategies to develop graduate engineers to be responsible in designing mineral processing plants?

If appropriate required skills are identified for a structured/ tailor-made engineering graduate programme, solution for the lack of quality performance by graduate engineers would be found and applied to reduce the number of projects’ schedule re-runs and re-works. The reduction of over-runs and re-works will increase quality project deliverables which will satisfy clients and their confidence on doing business with the organisation.
1.5 Research Process

The research process to be adapted to answer the research questions is the one from Blumberg et al., (2005):

![Research Process Diagram](image)

**Figure 1: Research process (Blumberg et al., 2005)**

1.5.1 Clarifying the research question

Theoretically, a research question explores the relations amongst constructs (Heppner & Heppner, 2015). As mentioned by Hair, Money, Page and Samouel (2007) a well-defined research question will enable researchers to specify their research objectives, determine information required, and determine suitable research design. The researcher identifies a problem that impacts on the project constraints such as time, cost and quality due to lack of technical and non-technical skills of graduate engineers in EPCM contracted projects. To explore the aforementioned problem will assist the researcher to find out about what other researchers explored about this research problem.
1.5.2 Research proposal

The proposal was written to document the purpose of and the feasibility of the study, by specifying the following:

- An outline of the research aims and objectives,
- A summary of the research before its commencement,
- Time schedule for the execution part of the research.

1.5.3 Research design

Welman and Kruger (2001) maintain that the research design is the strategy used to get participants, and further indicate how to collect data and what type of data from them, to reach a conclusion regarding the research question.

1.5.4 Data collection and preparation

The data selection criterion chosen was in a systematic pattern, to make sure that the collected data is aligned with the objectives of the research.

1.5.4.1 Data collection sampling

Sampling is an element of data collection, and selects only the specific portion of the population chosen for the research process (Bryman and Bell, 2007). The method to be applied in this research for sampling was taken from Iacobucci and Churchill (2005).

```
| Step 1: Define the target population |
| Step 2: Identifying the sampling frame |
| Step 3: Select a sampling procedure |
| Step 4: Determine the sampling size |
| Step 5: Select the sampling elements |
| Step 6: Collect the data from the elements |
```

Figure 2: The six-step procedure by Iacobucci and Churchill (2005)
1.5.5 Data analysis and interpretation

The data analysis is the editing and verification process on the data collected (Malhotra and Briks, 2006). This step of verification determined whether collected data is in line with the research topic and related to the previous similar researches.

1.5.6 Research reporting

This step of the research indicates the most important issues of the entire report and it is where the interrelation of all research processes is determined: it reconciles the literature survey, research questions and contribution to the relevant field of discipline (Bryman and Bell, 2007).

1.5.7 Research conclusion

The results and recommendations are documented to function as references for readers to follow the conducted research and comprehend the findings of the research along with recommendations and implications for future study.

1.5.8 Outline of the study

Subsequent to the introductory chapter, the literature review will follow. It discusses the study based on the academic background by previous researchers. The literature indicates how the issues relating to graduate engineers lack of technical and non-technical skills affect project success were investigated, and which of various skills the literature attributes to the project success. The methodology used for collecting data, analysing it is discussed in chapter 3. Findings of the previous two stages are discussed on chapter 4 and chapter 5 concludes this research study and summarises the findings.

1.6 Conclusion

This section is an introductory chapter of the research to give a general idea of the whole study. The literature indicated various influences to graduates ability in designing of mineral processing plants but this research looked only on the one caused by the lack of technical and non-technical skills developing oriented structured engineering graduate development program. Graduate engineers are required to possess skills which enable them to design mineral processing plants and produce project deliverables which conform to such constraints;
however, they are academically trained to possess theoretical knowledge of engineering which enables them to perform as required by engineering companies in a commercial environment. The designing of mineral processing plants' projects should comply with the constraints such as time, quality and cost.

This research identifies skills and programs significant for the development of graduate engineers to perform effectively on their tasks and assist them to avoid re-work and schedule re-runs on mineral processing plants design project. Lastly, this chapter highlighted the research design which includes an appropriate understanding of the study, problem statement, research objectives, research questions and process.
CHAPTER 2: LITERATURE STUDY

2. Introduction

Research on education curricula specified that graduates do not necessarily enhance the skills and competencies required by the engineering industry. This study will outline the essential aspects required to identify and develop relevant skills required by organisations. The questions that the study seeks to answer are as follow:

- What skills should graduate engineers possess to be responsible for the design of mineral processing plant’s projects?
- What activities should be carried out as an indication that graduates possess mineral process design skills?
- How can organisation implement strategies to develop graduate engineers to be responsible in designing mineral processing plants?

This chapter will review some of the relevant literature in relation to the development of graduate engineers. The review will highlight/outline important theories, themes, concepts and issues that are fundamental to the framework of this study.

2.1. Graduate Engineers

Graduate engineers are students who have completed bachelor of engineering (BEng), Bachelor of Science in engineering (BSc Eng.) and bachelor of technology (B Tech) in institutions of higher learning. Previous studies indicate a shortage of important skills amongst university and/or college graduates as expected by the industry. Skills such as interpersonal communication, problem solving, leadership, emotional intelligence and social ethics (Nair at el., 2008) are in demand by the corporate world. Farr & Brazil (2009) argue that core curriculum engineering is made of technical and theoretical courses which exclude extensive leadership and entrepreneurial skills required by industry.

In a globalised working environment, graduates are likely to be ill-prepared due to their ineptness to work in multi-cultural backgrounds (Wellington et al., 2002). Graduate engineers should possess skills such as teamwork, critical thinking, decision making and interpersonal communication skills to be effective leaders in the corporate worlds (Bhattacharyya, Nordin and Salleh, 2009). There is a difference in what the industry needs and the skills the graduates possess as supported by Motsoeneng, Schultz and Bezuidenhout,(2011) argue that
graduates frequently possess inadequate understanding on how to apply their theoretical knowledge in practice, specifically within the engineering industry.

2.2 The skills and attributes expected of engineering graduates

A graduate attributes range from the basic technical skills to the more sophisticated and intellectual abilities (Barrie, 2006). Globally, educational institutions and organisations are involved in developing graduates’ attributes. Factors such as life-long continuous education, which focuses on employability and development of outcome based measures to justify their quality, which is valued by the industry (Bath et al., 2004). Graduates should possess the least knowledge, competencies and skills required by the professional practice (Blomeke et al., 2013).

There are possibilities that graduates lack competencies that are accepted and appreciated by global companies (Lucena et al., 2008), they further emphasise that studies identified various responsibilities graduate engineers might find themselves accountable for, and competencies that organisations look for in graduates. Even though, there were specific organisational requirements, the study revealed that the graduate engineers’ skills and attributes should be categorised into: technical, personal, and business.

2.3 Technical Skills in design projects

A technical skill is an ability to conduct a specialised task that involves certain methods and processes to attain the expected work (Bateman and Zeithaml, 1993). ABET (2014) state that engineering program must ensure that their technical skills training enable graduates to have the following:

- Capability of applying mathematical, science, and engineering knowledge.
- An aptitude to conduct experiments, analyse, interpret data then design.
- Ability to design a process, system, equipment, component and meet desired requirements within realistic constraints such as economic, environmental, social, ethical, health, safety, manufacturability, and sustainability.

Engineering is the knowledge and process applied after the thoughts to design and operate something with a major technical content for a purpose from concept, model, process, system, technology and service (Malpas, 2000). Beder (1999) states that previous studies concluded that nowadays engineers do not have needed skills or capabilities to execute their obligations.
to a satisfactory level to attain employers’ expectation. Nowadays, graduate engineers are expected to equip themselves with technical competencies and broader attributes to take responsibility in the ever-changing engineering profession. (Shah, 2012) adds on the above that there are a whole lot of skills that are necessary for designing engineering projects such as the following: divergent thinking, visual thinking, analogical reasoning, sketching, spatial reasoning, decision framing and decision-making.

Shah (2012) defines divergent thinking as a capability to develop numerous alternative solutions by exploring the design space. In design, engineers should be able to apply the following (Jaros and Stretch, 2013):

- Mathematical and scientific skills for solving engineering problems,
- Knowledge about social, legal, health, safety and environmental constraints associated with design.
- Drawing skills, audio-visual skills and interpersonal skills to communicate the engineering designs to other people.

Previous studies emphasised on application of technical skills such as science and mathematics to solve issues affecting humankind, whilst considering factors such as environment, safety and environment. Further articulating on the importance of both technical and non-technical skills required.

The next section describes the significance of design skills in relation to mineral processing projects: how to obtain it and the role it plays within design. Technical skills assist the bearer to design effectively.

2.3.1 The need of a design skill for mineral process plant’s projects

Nicolai (1998) defines design as a cornerstone of engineering practice; to design commodities for the benefit of humanity, therefore, engineers must possess design skills. Design is a process in which an individual makes ideas and changes those concepts into a product that satisfies and meets the expectations associated with the design, furthermore, design should consider constraints that are viewed as limitations in relation to material, costs and environmental factors, and above all engineers should have the ability to brainstorm ideas and be creative (Moutons, 2012). As mentioned by ECSA (2014) graduate engineers must be able to design processes, systems, and components to attain the expectations of the users, and that the design should be within economic, environmental, social, quality, health and safety constraints. Mineral processing plants design engineers should possess skills which will
enable them to design mineral processing plant’s project effectively and make some valuable decisions when designing. It is further emphasised by Renade (2008) that graduates process engineers must have an ability to solve technical graduate problems and make profitable decisions.

2.3.1.1 Design as a basic skill for engineering projects

Mourton (2012) suggests that engineers in projects should apply mathematical, science and engineering skills and knowledge to design effectively. Goel (2006) supports the above suggestion by arguing that engineers should ponder what products to design, develop processes, and systems by means of science, to predict their behavior.

Angeles, Britton and Chang (2011) state that understanding the design process, awareness and use of the various design tools are the basics for a design competent engineer. Dym, Agogino, Eris, Frey and Leafier, (2005) define engineering design as a systematic process in which designers create, assess and specify concepts for systems, or practices whose form and function achieve clients’ objectives or needs whilst satisfying a specified set of constraints.

Design engineers need skills in kinematics since various parts of an engineering product can move, rotate, expand and retract, additionally they must possess the skills, which will assist them to assess whether the design will work or will not work (Mourton, 2012). Graduates should be able to apply mathematical equations and formulas to solve engineering problems and to do statistical analysis, he further emphasises that graduates should be able to creatively sketch, plan and work out designs effectively (Nguyen, 1998).

The research study by Nguyen (1998) categorised technical and design skills into the following areas:

- Technical standards: engineers should familiarise themselves with the guidelines, codes of good practice and technical procedures.
- Specifications and inspection standards: acquaintance with specifications and standards
- Testing practices: understanding of the testing procedures in engineering.
- Environmental constraints: engineers should place a cognisance of environmental standards and regulations that must be addressed when applying engineering practice.
- Code of ethics: obedience to the standards and codes set by professional bodies; awareness of professional and ethical responsibility to the community.
- Proficiency standards: acquaintance with the engineering code of practice, policies and guidelines.
Dieter (2000) emphasises that engineers should be well conversant with the terminology related to the design project phases such as conceptual design, preliminary design, basic design, detailed design, feasibility study, concurrent design and embodiment design which are terms that are used to describe phases of the design process.

Graduate engineers should first understand the design processes and procedures for designing engineering projects. And they should also familiarise themselves with uses of designing tools prior using such tools to design. The sections covered so far indicate a connection between technical skills and design. The next section describes the importance of technical and non-technical skills for processing plant design.

2.4 The importance of technical skills for process plant design

It is unambiguous understanding that technical skill is the core requirement for an engineering graduate (Spinks, Silburn and Birchall, 2012). Read (1998) defines technical skill as a representative of the traditional engineering knowledge, abilities gained academically and by professional experience. Nguyen (1998) states that engineers should possess technical skills such as computer skills, programming skills, design skills, analysis/synthesis skills, research and development skills to be effective in designing. Graduate engineers should have the ability to use of modern technology to design process plants projects with less supervision from seniors, they should design by considering constraints, be able to develop and use standards of engineering practice.

Table 1: Design-engineering competency (Angeles et al, 2011) & (Lucena et al. 2008)
<table>
<thead>
<tr>
<th>Operational Skills</th>
<th>To know how to use procedure, process and technology.</th>
<th>Execution and practicing of process design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiential Skills</td>
<td>To know how to use tacit knowledge</td>
<td>Design for similarity and experience</td>
</tr>
<tr>
<td>Social /Personal Skills</td>
<td>Listening, cooperate, work in a team</td>
<td>Communication, teamwork, leadership, negotiates professionalism.</td>
</tr>
<tr>
<td></td>
<td>Initiate, thorough, curious, etc.</td>
<td>Initiate, thorough, curious, humble, accountable, respectable.</td>
</tr>
<tr>
<td>To manage life (professional and personal); Feel (perception)</td>
<td>Manage emotions, self- motivation, self-awareness, empathy and handling relationships.</td>
<td></td>
</tr>
<tr>
<td>Cognitive skill</td>
<td>To design, solve problem, to take the decision, to manage a project.</td>
<td>Know your limitations create, to manage projects (including system engineering perspective), decision making, management of information and knowledge, defining problem, defining potential solution, management of resources, take risks and managing risks.</td>
</tr>
<tr>
<td>Technical skills</td>
<td>Technical</td>
<td>Theoretical understanding, technical breadth and practical application.</td>
</tr>
<tr>
<td>Personal skills</td>
<td>Soft skills</td>
<td>Communication, team work, creativity and innovation.</td>
</tr>
<tr>
<td>Business skills</td>
<td>Business skill</td>
<td>Commercial awareness</td>
</tr>
</tbody>
</table>

Table 1 outlines the relevant skills required for graduate engineers and it further indicates that to be an effective engineer, one need to have a knowledge of mathematics, sciences and engineering sciences which will enable development of technical information such as mass transfer, heat transfer and mechanics. It further shows that for an engineer to be involved in designing, they should have knowledge of procedures, rules, standards, ethics and safety associated with processing plant design or whatever product they designing.

The table also specifies which of hard skills the engineers should apply, skills such as experimenting, designing, execution and practicing of process design, for them to know the application of procedures, process and technology associated with processing plant design. The soft skills (communication and interpersonal) for knowledge transferring during design, commissioning and operations are very important for graduates to possess. And so is the business skills to conduct commercial related tasks, design for cost and conduct cost estimations.
2.5 The importance of graphical/drawing skills for process engineers to design

Numerous design houses utilise computer aided drawings’ program when developing block flow diagrams, process flow diagrams, piping and instrumentation diagrams and other processing plant related drawings (Sinnot & Towler, 2009). Moutorn (2012) argues that engineers should have the ability to use the design tools in order to translate mental images into visually recognisable form to convey creative work to technical and non-technical communities. It is further stated by De Anza (2008) that engineers should develop, maintain and improve their design skills by understanding design tools such as AutoCAD, Pro-Engineer Wildfire and other design tools. Engineers should be trained to use the design and technological tools such as Microsoft Visio and Excel for the development of basic drawings which depicts process flow/sheets. They should then be further trained to create drawings from much complex tools such as CAD, Smart Plant, ASCEND and 3D.

Basic deliverables expected from graduate engineers to design mineral processing plants are process flow diagrams, piping & instrumentation diagrams and block flow diagrams. Walas (2003) supports the above assumption when he argues that graduate process engineers should be able to develop block flow diagrams (BFD) related to the selected process and develop material balance for the plant. Ray and Johnston (2003) indicate that engineers during inception/concept stage should develop a rough drawing depicting the proposed process to show block flow diagrams.

A block flow diagram is a simple diagram which can summarise the whole process on a single sheet, more detailed information is found on the process flow diagram which is a precursor of the piping and instrumentation diagram, basically, process flow diagram is used by process design engineers to conduct basic layout of plant’s process (Walker,2009). Graduates should be trained by revising drawings, allowed to draw basic single-line isometrics, prepare material take off sheets until they are familiar with the process, then they can be given an opportunity to do simple design work (Bausbacher and Hunt, 1993). Process Flow Diagram (PFD) is the basic and important document for the designing of mineral processing plant; it entails preliminary mass balance, quantity of equipment, streams of flows and material for construction. Engineers should devise these drawings, understand other process related documents, and learn how these documents are developed. Development of such ideas is further explored in the next section.
2.6 Development of process documents essential for process design

Engineers involved in EPCM contract are prone to potential liabilities such as negligence in the performance of the design work, preparation of budget cost estimates, preparation of estimated period of work, managing procurement, trade contract administration, co-ordination of design and construction between the trade contractors (Henchie, 2008). A process engineer should possess the capabilities to execute all the tasks stated above (Watermeyer, 2002). Process design boundaries will be essential in the development of an effective prescriptive process to assist creativity thought-out design process (Howard et al, 2007). Process design engineers should have knowledge of projects phases and what to deliver during phases such as concept, prefeasibility, feasibility and detailed designing as indicated by (Watermeyer, 2002)

Prior developing a plant, mineral process plant design engineers should know what stages of projects, durations of such stages and which deliverables to conduct at each stage of the project such as inception/ conceptual, preliminary assessment of economic, development of data essential for design, final economic evaluation, procurement, construction, startup and handover (Peters and Timmerhaus, 1991). Walas (1990) indicates that sometimes it is only two stages which are crucial: the preliminary design and cost establishment to assess the advisability of the proposed plant design as the preliminary design cost is the one used to obtain funds for the development of such a project.

![Figure 3: Project-production cycle for mineral processes from (Allen et al., 1997)](image)

Figure 3: Project-production cycle for mineral processes from (Allen et al., 1997)
2.6.1 Research and Development

Project-production cycle for mineral processes begins with research and development phase. Process research is defined as action to evaluate technical and economic viability of the proposed processing plants, and it includes plant experiments, test works and pilot plant (Silla, 2003). Mineral processing is defined as the mechanical processes that prepare and refine ore for metallurgical processing without altering its chemical composition and refine it without altering its chemical composition (Napier-Munn & Wills, 2006). Figure 3, depicts production cycle for mineral process which begins with research and development.

Mineral processing plant is designed in accordance to metallurgical tests performed by research and development (R&D) institution to conduct ore composites samples and the range of recoveries is discovered by testing ore composites for variability (SRK, 2013). Sinnott (2009) indicates that prior to the mineral process plant design, the research engineers liaise with process engineers to develop a cost effective and best suited process by conducting the following: research, testworks and pilot plant operation. These are conducted to predict the actual physical operation of the envisaged plant.

2.6.2 Concept/basic design phase

Conceptual is the basic step in design where engineers come up with new ideas or solutions to new or older problem associated with engineering (Pugh, 1981). The understanding of fundamental process system is imperative and one of the first steps for proper design of mineral/chemical processing plants (Courtenay, 2007). The first step on process design of plant is to devise a new process design by drawing a rough block flow diagram (BFD) depicting major stages in the process (Sinnott, 2009). Munroe (1995) defines conceptual design as stage one of detailed design and engineering, in which drawings are the main output. He further states that the produced drawings are frequently simple ideas with little detail, however, they aim to commit ideas to paper. Graduates should be taught to read, understand and develop diagrams to articulate specific process flow of the potential mineral processing plant project.

Mody and Strong (2006) argue that the initial step when designing the process is to develop a sequence of probable solutions to the problem by developing various one-dimensional representation of a process which is called block flow diagram (BFD), which is differentiated by the fact that not any real equipment is essential to be documented. Figure 4, depicts a simplistic example flowsheet which shows the BFD for the process plant. It begins where the plant starts through to where it produces the end products.
A simplistic example of a BFD is depicted below:

![Block Flow Diagram](image)

**Figure 4: Block Flow Diagram adapted from Mody and Strong (2006)**

The concept stage must have most basic type process design drawings, related process documents and activities, such as BFD and PFDs. Figure 4 depicts a basic BFD showing waste treatment process flow. The next mineral processing plant design Project-production cycle is the pre-feasibility study.

### 2.6.3 Pre-Feasibility Study

Preliminary Feasibility Study is used to determine whether the major expenditure required for a comprehensive appraisal is warranted (De la Vergne, 2014). Process design engineers should know that the overall characteristics of process design is basically originating on the mass balance, energy balance and equipment specifications (Walas, 1990). There is a need for procedure to design, application of brainstorming techniques and synergies, to bring ideas for intractable problems related to designing (Jones, 1970).

He further argues that the above will assist as one of the initial steps of mineral processing designs. The purpose is to prepare the ore prior to downstream purification processes. Jones (1970) further indicates that at the completion of the pilot-scale tests, the process is evaluated once more. Due to this requirement a substantial increase in capital investment when
evaluating the process-design phase of the project, the project/design calculations need an improved accuracy.

Process engineers express their thoughts to describe the logic behind their potential process by developing a PFD at an early stage of the process design, engineers draw numerous flow diagrams to elucidate various alternatives processes, subsequent to the initial stage (Salli, 2003). A preliminary screening is conducted to reduce alternatives to the most promising; which will be studied in detail. Smith (2005), states that it is imperative to finalise flowsheet as it will assist in costing the plant design and emphasises that the best process flowsheet cannot be identified without first optimising the operating condition of it.

2.6.4 The Feasibility Study

The feasibility study determines the possibility of the design, for instance, the viability to build a processing plant for a manufacturing process it explores the technical and economic viability of the envisaged project. It is said to be exploratory evaluation because the process route has not yet been finalised, though an ultimate process route may be selected (Sinnot, 2005). Feasibility Study is defined as the principal document required to secure funding and it gives a basis for cost control and construction planning (De la Vergne, 2014).

2.6.5 Design

Sinnot (2005) indicates that subsequent to the feasibility study, the design project is evaluated and comparison of the other process routes takes place, thereafter an appropriate process is selected. However, the selection can be revised at a later stage, prior the plant is built, to avoid a wasteful expenditure by building an uneconomic or unsafe plant.

Ray and Sneesby (1998) suggest that the aim of the process design is to ensure that the plant is proficiently designed, and attain the design parameters as the equipment operates appropriately to achieve the clients’ specification. Graduates should know what is needed on the basic/concept study and be able to differentiate the deliverables as indicated by Mody & Strong (2006) that the PFD differ from the BFD diagram by indicating a piece of equipment and its respective flows, temperatures, pressures that enter, or exit such equipment. Oden (1974) that PFD should include mass balance of all major equipment such as tanks, pumps, exchangers and that equipment should be numbered.
The Process Flow Diagram (PFD) is a distinct kind of a diagram which symbolises the configuration and processes of the whole processing plant displaying all pipe lines and other means necessary for the transfer, distribution and collection of utilities, material and energy. The process equipment in the PFD is symbolized as a box with inscriptions, for instance, the unique identification number and connections (IPS, 1996).

The following requirements are indicated on the title block of each diagram/drawing sheet (see Figure 5):

- Main Company’s name (e.g., Koeach Oil Company),
- Name of Company and Relevant Organisation, (e.g., Blacc Engineering and Construction),
- Name of refinery or plant,
- Company’s emblem,
- Contractor’s name, Drawing title, Company’s project number.
- Contractor’s job number. (Optional),
- Contractor’s drawing number. (Optional) and Company’s drawing number.

A simplistic example of PFD is depicted below:
<table>
<thead>
<tr>
<th>Item</th>
<th>Equipment</th>
<th>Quantity</th>
<th>Units</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water Tank No1</td>
<td>1</td>
<td>m³</td>
<td>300</td>
</tr>
<tr>
<td>2</td>
<td>Water Tank No2</td>
<td>1</td>
<td>m³</td>
<td>300</td>
</tr>
<tr>
<td>3</td>
<td>Water Tank 1 Pump</td>
<td>1</td>
<td>kW</td>
<td>110</td>
</tr>
<tr>
<td>4</td>
<td>Water Tank 2 Pump</td>
<td>1</td>
<td>kW</td>
<td>110</td>
</tr>
<tr>
<td>5</td>
<td>Agitator</td>
<td>1</td>
<td>kW</td>
<td>45</td>
</tr>
<tr>
<td>6</td>
<td>Mixer Tank</td>
<td>1</td>
<td>m³</td>
<td>400</td>
</tr>
<tr>
<td>7</td>
<td>Mixer Pump</td>
<td>3</td>
<td>kW</td>
<td>250</td>
</tr>
</tbody>
</table>

**Mass Balance**

<table>
<thead>
<tr>
<th>Stream 1</th>
<th>Stream 2</th>
<th>Stream 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulp m³/hr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water m³/hr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Tons (t)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 5: Typical Process Flow Diagram Blacc Engineering Services (BES, 2015)**
Figure 5 depicts a PFD which shows equipment and stream numbers of the flow lines, mass balance and equipment unit of the process plant. The succeeding step in process design after the block flow, mass balance, process design criteria, process description, block flow diagram and flow-sheet is the preparation of plot plan often called the plant layout.

2.6.5.1 Process Description and Equipment List

Ray and Johnston (1989) suggest that subsequent to the selection of process routes, it is important to develop an equipment list or equipment schedule. The development of the process design criteria, process description, preliminary design calculations and equipment listing is typically performed at the same time as the initial mass and energy balance. The following data must be considered when developing the equipment list for the determination of purchasing and installation costs.

- Equipment type: equipment size and material of construction.
- Operating parameters such as pressure, temperatures, and other similar parameters.
- Insulation requirements: corrosive allowances and exceptional features.
- Plant items’ duplication

The detailed equipment list should be developed to ensure appropriate type of equipment to be installed, however it will not be complete while waiting for the availability/completion of the detailed equipment designs.

2.6.5.2 Piping and Instrumentation Diagram (P&ID)

ANSI (1989) describes the P&ID, as a drawing developed from the PFD, it characterises the technical understanding of a process by using graphical symbols for pipes, equipment, process control and measurement functions. Oden (1974) briefly states that, thoughtful engineering decision must be used to transform the process flow diagram into a real working process that will be documented by the piping and Instrumentation Diagram.

When the PFD and material balance is considered to have no more issues that are required be resolved, then preparation the piping and instrumentation diagrams take place, P&ID’s are vital to any further design. These diagrams define how the envisaged plant will look and operate better than any single other document. It is at their development that all other engineering disciplines (electrical, instrumentation, civil, mechanical, piping, HVAC, fire protection) can begin their preliminary design. When all disciplines developed their preliminary design, then they accurately determine cost estimates of material quantities.
The P&ID’s shows the arrangement of the process equipment, piping, pumps, instruments, valves and other fittings. It should include:

- Identification of all equipment using a unique equipment number, equipment and location of nozzles.
- Pipes, identified by a line number, pipe sizes, and material of construction should be shown.
- Identification of all control and block valves using unique number, type and size should be shown. The type may be shown by the symbol used for the valve or included in the code used for the valve number.
- Ancillary fittings that are part of the piping system, such as inline sight-glasses, strainers and steam traps (they all should have identification number).
- Identification of all pumps by a suitable code or tag number.
- Identification of control loops and instruments.

2.6.5.3 Equipment sizing calculations and other process engineering calculations

P&ID usually describe the process in detail by including pipe connections, sizes and instrumentation, pipe sizes and equipment size, as a result, engineers should know process engineering calculations to determine pressure drop in pipelines because of friction (Sinnot & Towler, 2009).

Process design begins the sequence of physical and chemical operations, conditions of operations, specifications as well as material of constructions of all process equipment, general arrangement (GA) of the plant equipment that are required to confirm proper functioning of the entire plant, line size and key instructions (Walas, 1990). Graduate process design engineers should know how to size all minerals processing equipment items accurately to ensure optimal operation of the process plant.

2.6.5.4 Finalisation of a plant layout

The accepted plant layout must be influenced by the plant operation’s safety, any subsequent modifications or extensions of the plant (Ray and Johnston, 1989). They further argue that this should include selection of a plant site for greenfield project. They emphasise that graduates should depict plant by showing blocks of office building, configure the plant, place units of equipment graphically. In addition, Ray and Johnston (1989) indicate that a fundamental establishment of the plant layout considers how the pipe runs through the plant and pressure
drops, access for maintenance and repair and in the event of accidents and spills, and location of the control room and administrative offices.

Sinnot (2005) states that the plant layout should give a general idea of the envisaged processing plant configuration and the equipment depicted on the layout should be accurately on scale. The preliminary plant layout assists the process engineers to detect the unwanted and unpredicted difficulties with the chosen site, and may require a revision of the site selection (Ray and Johnston, 1989). The recommended plant layout must be considered early in the design work, and in an adequate detail, to make sure that economical construction and efficient operation of the completed plant are considered.

![Diagram of Plant Layout](image)

**Figure 6: Plot Plan adopted from (Ray and Johnston, 1989)**

Plant layout should depict the buildings and other essential areas of the plant as shown on Figure 6. The graduate shall properly design with cost effectiveness, by considering the implications associated with plat layout. They should reduce maintenance cost, operating cost, construction costs, hazards to human beings and damage to property because of fire or explosion as they will learn how to safely space equipment and buildings.

As mentioned by Courtnay (2007), the significant features of layout for successful design of a processing plant should include the following:

- Densities and flows of main streams, equipment sizes and the ground conditions of the preferred site
- Environmental conditions of the preferred site including (wind and seismic factors)
- Access for removal of items requiring regular maintenance
- Personnel accessibility required for certain areas
• Supporting structure layout and elevation/location of walkways

When considering daily operation and maintenance tasks into the plant design from the design initiation phase, it is most likely there will be a better operational consistency, increased safety measures and a reduced amount of maintenance downtime. It is further emphasised by IDC Training (2015), that the plant layout deliverables should consider the following: Plant layout specifications, codes, safety considerations and equipment arrangement drawings.

2.6.6 Detailed design and engineering

Monrue (1995) describes detailed engineering design as a process which involves the conceptual, embodiment and detail designs. When professionally executed, it will result in a well-designed solution.

The process design of a mineral processing plant follows reasonable steps, one built on another, to explain the circuit requirements. The procedure utilised, documentation and drawings produced are the same for a pre-feasibility study, feasibility study and a complete design, irrespective of the process complexity or the commodity being processed, the only difference in terms of the procedure utilised, documentation and drawings produced is the amount of detail information developed at each stage. (SRK, 2013)

The detailed engineering design phase results in information packages that define the plant in an adequate detail to begin construction (Mody and Strong, 2006). Courtenay (2008) states that it is significant to consider the relationship between the process system and the surrounding structure, and the way in which these two factors integrate via the plant layout especially at the initial plant design stage.

Courtenay (2008) suggests that with the plant process defined, elevations confirmed and structure determined, the designers should think of how best the plant can be controlled. The plant designer should take into cognisance the plant ‘outputs’ such as motors and actuated equipment prior to the assessment of the required ‘inputs’. The plant designer should determine how the equipment will be operated, and determine the type and accuracy of the required sensor, above all whether it is digitally operated or analogue operated through a range. The processing plant’s sensors typically include level sensors, pressure sensors and flow meters. The P&ID is developed in phases and remains a live document up until the beginning of construction. At this phase in the project, all the equipment including spares, controls and
piping will be presented on the diagram. Depending on the estimate’s accuracy that is proposed to be developed, the pipe codes, insulation, and requirements for tracing will also be shown (Mody & Strong, 2006).

Special printed sheets are used as drawings for all project diagrams, with the name of client’s and an EPCM organisation’s companies, project name and number; drawing title and identification number; names of a draughtsman and checker, revision control number, clearly set out in a box in the bottom right-hand corner. Provision should also be made for noting on the drawing all modifications to the initial issue. The revision control on drawings should be clearly identified by placing a revision triangle and revision letter or number, in the revised area of the drawing. A brief informative statement of the revision made should be shown in the revision block (Phillpot, 2008).

The process engineer will have to provide some reasonably accurate line sizes as input to the piping model. Similarly, weights of equipment and sizes must be available for the structural group, Isometrics, piping system design and pipe line list. After the completion of P&ID, a material balance, and 3D models, a hazop workshop is conducted to make sure that all the hazards are identified and satisfactory levels of protection are provided to ensure that risks are acknowledged and mitigated.

2.6.7 Construction and commissioning

The EPCM project delivery organisation does not conduct construction of any structure; they select a construction company and execute construction and project management role within the processing plant construction (Charles, 2009). EPCM contractor performs the coordinate, supervise and manage construction activities being performed by various construction firms (Loots & Henchie, 2007). Commissioning is the process of ensuring all systems, equipment and components of a mineral process are designed, installed, tested, operated, and maintained according to the operational requirements of the client.

Graduate engineers should be involved in commissioning of the mineral process plants to test the design equipment if they operate according to the design, to successfully commission the plant, graduates must conduct mineral process plant design activities, and put in to practice testworks, check if all the equipment are according to the piping and instrumentation diagrams, process flow according to the design. The activities stipulated on the next section, indicate what should be done before execution stage. The execution stage is where commissioning take place. The commissioning stage comprises two phases: the cold commissioning where
the integrity of the plant is tested with water and hot commissioning is where the integrity is tested by the feed that will be processed.

2.7. Activities needed to acquire plant design skills

Table 2 depicts the activities essential when designing processing plant. It further indicates design phases starting from process research, process development, process design, construction, commissioning and optimisation.

Table 2: Essential activities for process-design engineers (Silla, 2003)

<table>
<thead>
<tr>
<th>Phases</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Process Research</strong></td>
<td>Develop a preliminary process flowsheet</td>
</tr>
<tr>
<td>(Process evaluation)</td>
<td>Equipment selection and sizing</td>
</tr>
<tr>
<td>The purpose is to assess</td>
<td>Economic assessment</td>
</tr>
<tr>
<td>technical &amp; economic</td>
<td>Locate areas needing research</td>
</tr>
<tr>
<td>viability of the envisaged</td>
<td></td>
</tr>
<tr>
<td>process.</td>
<td></td>
</tr>
<tr>
<td><em>(Bench scale Studies)</em></td>
<td></td>
</tr>
<tr>
<td>The purpose is to attain</td>
<td></td>
</tr>
<tr>
<td>sufficient data for process</td>
<td></td>
</tr>
<tr>
<td>evaluation.</td>
<td></td>
</tr>
<tr>
<td>Plant experiment, design</td>
<td></td>
</tr>
<tr>
<td>experimental setup &amp; correlate</td>
<td></td>
</tr>
<tr>
<td>data</td>
<td></td>
</tr>
<tr>
<td>Revise flow sheet</td>
<td></td>
</tr>
<tr>
<td>Revise economic viability</td>
<td></td>
</tr>
<tr>
<td>Locate areas needing research</td>
<td></td>
</tr>
<tr>
<td><strong>2. Process Development</strong></td>
<td>Design pilot plant</td>
</tr>
<tr>
<td>The purpose is to attain</td>
<td>Supervise pilot plant</td>
</tr>
<tr>
<td>more data regarding the</td>
<td>Correlate data</td>
</tr>
<tr>
<td>process.</td>
<td>Revise flow sheet</td>
</tr>
<tr>
<td></td>
<td>Revise economic viability</td>
</tr>
<tr>
<td><strong>3. Process Design</strong></td>
<td>Develop a preliminary process flowsheet</td>
</tr>
<tr>
<td>To establish process and</td>
<td>Develop mass and energy balance</td>
</tr>
<tr>
<td>equipment specifications</td>
<td>Look for design/process alterations</td>
</tr>
<tr>
<td></td>
<td>Equipment sizing &amp; develop process design controls systems</td>
</tr>
<tr>
<td></td>
<td>Conduct economic and optimisation studies</td>
</tr>
<tr>
<td></td>
<td>Conduct Environmental Impact studies</td>
</tr>
<tr>
<td></td>
<td>Assess the safety, health and quality</td>
</tr>
<tr>
<td><strong>4. Process Design &amp;</strong></td>
<td>Specify equipment</td>
</tr>
<tr>
<td><strong>Construction</strong></td>
<td>Design all mechanical equipment</td>
</tr>
<tr>
<td>To implement the process</td>
<td>Design process piping system</td>
</tr>
<tr>
<td>design</td>
<td>Design electrical distribution system</td>
</tr>
<tr>
<td></td>
<td>Design data acquisition system</td>
</tr>
<tr>
<td></td>
<td>Procure equipment</td>
</tr>
<tr>
<td></td>
<td>Coordination and scheduling of the project</td>
</tr>
<tr>
<td></td>
<td>Project’s progress monitoring</td>
</tr>
<tr>
<td><strong>5. Commissioning</strong></td>
<td>Cold commission (water test the equipment &amp; integrity test)</td>
</tr>
<tr>
<td>Testing of the integrity of</td>
<td>Hot commissioning (Start the plant using the correct feed)</td>
</tr>
<tr>
<td>the designed plant</td>
<td></td>
</tr>
<tr>
<td><strong>6. Operation</strong></td>
<td>Plant Start-up and Trouble Shooting</td>
</tr>
</tbody>
</table>
Table 2 above defines the crucial activities for process-design engineers should conduct to demonstrate mineral processing plant design skills. The activities made up by various phases, which begins with process research, where the graduate engineers should assess the technical and economic viability of the envisaged process. The activities on this phase are identification of research areas, preliminary process flowsheet development, equipment selection, equipment sizing and economic assessment.

Phase 2 process developments to attain more information by design, operate the pilot plant, revision of flowsheet and economic viability. Phase 3, defines process design to establish process and equipment specifications which comprises activities such as preliminary flowsheet development, development of material balance, looking for design alternatives, conducting economic study and evaluation of safety, health and quality.

The other phases are the construction, commissioning and operation. Design and constructions include specifying equipment; designing all mechanical, piping, electrical and data acquisition equipment; procuring equipment, project scheduling and monitoring.
Commissioning is defined as an action taken to test the integrity of the designed plant and has stages such as cold, were the plant equipment are tested with water, whilst hot commissioning is the use of correct feed. Last phase is the plat operation as per design parameters. All these stage graduates in process plant design should be familiar with to possess the required skills crucial for the EPCM project delivery organisation.

These skills supplement the multidisciplinary setup of the mineral processing plant design, as the processing plant require project management, project engineering management, technical specialisation and corporate leadership. A graduate as they progress can select which roles they will like to play once they possess appropriate skills and experience. All these skills are significant for the success of the processing plant design. Figure 7, depicts careers path that can be followed by graduate engineers working in mineral processing plant design environment.

2.8 Other careers for graduates in mineral processing plant design projects
Mineral processing plant design career path gets wider once graduates acquire skills. These skills assist the graduates to broaden their knowledge for designing and begin to practice in other branches of design such as project management, engineering management, commercial and to specialize in a technical area. (Tang, 2000) states that the ultimate goal of engineers regarding their career path is to switch from technical skills’ level to managerial level. It can range from trainee, junior, intermediate, senior, principal and manager.

Figure 7: Career path for engineers in processing plant design (TWP, 2008)
2.8.1 Roles and requirements of Process engineers in mineral processing design

An EPCM project delivery organisation should have clear defined roles and responsibility of various engineering positions to indicate what is expected on their positions, what skills is required for certain position (Tang, 2000). These roles and responsibilities assist engineers to focus their energy to upskill themselves for upper level positions.

Table 3: Roles and requirements for process engineers (TWP, 2008)

<table>
<thead>
<tr>
<th>Descriptions</th>
<th>Senior Discipline Engineer</th>
<th>Discipline Engineer</th>
<th>Junior Discipline Engineer/Graduate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Purpose of the Job</strong></td>
<td>Leading process discipline designing and procuring activities in studies and/or execution projects.</td>
<td>Executing engineering, designing and procuring activities in studies and/or execution projects as part of a discipline team with limited levels of supervision.</td>
<td>Supporting and/or executing engineering, designing and procuring activities in studies and/or execution projects as part of a discipline team with significant levels of supervision.</td>
</tr>
<tr>
<td><strong>Target Group</strong></td>
<td>Discipline Engineers wishing to remain within the discipline</td>
<td>Junior Discipline Engineers wishing to remain within the discipline</td>
<td>Graduate engineers wishing to develop as a discipline Project Engineer</td>
</tr>
<tr>
<td><strong>Expertise</strong></td>
<td>Solid experience as a discipline engineer on multiple projects.</td>
<td>Reasonable experience as a discipline engineer on multiple projects.</td>
<td>Exposure to discipline project engineering as a student or trainee</td>
</tr>
<tr>
<td><strong>Recognition</strong></td>
<td>Internally recognised as having the ability to lead the discipline engineering on a medium size project with limited supervision.</td>
<td>Internally recognised as having the ability to perform discipline design and engineering on a medium size project with limited supervision.</td>
<td>Internally recognised as having the ability and desire to develop as a discipline project engineer.</td>
</tr>
<tr>
<td><strong>Authority</strong></td>
<td>Routine discipline project decisions may be made independently. Significant discipline project decisions will typically make in consultation with the HOD, and/or peers</td>
<td>Discipline project design/engineering decisions will typically made in consultation with the lead engineer</td>
<td>Discipline project design/engineering decisions will be limited and typically made in consultation with the intermediate engineer</td>
</tr>
<tr>
<td><strong>Development</strong></td>
<td>This may be supported by technical literature.</td>
<td>This may be supported by</td>
<td>This may be supported by</td>
</tr>
</tbody>
</table>
courses and conferences and by the development of networks with clients, external peers, suppliers, consultants and other related industry players. May publish internal guidance and interpretation papers, procedures, standard designs or best practices in area of expertise. May also prepare and deliver papers to technical conferences.

<table>
<thead>
<tr>
<th>Qualifications</th>
<th>BSc (Eng), B.Eng. or B.Tech. (NHD with additional experience)</th>
<th>BSc (Eng), B.Eng. or B.Tech. (NHD with additional experience)</th>
<th>BSc (Eng), B.Eng. or B.Tech. (NHD with additional experience)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Registrations and Associations</td>
<td>Pr.Eng, Pr. Tech Eng or Pr Nat.Sci.</td>
<td>Pr.Eng, Pr. Tech Eng or Pr Nat.Sci.</td>
<td>Registration as candidate engineer or scientist</td>
</tr>
<tr>
<td>Minimum Relevant Experience</td>
<td>7y qualified inc. 3y Project (NHD + 10y)</td>
<td>3y qualified inc. 3y Project (NHD + 5y)</td>
<td>0 yr qualified</td>
</tr>
</tbody>
</table>

The above table indicates the job descriptions of junior, intermediate and senior engineers in the mineral processing plant design. It further stipulates the requirements such as the minimum desired experience for one to practices as per the roles. Additionally, it indicates the professional registration level required per specific role.

Furthermore, the table states the developmental strategy to develop a junior to be intermediate, intermediate to seniors, as well as the authority level within the mineral process plant design environment in the EPCM project delivery organisation. Lastly, the table outlines the purpose of the following roles within the mineral process designing:

- Senior: leads process discipline designing and procuring activities in studies and execution of projects.
• Intermediate: execute engineering, designing and procuring activities in studies and execution projects as part of a discipline team with limited levels of supervision.

• Junior: Supporting and/or executing engineering, designing and procuring activities in studies and/or execution projects as part of a discipline team with significant levels of supervision.

The following section describes what the EPCM projects delivery organisation can do to assist graduates for quick grasp of knowledge in designing mineral processing plants.

2.9 What organisation should do to provide the skills

Business continues to request universities to produce graduates who possess both technical and generic skills (Jackling, Friederika and Clark, 2013). Alipour (2009) states that an organisation that wishes for success, should keep continuously aid its workers to learn and develop. He further argues that training should provide knowledge, capabilities and attitudes that will assist in getting rid of lackluster performance throughout their job.

General objectives of training activities include: assisting employees to perform their current jobs appropriately to the best of their ability, assist employees to be suitable for the future jobs, retaining employees and providing opportunities for personal development (Drummond, 1989). The main aim of the on-the-job training term is to afford engineers an opportunity to gain task-specific knowledge and skills in their respective field.

2.9.1 Training and development

The development of skills is best facilitated by providing graduates with practice and not simply by speaking about or demonstrating what to do (Woods, et al., 2000). Frise (2002) indicates that there are too few organisations that train graduates with explicit design competency and in many instances, graduates are not prepared to enter the workforce as their curriculum did not match the required standard by the industry. Motsoeneng et al., (2011) state that as part of preparation for graduates to be work ready, organisations should put a development program in place as specified by the sector skills plan for the mining and minerals Sector.

According to Connor and Shaw (2011), organisation should establish graduate employment and development as the most significant input to the talent pipelines for higher positions, and to fast track graduates’ careers. Hayman and Lorman (2004) argue that in recently graduate development structures have not only grown in popularity but that graduates on such
structures have demonstrated more accelerated career progression than direct entry graduates.

Prahalad and Hamel (1990) indicate that a graduate training programme should instill a skilled talent pool based on business competences and technical capabilities meeting current staffing and future leadership needs. Connor and Shaw (2011) state that there is greater emphasis on experiential learning, and more tailored forms of training, also more mentoring and coaching, especially for personal development and giving “people skills” seen as central to leadership development.

2.9.2 Other Training and development approaches

Salopek (2008) defines employee training as the conveyance of job-related knowledge and skills and career development to activities, which facilitate movement within an organisation, such as performance management, succession planning and promotions. Silverman (2003) emphasises that on job training is crucial as employees are supported, observed and evaluated for their career growth. He further emphasises in job rotation, mentoring and team working.

2.9.2.1 Coaching

Alipour (2009) defines coaching as the process of one-on-one supervision and instruction to expand knowledge, skills and work performance. Silverman (2003) argues that coaching is explicitly concerned with the development of employees’ skills and performance related with their present job responsibilities. The intermediate /senior engineers should teach or coach graduate step by step from mass balance, BFD, PFD, and P&ID.

2.9.2.2 Mentoring

Mentoring is more focused on exchanging the wisdom, instilling learning, providing support and guidance for career growth (Silverman, 2003). A mentor should be a person preferred by the graduate SAIMM (2012). The mentor should ensure that graduate/ mentee is progressing effectively per their deliverables through all the project phases. Such as mentoring them to design plants effectively and efficiently, compiling process descriptions, process design criteria, mass balance and equipment selection and sizing under the guidance of a mentor.
2.9.2.3 Rotation Exposure Experience Programme (REEP)

Job rotation is about the movement of staff between different job tasks over a period of time and this movement is planned to achieve different purposes (Bennett, 2003). Woods et al., (1995) defines job rotation as a methodical movement of employees from job to job or project to project within an organisation, to attain numerous human resources objectives such as improving career development and getting exposed to various work environments. Job rotation is valued by organisations that require firm-specific skills because it provides an incentive to organisations to promote engineers from within. Graduates must be allowed to start from the basic activities of design such as drawing office to acclimatise themselves with various types of drawing for instance, BFD, PFD, P&ID, GA and piping isometrics; then moved to the study group to know more about test works, pilot plant desktop studies; and further to designing division to learn about process selection, mass balance, equipment sizing and calculations regarding process.

2.9.2.4 Intercultural training

Del Vitto (2008) describes intercultural training as a training that provides individuals with indispensable information, assertiveness and skills to function efficiently in a country other than their own. Due to the limited procedural protocol and standardisation regarding cross-cultural training, organisation should develop and emphasise this training. The engineering field has grown significantly such that one engineer can design here in South Africa and send the calculations to offshore country for the development of piping and instrumentation drawings. The activity is quite simple when one tolerates and accepts other engineer’s cultures.

2.10 Duration of the graduate development program

SAIMM (2012) stated that any career development program should have a long-term objective and include time lines for tasks to be accomplished to attain the objective. Companies should provide an extensive time for skill practicing and suggest structured activities that would enhance the skills required for the graduates to effectively demonstrate the knowledge Woods et al., (1995). It has to be practiced many times to acquire the required skills and get guidance to improve their performance. Coaching program should be designed, conducted and completed within a year (Silva et al, 2014). Jenner (2008) argues that there should be a six-
monthly personal development review. Benefer (2007) indicates that the objective is to develop employees to their maximum capabilities, enable career progression, succession planning, and improve the performance of the organisation over the medium to a long term. Graduate programme should have a long-term objective, the duration could be as long as three to five years depending on the contents and understanding of the content by each graduate. Graduates should cover crucial part of activities and would have to reach a substantive position in the company’s process engineering structure that commensurate with the investment in the development programme.

A case study was conducted by O’Donnell et al., (2008) to describe the development of graduate engineers in a successful international engineering and construction organisation. Kentz Engineering and Construction Company, outlines the significance of mentoring, exposure by experiential learning using a process of rotation through various divisions, operations, and peer support within a formal socialisation and developmental process. Kentz engineering prefers this type of development programme with the period depicted on figure 8.

Figure 8: KENTZ graduate program model adapted from Connor & Shaw (2008)

Figure 8 describes the Kentz ideal process of developing the graduate engineers. The process begins with mentorship and coaching for about six months. It emphasizes the 18 months’ total duration and job rotation for engineers to be familiar with all the necessary activities associated with plant design, economic evaluations, quality, safety, procurement and commissioning.
2.11 CONCLUSION

This chapter provided the information about the type of skills graduate engineers need to design accordingly on their own with less supervision and on how to develop skills required for a graduate engineer. The chapter also defined the connections between engineering skills and engineering design. It has indicated the significance of understanding the application of those skills and the methods of acquiring them as well as the consequences if these methods are not performed properly.

The study provided valuable information regarding design engineering skills within the EPCM context. The engineering skills required for the design of the mineral processing plants are mainly communication, analytical, graphical and design skills. Most project delivery houses lack effective training programmes to ensure that their graduates are sufficiently skilled to design mineral processing plant’s projects successfully. From this reason, the study investigates how to develop the skills required for effective designing. The investigation identifies the important skills and suggests a method which ensures a proper development of design skills.
Chapter 3: Methodology

3.1. Introduction

The research method was required to attain an in-depth understanding required to know which activities are critical for graduate engineers to be responsible in designing mineral processing plants. This chapter covers research method in the analysis of technical and non-technical skills requirements as well as attaining an in-depth knowledge. Research methodology focuses on the research process and the type of the tools and procedures to be utilised (Van Wyk, 2013).

In addition, this chapter will also discuss research questions, research design, research method selected, data collection, data analysis and validity.

3.2 Case study definition

Case study is an orderly inquiry about the occurrence of related events which describe and explains the phenomenon of interest (Bromley, 1990). Yin (1984) defines it as an empirical inquiry investigation of contemporary phenomenon of the real-life issues, where and when the boundaries between issues and phenomenon are not clearly defined. Kumar (2011) states that case study provide as much information as possible to understand a certain issue in its totality.

Hartley (2004) describes a case study research as a detailed inquiry, frequently with data collected over a certain period about phenomena (within the context), to provide an analysis of the context and processes which provide information about theoretical issues being studied. In a case study design the ‘case’ selected becomes the basis of a thorough, holistic and in-depth exploration of the aspect(s) that need to be established. It is an approach in which a certain case or a few carefully selected cases are intensively studied (Gilbert 2008). Thomas (2011), states that case studies are analyses of persons, events, decisions, periods, projects, policies, institutions, or other systems that are studied holistically by one or more methods. He further alludes that the case that is the subject of the inquiry will be an instance of a class of phenomena that provide an analytical frame -an object - within which the study is conducted and which the case illuminates and explicates.
3.3 Advantages and disadvantages of a case study

The following are the advantages that the researcher should appreciate when adopting a case study method.

- A case study portrays real life situations involving decision making by participants using a set of questions or through interviews. A case study analysis requires you to investigate a business problem, examine the alternative solutions, and propose the most effective solution using supporting evidence.

- The case study is the most flexible of all research designs, allowing the researcher to retain the holistic characteristics of real life events whilst investigating empirical events (Schell, 1992). Yin (1984) states that case study investigate a contemporary phenomenon within real life contexts especially when there is unclear evidence between phenomenon and context.

The following are the disadvantages that the researcher should observe when using a case study method.

- Case study method has limited representatives due to narrow focuses, that makes generalization to be less considered (Farooq, 2013).

- Due to narrow study, the discrimination and bias can occur in the investigation (Farooq, 2013). Yin (1984) states that researchers do not always apply systematic process and are eventually biased and influence findings.

These points indicate that this method can provides an in-depth knowledge about the significance of developing technical and non-technical competences in designing mineral processing plants. Though the systematic process must be applied and adhered to in designing a good research, the advantages substantiate the need to apply case study as the research strategy chosen.

3.4 The case study against other research methods

The research design requires a choice of research strategy, a decision to use experimentation, survey methods, archival analysis, histories or case studies. Yin (2003) states that there are three conditions which could determine the type of research programme indicated: the type of research question; the degree of researcher control possible; and the degree of focus on contemporary events desired. Table 4 below provides an outline of the relative performance of each type of research strategy under each condition:
Table 4: Choosing research strategies (Yin, 1984)

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Form of research question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment</td>
<td>How, why</td>
</tr>
<tr>
<td>Survey</td>
<td>Who, what, where</td>
</tr>
<tr>
<td></td>
<td>How many</td>
</tr>
<tr>
<td></td>
<td>How much</td>
</tr>
<tr>
<td>Archival analysis</td>
<td>Who, what, where</td>
</tr>
<tr>
<td></td>
<td>How many</td>
</tr>
<tr>
<td></td>
<td>How much</td>
</tr>
<tr>
<td>History</td>
<td>How, why</td>
</tr>
<tr>
<td>Case Study</td>
<td>How, why</td>
</tr>
</tbody>
</table>

The above table indicates what type of research strategy can be selected based on the research questions the researcher asked. According to the table, questions that begin with *how* or *why* is usually exploratory and are more likely to be used on experiments, histories and case studies. Questions which start with “*who* or *where*” are used for survey or archival analysis.

Research questions in this research study were utilised to understand in detail how graduate engineers obtain required skills and what skills are required to be responsible in designing mineral process plants. The case study was selected as the method because the “*how*” research question was investigated and also by the fact that the case study is an ideal methodology when a holistic, in-depth investigation is required (Feagin et al., 1991). The selection of this research strategy to attain the objective of this study was further strengthened by the fact that the researcher investigates certain phenomenon with a group of people, and that the researcher does not have any control over the phenomenon investigated. This formed a basis of selection of the case study.

### 3.5 Reason for research method selected

The method applied for this research was based on a case study which employed questionnaires to gather relevant data. The background information from this case study and literature forms a basis of questionnaire for this research. Simons (2009) argues that a case study allows a researcher to acquire a comprehensive understanding of a certain issue in the context of an organisation’s life. This is one of the reasons a case study was selected as the research method to investigate the development of technical and non-technical capabilities for
graduate engineers to be responsible for design of mineral process plants in the context of EPCM project delivery organisations.

### 3.6 Case study procedure

Hartley (2004) defines research design as an argument for the logical steps which will be taken to link the research question(s) as well as issues to data collection, analysis and interpretation in a logical way. The systematic approach of developing a case study is based on the following six steps emphasized by Bhakogainnis, Siti, Vassi, Christodoulopoulou and Kyriakakis (2014) as depicted in figure 9.

Yin (1994) further elaborated on his research that a case study should have the following five components: The research questions, its propositions, unit of analysis, determination on how data will be linked to the propositions and criterion to interpret the findings.

![Case Study Steps Diagram](image)

**Figure 9: Case Study Steps (Bhakogainnis et al., 2014)**

**Step 1: Determination and definition of research questions** - The initial step in case study is to establish a focus to which the research will be based on as discussed in literature. This is conducted by developing questions about the situation to be investigated and subsequently determine the purpose of the study.

**Step 2: Select case study, data gathering and analysis** - The useful step in selecting case study is to repeatedly refer back to the purpose of the study in order to focus the attention on where to look for the cases that will satisfy the purpose of the study and answer the posed research questions. After case selection, the researcher should determine what evidence to gather and what analysis technique to use with data in order to answer research questions.
Step 3: Preparation of data collection - Systematical data collection is essential for the researcher to avoid overwhelming of huge amount of data and shifting away from the research purpose and questions.

Step 4: Data collection in the field - The researcher should collect document and archive sources of evidence systematically and comprehensively in way that they can be readily available for subsequent reinterpretation.

Step 5: Data assessment and analyzing - The collected data should be evaluated, and analyzed. The researcher examines data utilising various interpretations to find a link between research object and the outcome in relation to research questions.

Step 6: Preparation of the report - After data evaluation and analyzes, the researcher should report the data in way that is understandable to the reader.

The above steps are further defined on the next sub-section to indicate how they were executed in this research study to develop a proper case study.

3.6.1 Determination and definition of research questions

Research design is the logic that links the data to be collected to the initial questions of the study in order to draw an explicit conclusion regarding the investigated issue. The initial step in research begins with determining and defining research questions. The questions were formulated from the situation to be studied in relation to technical and non-technical competencies of graduate engineers on mineral process design. The case study explores if there is a link between technical, non-technical skills and an effective design of mineral processing plants in EPCM project delivery organisations. The literature review was considered as it establishes what similar researches have been previously conducted. Data that was collected to substantiate assumption that the performance of graduate in designing of mineral processing plants was affected by technical and non-technical competencies.

The questions for this study are:

- What skills or capabilities do graduate engineers need to be responsible for designing mineral processing plant’s projects?
- What activities should be carried out as an indication that graduates possess mineral process design skills?
- How will the organisation implement strategies to develop graduate engineers to be responsible in designing mineral processing plants?
Literature review was conducted based on the previously researched cases and views were acquired on what skills needed to design responsibly, how to get the required skills and how the organisations should instill the needed skills. The process of selecting the case, data gathering and analysis follow in the next section.

3.6.2 Select case study, data gathering and analysis

The third component in design of a case study is the unit of analysis which defines the case to be investigated, as the aim of this study is to attain various perspectives regarding the development of technical and non-technical competencies related to the design of mineral process plants in EPCM context.

The relevant data was gathered to investigate the relation between skills for graduates engineers and designing of mineral process plants. The following objectives were applied to provide details about the relationship of skills and design of mineral processing plants:

- To identify the relevant skills that can contributes to the effective and efficient design of mineral processing plants.
- To identify training approach to develop the desired skills to enable graduates to be responsible in design of mineral processing plants.

To ascertain the above, the following were utilised to ensure that the case has relevant data to gather:

- The mineral processing plant design training processes and system were in place during the development of skills to assess whether training was productive or unproductive for graduates engineers to be responsible in the design of mineral process plants in an EPCM project delivery organisation.
- Assessment of the literature’s preferred skill developing method for engineers to be responsible for designing of mineral processing plants.

Yin (2003) suggests that the following guidelines must be applied to ensure an appropriate case selection:

- Selection of a case should be done where relevant data required is easily accessed.
- It should be done where potential exists to derive data to respond to the research question.

3.6.2.1 Case Selected
The name of the case study organisation is undisclosed as other EPCM projects delivery competitors may get hold of this confidential information of the aforesaid organisation. The researcher has pledged to respect the confidentiality of this information by conforming to a non-disclosure agreement to avoid ramifications. The focus is based on the process that suites the study not the detailed results based on the processes. In terms of recognition regarding the case study, the organisation will be called company A.

The purpose of this section is to outline the case organisation and define how it develops the engineers on how to design mineral processing plant. The case study looks at the current methodologies applied for developing technical and non-technical competencies required for graduate engineers to design mineral processing plants responsibly without much supervision needed, in an EPCM project delivery organisations.

Responding to the research questions, the following criteria were used to ensure appropriate data collection:

- The development of technical and non-technical competencies should provide output that will bring either total success or failure, in developing the ability to design responsibly in connection to mineral process plant projects.
- The duration and program of the training should be completed to ensure that the study investigates if the development training is a success or not.

3.6.2.2 Selected Case brief description

Company A implemented training intervention whereby the senior engineers met with graduate and junior engineers at lunch break for an hour to prepare them on how to design mineral processing plant. However, each preparation session allowed all who were willing, not enforced to all the graduates and as a result others were better than their peers in terms of accumulating skills. Secondly, the training intervention was more into technical capacity instead of developing both technical and non-technical capabilities. The engineering division’s senior engineers of Company A were not satisfied with the outcome of training intervention. However, the training intervention was reviewed to accommodate the following points:

- All graduates (process design engineers) were asked to attend the training which will enable them to design responsibly with less supervision.
- Appointment of a mentor, mentorship training was to be conducted by external consultants to ensure that mentors well equipped and that job rotation was implemented.
- Development of a systematic approach to ensure that at the end of envisaged period, graduates are well versed with design and possess both technical and non-technical skills.
With the aforesaid changes, Company A reintroduced the training intervention whereby the consultants, senior and intermediate engineers were selected by the HODs (Head of departments) to focus on developing technical and non-technical competencies on graduate and junior engineers to design mineral process plants. The training intervention would have a timeframe, it would be monitored to ensure that after certain period graduates must be at a certain level of understanding the design processes and be able to design with less supervision.

3.6.2.2.1 Company A: Overview
Company A is an EPCM organisation, involved in designing mineral processing plants. All the mineral processing projects around the world are designed here in Company A - an RSA office - by a team of mineral processing plant design engineers. As stipulated on section above, the design team comprises multidisciplinary engineers, with an interdisciplinary approach to design a well-functioning mineral processing plant.

The technical and non-technical skills expected by company A are world class, which are supposed to be invested heavily on the graduates to keep the same level of competency with time. The primary intentions of the company are to ensure that senior engineers cultivate skills that help graduates and junior engineers to effectively design mineral process plants. Graduates are given exercises to develop mass balances, equipment selection and sizing, though this only happened when there were less projects at hand. Less time was dedicated by senior engineers to training of graduates and juniors especially when they were busy with projects. There was no “tailor-made” training to quicken the understanding and design capabilities of graduate engineers with a tangible outcome to show that the gap between intermediate engineers and graduate was closing or getting narrow. The mineral processing design is a complex activity that requires a remarkable technical and non-technical capacity, with knowledge of developing flow sheets of various commodities, an orthodox statistical approach that assists in the understanding of the design unit processes.

3.6.2.2.2 Company A’s engineering disciplines
Company A comprises various/multidiscipline engineering expertise to design mineral process design projects which include:

3.6.2.2.2.1 Process/Chemical Engineers
These engineers develop the following design criteria, equipment-sizing calculations, pipeline sizing calculations, then piping & instrumentation diagrams, process flow diagrams, utilities flow diagrams, mass balances and energy balances.
3.6.2.2.2 Civil and Structural Engineers
Civil and structural engineers develop structural and civil layouts, beams and supports to hold equipment for mineral process plants.

3.6.2.2.3 Mechanical and Piping Engineers
These engineers design systems, equipment and components for conveying material, energy and material flows and bulk material handling. They should have knowledge of Automatic Computer Aided Design, Computer Aided Design, Pro Engineer, Mathematic Computer Aided Design, and FEA (Finite Element Analysis) piping design.

3.6.2.2.4 Electrical Engineering, Control and Instrumentation Engineers
They study the design and application of electricity, electronics and electromagnetisms, control systems, instrumentation and microelectronics.

- **Power Engineer**: Works with electrical and designs electrical devices such as motors, transformers, generators and power electronics.

- **Control and instrumentation Engineer**: Deals with design of controllers that causes systems to behave in a certain manner utilising programmable logic controllers (PLC)/Human Machine Interfaces (HMI) for Supervisory Control and Data Acquisition (SCADA) in plant operation, digital signals processors and electric circuits. Together with process engineers, they develop control narratives and control philosophy to get the plant control such as level indicators, flow meters, weight meters, etc. working.

*The following are the supports for the engineers:*

3.6.2.2.5 Procurement Officer
Plans and coordinates the work of buyers and purchasing agents for all equipment.

3.6.2.2.6 Quality Manager
Devise and establishes the company's quality procedures, standards and specifications.

3.6.2.2.7 Risk Manager
Identifies, controls and mitigates all the risk associated with the project. The risk management is involved in development of Hazops and Hazids.

3.6.2.2.8 Draftsmen
Make detailed technical drawings for machinery, buildings, electronics, infrastructure, sections, etc. The drawings include technical details and specifications such as materials, dimensions and procedures.
Figure 10: EPCM business model by Kaleidoscopic (Chatapahya & Mo, 2010)

The multidisciplinary engineering fields must collaborate with other disciplines to ensure proper execution of an EPCM model (Chatapahya & Mo, 2010). EPCM engineers should be able to complete their deliverables on time, within budget and with expected quality of work. (Sridharan and Berry, 1990)
The case definition, brief description of the case, and what data was relevant to answer research question were defined. The method and techniques used to gather the data are describes in the next section.

3.7 Data Collection Protocol

There is a variety of data collection methods that can be used ranging from personal interviews, questionnaire, observations and postal surveys. Yin (2003) states that the benefits from the above-mentioned sources can be exploited by applying the following principles: creation of a case study database and maintaining a chain of evidence.

Data collection for this study was carried out in form of questionnaire, A questionnaire enables responses to be gathered from large numbers relatively quickly, and cost efficiently (De Vaus 1991). The questionnaire was administered by the researcher to respondents and duration of two weeks was given to ensure completion of the questionnaire by respondents. The permission was requested from the company through an authorisation letter, to link the online
questionnaire tool to their MS outlook. The questionnaire was compiled using “survey monkey” online assessment and was electronically distributed.

The questionnaire used is attached in Appendix B. A data base was developed by collecting evidence in order for the researcher to conduct data analysis. The raw data was not available for independent inspection by other researchers, as the researcher made a concession in section 3.10 due to ethical considerations made. The researcher maintained the chain of evidence to make sure that the case study report contained sufficient references of the relevant data sources collected. For instance, the database developed a reference to make certain that the evidence was from relevant documents specifies and the questionnaire.

3.7.1 Questionnaire design

Three questionnaire sections were designed for the purpose of developing technical and non-technical competencies for graduate engineers to be responsible in designing mineral processing plant. Section one required the respondents to provide the skills relevant for designing mineral processing plants. Section two, was about the activities that identify possession of skills in the mineral process plant design unit of the EPCM firm. Section three aimed at gathering more details on how the company can implement the development strategy of developing graduate engineers.

The questionnaire utilised to answer the research questions were derived from the literature review in the following manner:

RQ 1: What skills do graduate engineers need to successfully design mineral processing plants as part of mining projects

- Table 1 in literature review was used to develop research question 1.

RQ 2: What activities should be carried out as an indication that graduates possess mineral process design skills?

- Table 2 in the literature review was used to identify necessary activities for process-design engineers to acquire plant design skills

RQ 3: How would the organisation implement strategies to develop graduate engineers to be responsible in designing mineral processing plants?

- Sub-heading 2.9 “What organisation should do to provide the skills” from literature review was used to extract questions relevant for the research question 3.
3.7.1.1 The data was gathered using self-administered questionnaires, using the following procedures

The introductory consent letter (Appendix A) was sent via e-mail to recruit participants who were in mineral process plant design environment. The researcher informed the training and development division’s head, who in turn informed recruited participants and sent out the questionnaire mail to participants, including a link to the study’s questionnaire. The e-mail to all participants included:

- The purpose of the study, the name and particular of the researcher
- A request for their participation with confidentiality of clause
- A link to the online questionnaire, starting with the consent form.

The participants electronically signed the consent form when they follow the link to “monkey survey” and agreed to take part in the study. The survey was then automatically available to the participant.

3.7.1.2 Questionnaire Structure

Section I: Requirement of relevant skills

The requirement of relevant skills section of the questionnaire was specifically designed for graduate engineers to indicate what relevant technical and non-technical skills are essential to enable them to be responsible for designing mineral processing plants effectively and efficiently with less supervision from their superiors/seniors.

Section II: Activities that identify graduate engineers’ possession of relevant mineral process plant design skills.

The approach section of the questionnaire was constructed based on the findings from the literatures review. It included duration of development, activities engineer should demonstrate to ascertain possession of mineral process plant design skills, required design tools, and contexts in which the design tools are used.

Section III: Organisational approach in implementing training strategies

The organisational approach section of the questionnaire was constructed based on the findings from the literatures review. It included duration of the development, developmental plan, frequency of development activities, types of training methods, and contexts in which the training methods can be conducted.

Table 5: Questionnaire structure
**Questionnaire type** | **Questionnaire Purpose** | **References and Questionnaire Questions**
---|---|---
Confirm literature review about the skills that are not correctly structured by the company in relation to mineral process plant design. | To determine the skills developed are relevant for the graduates to possess a concrete knowledge and desired skills of designing. | Please refer to appendix B; Section 1 -
Confirm literature review about the necessary activities that identifies possession of relevant mineral process plant design skills. | Identify which activities to put in place for graduates to demonstrate required skills. | Please refer to appendix B; Section 2 -
Confirm literature review about the activities the organisations should implement to help graduates to attain required skills. | Identification of training methods which are relevant for developing design skills of graduate engineers in EPCM. | Please refer to appendix B; Section 3

### 3.7.1.2 Questionnaire response

The well-structured questionnaire utilised in this study have provided the participants with numerous options to respond. The respondents had to select one of the various answers as indicated in Error! Reference source not found.6 below. The reason for this method is to provide various options to articulate their response instead of the dichotomous type of question such as yes, or no.

**Table 6: Questionnaire responses table**

<table>
<thead>
<tr>
<th>Level of response</th>
<th>Not important</th>
<th>Slightly Important</th>
<th>Neither/Nor</th>
<th>Important</th>
<th>Very Important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratings</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

### 3.8 Population and demographics of participants

Burgess (2001) defines population as members of a group of people that the researcher has identified, selected with interest for the data collection. For this study, the participants were project managers, engineering managers and engineers (seniors, intermediate and juniors) of...
all disciplines involved in mineral processing plant design projects, in context of EPCM projects delivery organisation. The participants were selected based on their experiences. The study targeted engineers ranging from junior to senior engineers: 20 process engineers, 5 civil engineers, 5 mechanical engineers, 5 electrical engineers, 3 projects managers and 3 engineering managers. Some of the juniors’ engineers were exposed to training intervention, whilst others were not. The participation assisted in determining which skills are appropriate for the development of junior engineers.

Table 7: Participants demographics

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Number of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>20</td>
</tr>
<tr>
<td>Civil</td>
<td>5</td>
</tr>
<tr>
<td>Mechanical</td>
<td>5</td>
</tr>
<tr>
<td>Electrical</td>
<td>5</td>
</tr>
<tr>
<td>Control &amp; Instrumentations</td>
<td>5</td>
</tr>
<tr>
<td>Project Management</td>
<td>3</td>
</tr>
<tr>
<td>Engineering Management</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total Target</strong></td>
<td><strong>46</strong></td>
</tr>
</tbody>
</table>

3.8.1 Assumptions

Assumptions are issues which are under the researcher’s control but they should be highlighted, otherwise they would make the study irrelevant (Simon, 2011). Assumptions are important for the study, without appearing on the study then the research problem could not exist (Leedy & Ormond, 2010). In this study, the researcher assumed that the participants would collaborate to complete the questionnaire within specified conditions such as time, with honesty and confidentiality. The researcher further assumed that the respondents had experience in EPCM project’s delivery houses, have experience in designing mineral processing plants, possess appropriate qualifications and aware of the deliverables required to design mineral processing plants.

3.8.2 Delimitations

Delimitations are defined as characteristics which describe the boundaries used of the study, and limit the scope of the study (Simon, 2011). He further emphasises that delimitation on the study explicate the criterion used to choose participants, geographic area/location covered on the study, professions and the type of organisation involved. Due to time constraints in relation
to the distribution of the study, the researcher decided to restrict the distribution of the study to participants on one of the biggest EPCM project delivery organisation, which deals with design of mineral processing projects, globally. The organisation is based in Johannesburg, RSA.

3.8.3 Limitations

Limitations are factors which are beyond the researcher’s control that can have an impact on the research output. They are much helpful to address on the study as they imply that errors are prone to happen (Baron, 2008). Limitations are potential weaknesses which are beyond the researcher’s control (Simon, 2011).

Limitations that may have an impact on this study:

- Participants may respond bias in favour of a socially acceptable manner even though the questionnaire does not require disclosure of identity.
- The questionnaire may be perceived difficult by the participants.

The researcher noted that there might be a hinder, due to the unwillingness of the participants to disclose information with integrity, should that happen, it could weaken the study. The research focused on one EPCM organisation, however it is one of the biggest in that industry, and their mineral processing plant design division services their global clients.

3.9 Quality of the research

The quality measurements were considered during the design of the study using questionnaire to address quality of data. Moreover, measurement such as validity and reliability were considered. Validity has been defined as the extent to which a test is carried out to measure what it claims it is measuring (Gregory, 1992). Yin (2009) states that there are four tests to ensure validity of the study such as: constructs validity, internal validity, external validity and reliability. Kindder and Judd (1986) define validities as follow:

**Construct validity:** Establishes appropriate operational measures for the concepts to be studied. The researcher ensured that what to measure is in agreement with what the study anticipates measuring. The aim of the study was to identify proper development of technical and non-technical skills required for graduate engineers to be responsible in designing mineral processing plants. Literatures review was utilised by the researcher as a guideline to keep the research study intact in getting the in-depth understanding of why graduates with less
technical and non-technical competency struggle to be responsible in designing processing plants.

Cooper and Schneider (2003) state that validity can either be internal of external, as indicated below:

- **Internal validity**: Establishes a causal relationship whereby certain conditions are shown to lead to other conditions, as distinguished from spurious relationship. This type of validity is for casual studies only, not for exploratory or descriptive studies. Internal validity is irrelevant for this study as it is concerned with causal, for instance, where the research would like to find out if event Y leads to event Z.

- **External validity**: Establishes the domain to which the findings of the study can be generalised. The researcher is trying to generalise the study’s set of findings to some broader theory. Case study was done across the company with renowned reputation in designing mineral processing plant, with the assumption that the study can be generalised across other cases in various EPCM project delivery organisations.

**Reliability**: Demonstrates that the operations of a study such as data gathering procedure can be repeated, with the same results. Golafshani (2003) asserts that the reliability denotes a measurability of quality, to qualify the study as a good quality research study. For this study, a proper case study design and processes as indicated on section 3.6 were followed to minimise mistakes and biasness.

During data gathering a well-structured questionnaire and the case study data base were developed to ensure that if the same case can be studied using the same “documented” procedures, the next researcher can attain similar findings.

Golafshani (2003) defines reliability as an extent at which results over a certain period are consistent and accurately represent the entire population, he further suggested that if the results can be reproduced under the same methodology, then the research instrument is taken to be reliable. According to Yin (2009), there are three strategies for improving construct validity-using multiple sources of evidence: having key informants review the case, study report, and maintaining a chain of evidence. Case study tactics used in this study is specified on table 8.
Table 8: Case study tactics for four design tests (Yin, 2009)

<table>
<thead>
<tr>
<th>Test(s)</th>
<th>Case Study tactics</th>
<th>Sections of the research in which tactics applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construct Validity</td>
<td>Questionnaire for participants to respond to the study.</td>
<td>Data Collection</td>
</tr>
<tr>
<td>Internal validity</td>
<td>Pattern matching</td>
<td>Data analyzing</td>
</tr>
<tr>
<td>External</td>
<td>Literature review</td>
<td>Composition</td>
</tr>
<tr>
<td>Reliability</td>
<td>Use case study protocol. Develop case study data base</td>
<td>Data collection</td>
</tr>
</tbody>
</table>

3.10 Ethical Considerations

Kumar (2011) indicates that ethics consideration should include requesting the participants’ permission in advance and that they should express their willingness and informed consent. This research study considered all moral and legal issues in respect to the topic. All the participants’ identification and responses were anonymously kept. The online copies of the questionnaire completed were collected and stored without any intervention by the researcher. Data was stored to conduct basic statistical analysis, that data was stored on the researcher’s external storage data and kept for a period of six months after approval and publication of the dissertation, and then subsequent to that, it will be demolished.

Table 9: Ethical issue sourced from Hay (2003)

<table>
<thead>
<tr>
<th>Ethical issue</th>
<th>Questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access</td>
<td>Permission was sought from training &amp; development department to send the questionnaires to participants</td>
</tr>
<tr>
<td>Consent</td>
<td>Participants were invited to take part in the questionnaire. It was made clear that participation was voluntary.</td>
</tr>
<tr>
<td>Confidentiality</td>
<td>All questionnaires responses were anonymous. The data collected could not be traced back to a respondent.</td>
</tr>
<tr>
<td>Harm</td>
<td>It was made clear that there will be no harm to participant whether they partake or not.</td>
</tr>
<tr>
<td>Dissemination</td>
<td>The questionnaire was sent across in an electronic version using the survey monkey data collection tools.</td>
</tr>
</tbody>
</table>
3.11 Data analysis

This section also outlines the data patterns discussed in the previous chapter, to analyse each case study. Yin (2003) discusses the need for searching the data for patterns which may identify causal links in the data base. In this study, pattern matching was used as a technique during data analysis, where a set of results will be predicted and then compared to actual results.

Data from Company A, an EPCM company involved in mineral processing plant was compared to the literature theories to evaluate which of the skills, activities and training intervention are crucial for the development of technical and non-technical skills that are critical for the design of mineral processing plant. The researcher collected the data, dismantled it and re-constructed it again to categorise it. Categorising assisted the researcher to compares between patterns, to replicate certain patterns and complex threads of the data and make sense out of them. The questions were posed to which respondents answered in the form of a questionnaire. The results of the questionnaire were analysed to address the research question of the study. The analysis of the data was based on the following steps:

- Evaluation of the returned questionnaire and create an Excel database; Data codification
- Entering and cleaning of data; analyse data, tabulate and use of graphs for data interpretation.

Data collected were analysed after the researcher accepted the completed copies of the questionnaire from the participants. The analysis of the data relied on all the relevant evidence collected to address the research questions. The responses were analysed using the frequencies. The responses were assessed to ensure that the outcome is significant to the study. Microsoft excel was used for the data tabulation and processing. The responses were copied from each copy of the questionnaire to Microsoft excel spreadsheet and cleaned of duplication and errors.

3.12 Reporting

Stake (1995) states that case study is about a process of inquiry about the case and the product of that inquiry. Reporting a case study is about bringing the findings to closure. The report should focus the researcher’s views regarding future research to develop effective and efficient methods that can be used to develop technical and non-technical competencies for
graduate engineers to be responsible in designing mineral processing plants, in a context of EPCM project delivery organisations.

3.13 Conclusion

This section of the study focused on the definition of case study research methods definition and description of the case study methods. It explained the techniques, the pros and cons of this research method. Case study was developed to offer the researcher an in-depth understanding of the particular issue identified, two cases were selected to investigate the impact of possessing technical and non-technical skills in designing mineral processing plants.

The study suggested the idea of developing an effective technique to develop technical and non-technical capabilities of graduate engineers to be responsible in designing mineral processing plants. To ensure proper research, a case study research method was recommended whose techniques, tactics and components were applied to attain reliable outcome. Additionally, it focused on a case study as a research method and explained the process that a researcher must follow to ensure rigour and validity. The following chapter discusses the findings of the case study and provides basics for detailed discussion of results.
Chapter 4: Data Analysis and Interpretation

4.1 Introduction

The purpose of this chapter is to provide an analysis and interpretation of the data obtained from the questionnaire as described in chapter 3. Marshall and Rossman (1999) defined data analysis as the process of bringing a structured order and meaning to the collected data. The data analysis and interpretation have been guided by the conceptual structure as provided in Table 6 in Chapter 3. This chapter consequently presents the empirical results (quantitative) obtained from the responses provided by participants through “monkey survey” tool.

The questionnaire was designed on Surveymonkey.com, as discussed in Chapter 3. One of the options included limiting responses to only one person / email address; this option was chosen to ensure that one person could not submit more than one survey. It was not likely that the participants would be completing the survey from public computers, as the mails were sent to the domain of the EPCM organisation. This option was appropriate and it provided further security for the online collection. Participants were sent emails by the human resources (HR) division, email entailed introductory letter and the questionnaire. The respondents were given three weeks to complete the questionnaire.

This chapter also outlines the data patterns discussed on the previous chapter to analyse each case study. A pattern matching was applied as a relevant technique to compares a realistic-based pattern with a predicted one; if the patterns coincide, the outcomes could assist a case study to strengthen internal validity, as well as indicating the system which identify the trends on the cases. A comparative study between literature theories and the EPCM mineral process plant design project delivery organisation was conducted to realise the desired skills essential for graduate engineers to be responsible in design mineral processing plants.

4.1.1 Reporting and Analysing of the data

Data from the structured questionnaire issued through the “Survey Monkey” tool which was organised into categories based on the descriptive analysis from research questions. Zikmund (2003) describes descriptive analysis as the transformation of raw data into a form that will make them easy to understand, interpret, re-arrange, order, and manipulate to generate descriptive information.
4.1.2 Respondents

The inclusion criteria for the sample consisted of graduate, intermediate, senior, principal and managers currently working in mineral processing plants design projects in EPCM projects delivery organisations. A breakdown of the questionnaire was carried out according to their involvement in EPCM’s mineral process design and experience categories as shown in Table 10. As previously indicated on table 7, the target was 46 participants, but only 20 responded. The response rate was \((20/46) \times 100 = 43\%\), which is an acceptable response for this research. For the purpose of conformity during the analysis, the 43% response rate is interpreted to be equal to a total of 100% respondents as a baseline, meaning the 20 people responded is taken as 100%, for instance should only 10 respond the same, that will be taken as 50% response.

Table 10: Demographic profile of respondents

<table>
<thead>
<tr>
<th>Categories</th>
<th>Total number of respondents per question</th>
<th>Response rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Involvement in mineral process plant design</td>
<td>20</td>
<td>90% (Yes) and 10% (No)</td>
</tr>
<tr>
<td>Duration in which a participant was involved in the design of mineral processing plants</td>
<td>20</td>
<td>10% (0 to 1 year) 35% (1 to 5 years) 30% (5 to 10 years) 25% (10 to 15 years) 0% (More than 15 years)</td>
</tr>
<tr>
<td>Position held within the mineral processing plant design environment in an EPCM project delivery organisation</td>
<td>20</td>
<td>20% (Graduate) 30% (Intermediate) 40% (Senior) 0% (Principal) 10% (Manager)</td>
</tr>
</tbody>
</table>

Table 10 indicated that out of 20 participants, 18 were the respondents who are involved with mineral processing plant design, 2 of the respondents were involved in petrochemical refineries’ design, that is \(18/20 \times 100 = 90\%\) and \(2/20 \times 100 = 10\%\).

Results related to the question regarding the duration in which participants were involved in designing mineral processing plants: 10% indicated that they have zero to one year experience, 35% fell under 1 to 5 years range, 30 % fell under 5 to 10 years range, whilst 25% of the respondents fell under 10 to 15 years. No one from the respondents had more than 15 years’ experience within the mineral process design environment. It was concluded that the 10% which has 0 to 1 year is the same 10% which indicated that they are were not involved in mineral process plant design.
The response in relation to the positions held within the mineral processing plant design environment indicated on table 10 indicated that 20% were the graduates, 30% intermediate, 40% are seniors and 10 percent are managers. The results indicate that the 10% which was not involved in mineral process responded indicating their positions in the entire process plant design department which is made of two divisions; mineral processing plant design and petrochemical plants design.

4.2 Case study data results

4.2.1 Descriptive analysis of the collected data

From the questionnaire responses, basic statistics were obtained in terms of percentages for assistance in understanding the meaning of the data being analysed.

4.2.1.1 Graduate development duration

Twenty participants who responded to the questionnaire indicated the number of years the engineering graduates should be involved in the development program prior to being active in designing mineral processing plants in EPCM project delivery organisation as depicted on Figure 11. From the survey, 10% of the participants felt that one year is sufficient, 50% felt that two years is enough, 20% said 3 years, 15% indicated that 5 years whilst 5% stated that if graduates cover all the syllabus which covers every subject deemed to be essential for the development of technical and non-technical skills it will enable graduates to be responsible for the designing of mineral processing plants. The following figure depicts the percentage of responses by the participants.

![Recommended Duration for training](image)

**Figure 11: Training Development Programme Duration**
4.2.1.2 Positions of the participants involved in designing mineral processing plants in an EPCM environment

![Position of Participants](image)

**Figure 12: Positions held by participants**

Figure 12 depicts that 20% of the respondents were graduates, 30% were intermediate engineers, 40% were senior engineers and 10%, none of the principal engineers as the results indicates 0% on that category.

4.2.1.3 Skills required for graduates to be responsible in designing mineral processing plants

For successful integration of graduate engineers into the field of mineral processing plant design, it was vital to know how important it is for graduates to possess the required skills for design. Twenty participants responded to the survey and this is depicted in Table 11. Twenty as a number of participants was regarded as hundred percent for this research, that is, one participant responded it was taken to be five percent (5%), two participants as (10%), that means one additional participant is equivalent to 5% increase. Process plant design environment requires certain skills from graduates to take part in designing projects. The graduates should apply the skills they learnt from the higher institution of learning, for them to easily acclimatisate and conduct basic activities expected by their seniors.

On Table 11, 12, 13 and 14, the researcher considered the combined result of sole both variables (important + very important) “yellow highlighted only”, not the combined result of all variables such as (not important, slightly important, neither/nor) with (important + very important). The reason being that, this research focused on what the participants considered
crucial for graduate engineers to build a combination set of skills, of which some is specialised, to become responsible for design of mineral processing plants.

Table 11: Responses from participants with regards to skills required

<table>
<thead>
<tr>
<th>Description</th>
<th>Not Important</th>
<th>Slightly Important</th>
<th>Neither /Nor</th>
<th>Important</th>
<th>Very Important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic mathematics and engineering design calculations</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>20%</td>
<td>80%</td>
</tr>
<tr>
<td>Knowledge of thermodynamics &amp; mechanics</td>
<td>25%</td>
<td>5%</td>
<td>10%</td>
<td>40%</td>
<td>20%</td>
</tr>
<tr>
<td>Knowledge of heat &amp; mass transfer</td>
<td>0%</td>
<td>0%</td>
<td>10%</td>
<td>35%</td>
<td>60%</td>
</tr>
<tr>
<td>Knowledge of standards, procedures, safety, liabilities and ethics</td>
<td>0%</td>
<td>5%</td>
<td>10%</td>
<td>25%</td>
<td>60%</td>
</tr>
<tr>
<td>Application of engineering design tools such as CAD, Visio, etc.</td>
<td>0%</td>
<td>30%</td>
<td>5%</td>
<td>50%</td>
<td>15%</td>
</tr>
<tr>
<td>Application of conducting cost estimation for processing plants</td>
<td>0%</td>
<td>20%</td>
<td>10%</td>
<td>40%</td>
<td>30%</td>
</tr>
<tr>
<td>Exposure to mineral processing plant environment</td>
<td>0%</td>
<td>0%</td>
<td>5%</td>
<td>15%</td>
<td>80%</td>
</tr>
</tbody>
</table>

The results are focused on the important and very important as such they will be combined and considered to be critical for this research. 20 participants of the targeted 43 responded and for this research, 20 participants were regarded to be 100%, for instance, a participant was taken to be 5%, 2 participants to 10%, that means the increment of 1 participant was conspired to be 5% of the previous percentage, therefore 3 respondents make 15%, etc. In addition, the results combine (important + very important) level of significance to be considered as one answer, and that combination must be equal and above 80% to be considered critical, if less than 80%, then it is not considered.

The percentages depicted on Table 11 represent the percentages of respondents. It was observed that 100% of the respondents selected basic mathematics and engineering design calculation as critical. Knowledge of Thermodynamics and mechanics were chosen by 60% which is less than the desired 80%, therefore it is deemed to be not crucial. Knowledge of conducting mass and heat transfer is one of the very important skills as 90% of respondents regarded it as very important.

Knowledge of standards, procedures, safety, liabilities and ethics, was selected by 85% as crucial. Application of engineering design tools such as CAD, Visio, was regarded by 65% as critical. Costing for process plant by graduates, 70% of respondents rated it as crucial,
however, it is less than the desired 80%, and therefore considered not critical. An exposure to mineral processing plant environment is regarded as a critical by 80% percent of the respondents.

4.2.1.4 Activities to be carried out for the development of graduate in mineral process plant design

Table 12: Responses with regards to activities to be executed

<table>
<thead>
<tr>
<th>Description</th>
<th>Not Important</th>
<th>Slightly Important</th>
<th>Neither /Nor</th>
<th>Important</th>
<th>Very Important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is it vital for graduates’ process engineers to possess knowledge in operating pilot plant? If so how important?</td>
<td>0%</td>
<td>0%</td>
<td>15%</td>
<td>45%</td>
<td>40%</td>
</tr>
<tr>
<td>Development of equipment specification by all involved in process plant design</td>
<td>0%</td>
<td>10%</td>
<td>5%</td>
<td>25%</td>
<td>60%</td>
</tr>
<tr>
<td>For C&amp;I graduates, how important is the knowledge of process control systems?</td>
<td>0%</td>
<td>5%</td>
<td>0%</td>
<td>30%</td>
<td>65%</td>
</tr>
<tr>
<td>Graduates process engineers for knowledge of alternative processes</td>
<td>0%</td>
<td>10%</td>
<td>5%</td>
<td>60%</td>
<td>25%</td>
</tr>
<tr>
<td>Knowledge of equipment selection and sizing</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>45%</td>
<td>55%</td>
</tr>
<tr>
<td>Knowledge of sizing process piping system</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>40%</td>
<td>60%</td>
</tr>
<tr>
<td>Knowledge of distribution by graduates electrical engineers.</td>
<td>0%</td>
<td>0%</td>
<td>10%</td>
<td>40%</td>
<td>50%</td>
</tr>
<tr>
<td>Knowledge of procurement, when designing &amp; constructing a process plant.</td>
<td>0%</td>
<td>30%</td>
<td>5%</td>
<td>40%</td>
<td>25%</td>
</tr>
</tbody>
</table>

The respondents rated knowledge of operating plant as critical at 85%. Development of equipment specification by all involved in process plant design is considered to be crucial by 85% of respondents.

Respondents regarded process control systems knowledge by C&I graduates as crucial at 95%. Alternative process selections knowledge by graduate process engineers, 85% regarded as critical. Knowledge of equipment sizing and selecting was regarded by 100% of respondents, as crucial. Sizing process piping was selected by 100% of respondents as critical. For graduate electrical engineers' knowledge of electrical reticulation, 90% chose it to be crucial. Knowledge of procurement by graduates when designing, 65% regarded it as crucial, which is less than the desired 80% response so it is considered not crucial for this research.
4.2.1.5 Cognitive skills required from graduates in mineral process plant design

Table 13: Responses with regard to cognitive skills required

<table>
<thead>
<tr>
<th>Description</th>
<th>Not Important</th>
<th>Slightly Important</th>
<th>Neither/Nor</th>
<th>Important</th>
<th>Very Important</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Application of communication &amp; interpersonal skills.</td>
<td>0%</td>
<td>5%</td>
<td>5%</td>
<td>35%</td>
<td>55%</td>
</tr>
<tr>
<td>2. Ability to influence decisions when designing.</td>
<td>0%</td>
<td>20%</td>
<td>15%</td>
<td>35%</td>
<td>30%</td>
</tr>
<tr>
<td>3. Ability to solve design related problems.</td>
<td>0%</td>
<td>10%</td>
<td>5%</td>
<td>30%</td>
<td>55%</td>
</tr>
<tr>
<td>4. Ability to manage design information</td>
<td>0%</td>
<td>25%</td>
<td>10%</td>
<td>20%</td>
<td>45%</td>
</tr>
<tr>
<td>5. Presentation skill</td>
<td>0%</td>
<td>5%</td>
<td>15%</td>
<td>25%</td>
<td>55%</td>
</tr>
<tr>
<td>6. Negotiation skill</td>
<td>0%</td>
<td>25%</td>
<td>20%</td>
<td>30%</td>
<td>25%</td>
</tr>
</tbody>
</table>

Participants rated the skills in Table 13 as follows: communication and interpersonal skills were rated by 90% crucial. An ability to influence decision during design as a graduate, also crucial at 65%, however less than the required 80%, then for this research it is not rated as crucial. Ability to solve design related problem was rated by 85% as crucial. For the ability to manage design information 65% respondents regarded it as crucial, but it is less than the required 80%, therefore, it is not taken as crucial for this research. Presentation skill 80% of respondents rated as a crucial skill. Negotiation skill, 55% of respondents regarded it as crucial, however, the expected rate must be 80% to be considered essential for this research.

4.2.1.6 Strategies EPCM project delivery organisations can implement to develop graduate engineers in designing of mineral processing plants

Table 14: Responses with regards to strategies to be implemented

<table>
<thead>
<tr>
<th>Description</th>
<th>Not Important</th>
<th>Slightly Important</th>
<th>Neither/Nor</th>
<th>Important</th>
<th>Very Important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mentoring of graduates to acquire technical and non-technical skills needed to design.</td>
<td>0%</td>
<td>5%</td>
<td>0%</td>
<td>10%</td>
<td>85%</td>
</tr>
<tr>
<td>Opportunities for continuous professional development (CPD) trainings.</td>
<td>0%</td>
<td>5%</td>
<td>10%</td>
<td>40%</td>
<td>45%</td>
</tr>
<tr>
<td>Job rotation system for graduates that ranges from testwork, design, commissioning, optimizing and operating).</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>20%</td>
<td>80%</td>
</tr>
</tbody>
</table>

From the results as shown in Table 14, percentages of respondents were as follows: mentoring for graduate to obtain technical and non-technical skills required to design (95% regarded it as critical for this research. Training based on continuous professional development (CPD) points system (45% of respondents rated as very important, 40% as
important, 10% were not sure and 5% regarded it as slightly important), so 85% of the respondents considered it to be essential. Job rotation system that ranges from test work, design, commission and (plants) operation (80% rated it as very important and 20% as important).

4.2.2 Interpretation of data

4.2.2.1 Results for skills, activities and strategies to be implemented in designing mineral processing plants

The results indicate that not all the skills, activities and strategies mentioned in the literature review are very significant for the design of process plants by graduates.

4.2.2.1.1 Skills

The literature review indicated that understanding the basic science such as thermodynamics and mechanics is essential for the design of the processing plants, whilst the results show the contrary as 60% of the respondents deemed it to be important as the number is lower than the acceptable 80%. The literature review stated basic mathematics and engineering science (design calculations) as critical and the results correspond with the literature as 100% of the respondents deemed these skills as significant.

Results indicate that the knowledge about mass and heat transfers was significant as 90% of respondents believed it to be a critical skill which is required to design. The results stated that 85% of participants considered knowledge of standards, procedure, safety, liabilities and ethics as crucial as stated in literature. 95% regarded an exposure to mineral processing plants' environment as vital for graduates in designing, which is in support of the literature.

The literature indicates importance of designing for cost and conducting of cost estimation by the graduates for the process plants design, but the results are to the contrary as 70% of the participants considered these skills inessential on the level of a graduate. Designing for cost and conducting of cost estimation scored less than 80%, therefore results do not consider these skills as critical.

Results do not affirm literature as 65% of the participants considered that graduates are not supposed to apply engineering design tools such as CAD, Visio, therefore it is not taken as critical for graduates to design mineral processing plants. The literature indicated the significance of operating skill such as knowledge of operating process unit, technology during execution of the process plant projects. The results indicate that 95% participants were in
support of graduates being exposed to the mineral processing plants environment. Literature indicates that application of communication and interpersonal skills are important and the sentiments are supported by results as 90% of the participants deemed these skills as critical. Results showed that at graduate level the ability to influence design decisions is not important, whilst the literature stated the contrary. An ability to solve design related problems is vital for graduate engineers to design plants, the literature is supported by the results as 80% selected it as critical. Literature stated that an ability to manage design information is vital whilst results stated opposite as 65%, therefore, for this research was deemed to be not-crucial. Presentation skill is supported by results as 80% deemed it to be crucial, it supports the literature. At a level of a graduate negotiation skills were deemed as not crucial since only 55% of the participants considered it to be crucial.

Table 15: Literature and results comparisons for skills

<table>
<thead>
<tr>
<th>Description</th>
<th>Literature</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic mathematics and engineering design calculations</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Knowledge of thermodynamics &amp; mechanics.</td>
<td>✓</td>
<td>Rated very low by participants</td>
</tr>
<tr>
<td>Knowledge of heat &amp; mass transfer.</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Knowledge of standards, procedures, safety, liabilities and ethics</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Application of engineering design tools such as CAD, Visio.</td>
<td>✓</td>
<td>Rated very low</td>
</tr>
<tr>
<td>Application of conducting cost estimation for processing plants</td>
<td>✓</td>
<td>Rated very low by participants</td>
</tr>
<tr>
<td>Exposure to mineral processing plant environment</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Application of communication &amp; interpersonal skills.</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Ability to influence decisions when designing.</td>
<td>✓</td>
<td>Rated very low by participants</td>
</tr>
<tr>
<td>Ability to solve design related problems.</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Ability to manage design information</td>
<td>✓</td>
<td>Rated very low by participants</td>
</tr>
<tr>
<td>Presentation skill</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Negotiation skill</td>
<td>✓</td>
<td>Rated very low by participants</td>
</tr>
</tbody>
</table>
4.2.2.1.2 Activities

Activities to be carried out were listed in the literature survey, the literature indicated that it is vital for graduates’ process engineers to possess knowledge in operating pilot plants; it was supported by the results as 85% of the participants regarded that as critical. Development of equipment specification by all involved in process plant design was regarded by 85% as critical and the importance of knowing the process control systems were regarded by 95% of participants as critical.

Literature indicated that graduate process engineers should have knowledge regarding the selection of an alternative processes when designing, and that was substantiated by the results as 85% of the participants felt it is crucial. Results supported the literature since 100% of the participants felt that knowledge of electrical distribution by graduates’ electrical engineers, knowledge of equipment selection and sizing are vital in designing of mineral processing plants. The results indicate a low response of 65% which is contrary to the literature. Literature indicates that knowledge of procurement, when designing and constructing a process plant as important.

Table 16: Literature and results comparisons for activities

<table>
<thead>
<tr>
<th>Description</th>
<th>Literature</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge in operating pilot plant? If so how important?</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Development of equipment specification</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>For C&amp;I graduates, how important is the knowledge of process control systems?</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Graduates process engineers for knowledge of alternative processes</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Knowledge of equipment selection and sizing</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Knowledge of electrical distribution by graduates’ electrical engineers.</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Knowledge of procurement, during design &amp; construction of a plant.</td>
<td>✓</td>
<td>Rated very low by participants</td>
</tr>
</tbody>
</table>

4.2.2.1.3 Strategies to be implemented

Results affirm the literature that mentoring of graduates to acquire technical and non-technical skills needed to design is crucial in development of graduates, 95% participants felt that mentoring is vital. 100% of participants felt that Job rotation system for graduates that range
from (test work, design, commissioning, optimising and operating). The other one is that graduate engineers must attend training which provide continuous professional development (CPD) points that are recognised by the professional bodies such as ECSA, the participants agreed with the literature as 85% agreed, though is the least amongst the three.

**Table 17: Literature and results comparisons for training strategies**

<table>
<thead>
<tr>
<th>Description</th>
<th>Literature</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mentoring of graduates to acquire technical and non-technical skills needed to design.</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Opportunities for continuous professional development (CPD) trainings.</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Job rotation system for graduates that ranges from (test work, design, commissioning, optimizing and operating).</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

4.2.4 Theorisation of new information

The results confirmed the problem statement that graduates who are trained, coached and mentored by senior engineers build skills, which enable them to become responsible for design of mineral processing plants. EPCM project delivery organisations should provide training and development that promote mentoring of graduates by seniors on their engineering disciplines. Job rotation system is critical for ensuring graduates are getting exposed to various roles from test work, experimenting, pilot plant operation, preliminary process selection, designing with comprises various stages conceptual, prefeasibility, feasibility and designing, commissioning and optimization. The organisations must ensure that career development program is effectively and efficiently structured for graduates to learn appropriate skills and conduct proper activities that will enhance their chance of being responsible in designing mineral processing plants.

In the mineral processing plant design division, the division looks for graduates who have the basic skills and desire to move up the career path. Senior engineers should discuss these qualities with them and mentor them to gain more skills, discuss opportunities that may arise and help steer them toward those opportunities. The division should do a lot of training, to aid seniors to recognise useful traits desirable for mentoring graduates to develop desired skills for designing. Seniors must begin this process very early in a graduates’ career and training should be aligned with the career paths to develop essential skills for EPCM organisations’-careers.
Chapter 5: Conclusion and Recommendations

This chapter presents the aim of the study, the findings of the study, conclusions and recommendations.

5.1 Introduction

The purpose of this research is to identify skills which should be developed through the engineering graduate development programme in context of mineral processing plant design projects for graduates to complete their design work on time within budget whilst monitoring quality. Furthermore, the research explored the training strategies in place at EPCM project delivery organisation to develop graduate skills and carry-out activities. The results indicate the skills, activities and strategies are significant. This chapter verifies whether the research served its purpose.

5.2 Results

The research objectives were to identify skills required for graduate engineers to be responsible in designing of the mineral processing plants, identify activities to be carried out by graduates to demonstrate skills possessed and selection of the tailored training intervention that will nurture the developed skills. There is a correlation on the skills, activities and training programme. If there are no skills acquired in relation to processing plants’ design, graduates will not understand what activities to conduct for designing mineral processing plants, thus is the consequence of the improperly structured training and development programme.

The research results confirmed that graduate engineers need to build a combination set of skills, of which some is specialised, to become responsible for design of mineral processing plants. However, the comparative study between literature and industry indicated that not all the skills, activities and development strategies are important in addressing the frequent problems experienced on mineral processing plant design environment, as some skills are of secondary importance in designing mineral processing plants.

To answer the research question 1: What skills do graduate engineers need to successfully design mineral processing plant’s as part of mining projects?

The results indicate that the following skills as listed per their significance:
1. Basic mathematics and engineering design calculations were rated as first crucial skill because 100% of participants deemed it to be vital.

2. An exposure to mineral processing plant’s environment was regarded as the second crucial by 95% of respondents.

3. Ability to conduct mass and heat transfer ranked third as 90% of the participants regarded it crucial.

4. Knowledge of standards, procedures, safety, liabilities and ethics related to processing plants’ design was rated fourth crucial skill by 85% of participants.

The following were not considered to be essential for this research as they accumulated less than the desired 80% of the participants.

5. An ability to conduct cost estimation for process plants when designing, at a graduate level, was rated the fifth crucial skill and it has accumulated 70% respondents. It was deemed unnecessary for this research

6. An ability to apply engineering design tools such as CAD, Visio. The participants rated this skill as the sixth crucial, however, only 65% responded which make it insignificant and invalid for this research.

7. Knowledge of thermodynamics and mechanics for the design of mineral processing plants, only 60% responded and that made it to be disregarded since it is less than the required 80%, so it was rated seventh crucial, basically is not required for this research.

For non-technical skills such as cognitive, results show that an ability to solve design problems, communication, interpersonal and presentations skills are very critical in designing. This is supplemented by (Van der molen, et-al, 2007) who indicates that engineers naturally possess technical skills but majority lack interpersonal skills

Non-technical skills required for graduates to design, the participants rated as follow:

1. An ability to communicate and application of interpersonal skills within the design team. These skills were rated as the first crucial, 90% of the participants deemed these skills as crucial.

2. An ability to solve design related problems was deemed to be the second crucial as it attained 85% response from the participants.

3. Presentation skill obtained 80% response which made it the third crucial non-technical skill required in designing mineral processing plants.

The following achieved less than the desired 80% response:
4. An ability to influence decisions when designing and ability to manage design information were both rated as forth crucial skills (they both achieved 65% from the participants).

5. Only 55% of the participants regarded the possession of negotiation skill by graduate engineers as critical. However, for this research it was disregarded and taken to be insignificant.

In response to research question 2: What activities should be carried out as an indication that graduates possess mineral process design skills?

The following activities were rated:

1. Knowledge of equipment selection, equipment sizing and pipe system sizing were regarded as the first crucial activities. They accumulated 100%.

2. Knowledge of process control systems by control and Instrumentation’s graduate engineers, attained 95% response, which made it second crucial activity.

3. Knowledge of electrical distribution by graduate electrical engineers was rated third by participants as it got 90% response.

4. Development of equipment specifications and pilot plant operation were rated the forth significant activity, as they both obtained 85% response from the participants.

All the above will assist graduate engineers to develop piping & instrumentation diagrams, process control narratives, general arrangement and finalisation of the plant layout. The following were not considered to be essential for this research as they accumulated less than the desired 80%, response from the participants.

5. Knowledge of procurement, when designing and constructing as a graduate engineer, was rated low at 65% which made it insignificant and void for this research.

To answer research question 3: How would the organisation implement strategies to develop graduate engineers to be responsible in designing mineral processing plants?

Lastly, the research results identify the following training strategies:

1. Job rotation from testwork, design, commission and optimisation was rated as the first crucial, 100% of participants deemed it as significant for graduates to be responsible in designing mineral processing plants.

2. Mentoring and attending of Continuing professional development (CPD) trainings were allocated 95% by the participants. That made them to be joint second crucial training and development approach for the development of technical and non-technical skills that should be possessed by the graduates in designing mineral processing plants.
5.3 Recommendations

The focus of the recommendation is to suggest a strategy on how to develop significant skills for graduates to design mineral processing plants effectively and efficiently. In order for proper development of skills, there should be appropriate identification of activities’ to be conducted by graduates’ engineers. However, it is imperative to apply mentoring and training based on continuous professional development courses with points accumulation system. This will assist graduate engineers to build a combination set of skills, of which some is specialised, to become responsible for design of mineral processing plants.

The literature review indicated a number of skills, activities and developmental strategies for the graduates in mineral processing plant design; however, the results indicated that not all the skills, activities and developmental strategies are crucial or equally significant for the designing of process plants. The results indicated that for successful integration of graduate engineers in the field of mineral process plant design in an EPCM project delivery organisation, graduates require skills that will enable them to be responsible in designing mineral process plants, the participants indicated the following in relation to the skills needed, activities and training strategy.

For non-technical, communication and interpersonal skills are critical. Communication skill is a significant component in the training of engineering students to facilitate not just students’ education but also prepare them for their future careers (Reimer, 2007). Shwon et al.,(1999) state that engineering designers communicate with clients, experts, teammates, seniors and superiors to improves the quality of the design. In addition, communication skills articulate the goals and refine the engineering designer’s thinking. Communication skill is a significant component in the training of engineering students to facilitate not just students’ education but also prepare them for their future careers (Reimer, 2007)

Table 18: Recommended skills, activities and appropriate approaches

<table>
<thead>
<tr>
<th>SKILLS</th>
<th>ACTIVITIES</th>
<th>DEVELOPMENT STRATEGIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Skills</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basic mathematics and engineering design calculations</td>
<td>Equipment selection and sizing</td>
<td>Training, mentoring and job rotation</td>
</tr>
<tr>
<td>Engineering sciences: Mass transfer and heat transfer</td>
<td>Process pipe sizing</td>
<td>Training, mentoring and job rotation</td>
</tr>
<tr>
<td>Specific knowledge in a professional environment: To know procedures, standards, technologies, safety, intellectual</td>
<td>Knowledge of electrical distribution, by electrical engineering graduate.</td>
<td>Training</td>
</tr>
<tr>
<td>properties, liabilities and ethics.</td>
<td>Knowledge of process control system, by C&amp;I graduate engineer. Development of equipment specifications</td>
<td></td>
</tr>
<tr>
<td>----------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Operational-skills: Exposure to mineral processing plants. Execution and practice process design.</td>
<td>Pilot plant operation Industry plant operation Job rotation</td>
<td></td>
</tr>
<tr>
<td>Non-Technical</td>
<td>Communication skill. Interpersonal skill. An ability to resolve design related problems. Presentation skill</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Process alterations by process engineers Mentoring and CPD training.</td>
<td></td>
</tr>
</tbody>
</table>

Possession of inappropriate skills by graduate engineers involved in designing mineral processing plants, in EPCM project delivery organisations contributes to graduates not being maximally responsible in designing and requires supervision from their superiors. Thus, development plan needs be bared under taken to improve the current situation. In this regard, this research recommended that the EPCM organisations should put a plan in place and communicate a clear vision to all processing plant design engineers.

The figure 12 depicts the recommended training structure based on the results given by the participants. The results indicated a preferred two years of training. The researcher distributed the two years as indicated in figure 12. The skills and activities are the selected by the participants to assist the graduate engineers to build a combination set of skills, of which some is specialised, to become responsible for design of mineral processing plants.
For integration of graduates engineers into the field of mineral processing plants' design. One should have a BTech, BSc or BEng.

**Figure 13: Recommended training and development plan**

- **Engineering Graduate**
  - **Start**
  - **Integration on mineral process plant design**
    - **Mentor/Mentee Meeting**
      - Seniors
      - Intermediates
      - Graduates
    - **Non-Technical**
      - Communication skills
      - Interpersonal skills
      - Presentation skill
    - **Technical**
      - Basic Mathematics
      - Engineering design calculations.
      - Mass & heat transfer calculation.
      - Standards, procedures, safety, ethics and liabilities
    - **Exposure**
      - Pilot plant operation (1 Month)
      - Industrial plant operation (3 Months)

- **Activities**
  - Equipment selection & sizing
  - Process piping system sizing
  - Non-Technical
  - Communication skills
    - Plant design
  - Career planning
- **Others**
  - Process engineering graduates: process alterations
  - C&I graduates: apply process control systems knowledge
  - Electrical engineering graduates: apply electrical distribution

**Syllabus:**
- Technical skills, non-technical skills, all the activities essential for designing processing plant
5.4 Limitations

The expected number of respondents could not be attained because the targeted EPCM project delivery organisation restructured and reduced numbers of mineral processing plant design engineers. Only forty three percent of the expected participants completed the research questionnaires.

5.5 Future Research

Further research on developing technical and non-technical skills of graduates’ engineers in EPCM project delivery organisations can be conducted. It should also compare skills competencies of graduate engineers against other South African based EPCM project delivery companies in determining the training priorities. Similar research could help other companies that experience technical and non-technical skills shortages so that all EPCM project delivery organisations may learn from the research and will be able to apply recommended strategies to address technical and non-technical skills/competencies shortages. Future research may include the following:

- The roles of South African institutions of higher learning and metallurgical research institutions: To include mineral processing plant design specific modules on their curriculum for preparation of graduates in mineral process design work to possess technical and non-technical skills required to execute the work prior joining the EPCM project delivery organisations.
- The enhancement of employee engagement among EPCMs mineral processing plant design engineers, ranging from graduates to principals.
- The effectiveness of Engineering Council of South Africa in mineral processing plant design specifically in EPCM project delivery organisation’s environment.
- The research must be extended to all big EPCM companies based in RSA, it should be enlarged to all disciplines and discipline specific skills.
6. REFERENCES


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Appendix A: Participants Request Letter

QUESSIONNAIRES COVER LETTER

Dear Participant,

This correspondence is to request your participate in a research study about the "development of technical and non-technical skills for engineers to design mineral processing projects - in Context of EPCM organizations", conducted by Tshepisio Banda, a masters (in Engineering Management) candidate at University of Johannesburg. The purpose of the study is to explore the factors that will assist in developing graduates skills to design mineral processing plant in the EPCM project delivery organisation. I believe that this awareness can lead to new ways of developing appropriate skills, promoting the tailored training intervention and enhance the delivery of design services.

You are eligible to participate if you are involved in mineral processing plant design at an EPCM organization. Specifically, if you have held a position where you lead, design processing plants or manage mineral process design projects. If you qualify, please consider assisting with this important research. The questionnaires will require approximately 15 minutes to complete.

There is no risk associated with participating. To ensure that all information will remain confidential, please do not include your name.

Please follow this link to complete the online survey: __________________________

Thank you again, your willingness to take part is greatly appreciated.

Tshepisio Banda,

Masters of Engineering Management Candidate (University of Johannesburg)
Appendix B: Questions Used in Questionnaire

Demographic Questions

1. Are you involved in mineral processing plant design?
   
<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
</table>

2. If yes, how long have you been designing mineral processing plants in an ECPM environment?

<table>
<thead>
<tr>
<th>(i) Zero to one year</th>
<th>(ii) One to five years</th>
<th>(iii) 5 to 10 years</th>
<th>(iv) 10 to 15</th>
<th>(v) More than 15 years</th>
</tr>
</thead>
</table>

3. What position do you hold in designing mineral processing plants in an ECPM environment?

<table>
<thead>
<tr>
<th>(ii) Graduate</th>
<th>(ii) Intermediate</th>
<th>(iii) Senior</th>
<th>(iv) Principal</th>
<th>(v) Manager</th>
</tr>
</thead>
</table>

4. How long should one be in a mineral process design graduate programme in an ECPM environment?

<table>
<thead>
<tr>
<th>(iii) One</th>
<th>(ii) 2</th>
<th>(iii) 3</th>
<th>(iv) 5</th>
<th>(v) As long as the mineral processing activities are covered</th>
</tr>
</thead>
</table>

Questionnaire

Section 1: What skills or capabilities do graduate engineers need to be responsible for designing mineral processing plant’s projects?

For successful integration of graduate engineers into the field of mineral plant design, how important should they possess the skills below as preliminary requirement?

<table>
<thead>
<tr>
<th>5. Basic mathematics and engineering design calculations.</th>
<th>(1) Not important</th>
<th>(2) Slightly Important</th>
<th>(3) Neither/Nor</th>
<th>(4) Important</th>
<th>(5) Very Important</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. Knowledge of knowing mass &amp; heat transfer.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8. Knowledge of standards, procedures, safety, liabilities & ethics in relation to process design.

6. Application of engineering design tools such as CAD, Visio, etc.

7. Cost estimation for processing plants?

8. An exposure to mineral processing plant environment

Section 2: What activities to be carried out as an indication that graduates possess mineral process design skills?

Based on your experience in the field of design, rate the level of importance of the skills and activities below in connection to graduates engineers within mineral process plant design space

<table>
<thead>
<tr>
<th></th>
<th>(1) Not Important</th>
<th>(2) Slightly Important</th>
<th>(3) Neither/Nor</th>
<th>(4) Important</th>
<th>(5) Very Important</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.</td>
<td>Is it vital for graduate’s process engineers to possess knowledge in operating pilot plant? If so how important?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Development equipment specification by all involve in process plant design.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>For C&amp;I graduates, how important is the knowledge of process control systems?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>Graduates process engineers for knowledge of alternative processes.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13.</td>
<td>Knowledge of equipment sizing and selecting.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14.</td>
<td>Knowledge in sizing of process piping system.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15.</td>
<td>Knowledge electrical distribution by graduate electrical engineers.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16.</td>
<td>Knowledge of procurement, when designing &amp; constructing a process plant.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Please rate the level of importance for cognitive skills needed for graduate engineers to design mineral process plants projects?**

<table>
<thead>
<tr>
<th></th>
<th>(1) Not important</th>
<th>(2) Slightly Important</th>
<th>(3) Neither/Nor</th>
<th>(4) Important</th>
<th>(5) Very Important</th>
</tr>
</thead>
<tbody>
<tr>
<td>17. Application of Communications &amp; interpersonal skills within the design team.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18. Ability to influence decisions when designing.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19. Ability to solve design related problem.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20. Ability to manage design information.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21. Presentation skill</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22. Negotiation skill</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Section 3: How would the organisation implement strategies to develop graduate engineers to be responsible in designing mineral processing plants?**

**Based on your experience within the EPCM organisation, please rate your level of importance of what organisations should apply to ensure proper development of graduates?**

<table>
<thead>
<tr>
<th></th>
<th>(1) Not important</th>
<th>(2) Slightly Important</th>
<th>(3) Neither/Nor</th>
<th>(4) Important</th>
<th>(5) Very Important</th>
</tr>
</thead>
<tbody>
<tr>
<td>23. Mentoring of graduates to acquire technical &amp; non-technical skills needed to design?</td>
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<tr>
<td>24. Opportunities for continuous professional development (CPD) trainings</td>
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<tr>
<td>25. Job rotation system for graduates from (test work, design, commissioning, optimising and operating)</td>
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