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Discipline Specific Training Guide (DSTG) for Registration as a Professional Engineer in Chemical Engineering

R-05-CHE-PE

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ECSA

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1. BACKGROUND: ECSA REGISTRATION SYSTEM DOCUMENTS

The illustration below defines the documents that comprise the Engineering Council of South Africa (ECSA) system for registration in professional categories. The illustration also locates the current document.

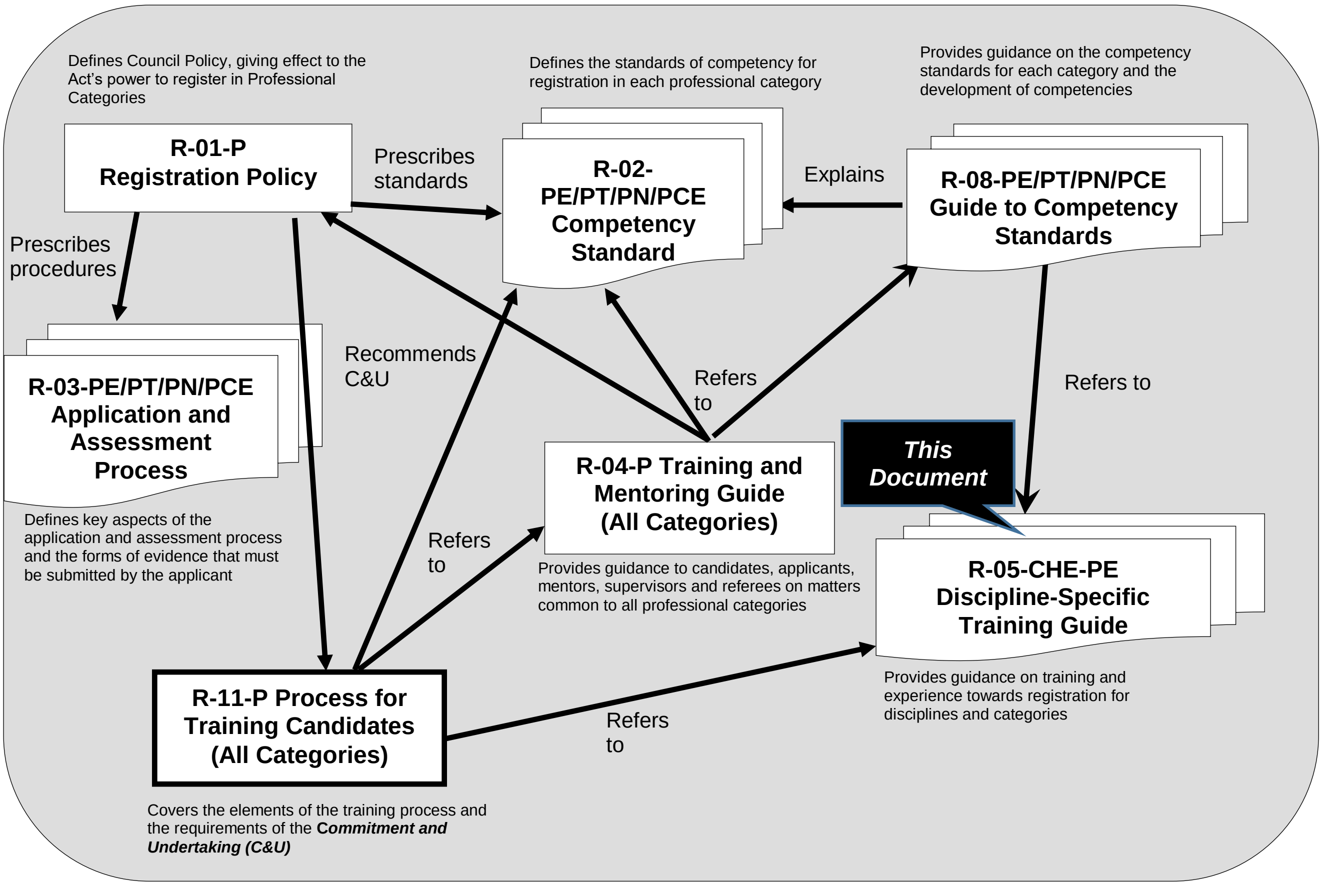

Figure 1: Documents defining the ECSA Registration System

2. PURPOSE

All persons applying for registration as Professional Engineers are expected to demonstrate the competencies specified in document R-02-PE through work performed at the prescribed level of responsibility, irrespective of the trainee's discipline.

This document supplements the generic *Training and Mentoring Guide* (document R-04-P) and *the Guide to the Competency Standards for Professional Engineers* (document R-08-PE).

In document R-04-P, attention is drawn to the following sections:

7.3.2 Duration of training and length of time working at level required for registration
7.3.3 Principles of planning, training and experience
7.3.4 Progression of training programme
7.3.5 Documenting training and experience
7.4 Demonstrating responsibility

The second document (document R-08-P) provides a high-level, outcome-by-outcome understanding of the competency standards that form an essential basis for this Discipline-Specific Training Guide (DSTG).

This guide and the documents R-04-P and R-08-PE are subordinate to the Policy on Registration (document R-01-P), the Competency Standard (document R-02-PE) and the application process definition (document R-03-PE).

3. AUDIENCE

This DSTG is directed towards candidates and their supervisors and mentors in the discipline of Chemical Engineering. The guide is intended to support a programme of training and experience through incorporating good practice elements.

The guide applies to persons who have

- completed the tertiary educational requirements in Chemical Engineering
  - by obtaining an accredited B.Eng.-type qualification from a recognised tertiary university in South Africa,
  - by obtaining a Washington Accord recognised qualification, or
  - through evaluation/assessment;
- registered with the ECSA as a Candidate Engineer; and/or

- embarked on a process of acceptable training under a registered Commitment and Undertaking (C&U) programme under the supervision of an assigned mentor guiding the professional development process at each stage.

4. PERSONS NOT REGISTERED AS A CANDIDATE AND/OR NOT TRAINED UNDER COMMITMENT AND UNDERTAKING

Irrespective of the development path followed, all applicants for registration must present the same evidence of competence and be assessed against the same standards. Application for registration as a Professional Engineer is permitted without being registered as a Candidate Engineer and without training under a C&U. Mentorship and adequate supervision are, however, key factors in effective development to the level required for registration.

If the employer of the trainee does not offer C&U, the trainee should establish the level of mentorship and supervision that the employer is able to provide. In the absence of an internal mentor, the services of an external mentor should be secured. The Voluntary Association for the discipline may be consulted for assistance in locating an external mentor. A mentor must keep abreast of all stages of the development process.

This DSTG is written for the recent graduate who is training and gaining experience towards registration. Mature applicants for registration may apply the guide retrospectively to identify possible gaps in their development.

Applicants who have not enjoyed mentorship are advised to request an experienced mentor (internal or external) to act as an application adviser while they prepare their application for registration.

5. ORGANISING FRAMEWORK FOR OCCUPATIONS

Chemical Engineering (Organising Framework for Occupations (OFO) 214501)

Obtaining a qualification in Chemical Engineering results in the development of high-level skills and specialisation. Chemical Engineering graduates are known for their problem-solving skills and are equipped to deal with problems within and outside the Chemical Engineering field. Many graduates in this field, both in South Africa and internationally, move directly into the finance sector where their analytical skills are put to use. Other graduates move into medicine, law or academia. This guide assumes that the candidate is intent on identifying and developing the competencies of a Chemical Engineer to the level of professional status.

To begin, consider the following definition of Chemical Engineering:

The planning, design, development, operation and maintenance of industrial-scale processes to convert raw and recycled materials to products through chemical and physical processes using engineering science such as thermodynamics, fluid mechanics and transfer processes.

Perhaps the most important takeaway from the definition provided is that fundamental knowledge, which includes the learning of specialised concepts from first principles, is holistically applied to a real-world problem scenario. It is also noteworthy that the word 'processes' is used in this definition; many industries refer to Chemical Engineers as 'process engineers', which may be more accurate in certain occupational roles.

Nevertheless, it is the development of the Chemical Engineering graduate into a professional Chemical Engineer that provides the impetus for this guide. Once formal learning is completed at tertiary level, there is 'an open road', so to speak, for the development of the candidate.

The following describes the various roles of Chemical Engineers in a professional context and provides clarity on the diversity of their functions:

- conducting research, advising on and developing commercial-scale processes to produce substances and items such as petroleum derivatives, chemicals, food and drink products, pulp and paper, pharmaceuticals and synthetic materials such as polymers and plastics;
- specifying chemical production methods, equipment, materials and quality standards and ensuring that these conform to specifications and accepted industry practices and standards;
- establishing control standards and procedures to ensure the safety of production operations and the safety of workers operating equipment or working in close proximity to on-going chemical reactions or processes;

- designing chemical plants and equipment and devising processes for manufacturing chemicals and other products while meeting targeted efficiencies;
- performing tests throughout the stages of production to determine the degree of control over process variables such as composition, temperature, density, specific gravity and pressure;
- developing operating procedures to be employed during design and operating phases, including start-up, shutdown and emergency;
- preparing estimates of production costs (CAPEX, OPEX and lifecycle) and production progress reports for management;
- conducting laboratory studies of steps in the manufacture of new products and testing proposed processes by employing a small-scale system such as a pilot plant;
- overseeing plant operation and management;
- optimising processes for improvement of prescribed performance indices such as profitability, sustainability, energy consumption, environmental sustainability and carbon efficiency;
- developing process-control philosophies and advanced process control (APC) systems against the requirements of the process parameters;
- evaluating environmental and legal aspects when a new process is intimated; and
- participating in and leading risk-assessment studies (e.g. hazard and operability studies) during the design and operation phases of the installation of new plants or the modification of existing plants.

Having mentioned the roles and descriptions of typical work carried out by Chemical Engineers, this guide considers the bases for the application of the skills. There are fields of work, particularly in specialised industries, that use experienced Professional Engineers to add value. These include

- development of biochemical processes for the pharmaceutical and biotechnology industry;
- application of experience in the legal field, for example, patent law for chemical engineering-related designs;
- development of standards relating to the field of process and Chemical Engineering; and
- process safety and incident investigations as expert witnesses and forensic specialists.

6. NATURE AND ORGANISATION OF THE INDUSTRY

'The industry' refers to the real-world environment in which Chemical Engineers carry out tasks and duties using their skills. It must be separated from the formalised learning environment. The industry is the setting in which aspiring Professional Engineers sharpen their skills and develop the requisite competencies.

Historically, the chemical engineering industry and related industries in South Africa have had two major driving forces:

1. International sanctions and embargoes imposed on South Africa, leading to the formation of SASOL Limited
2. Extensive mineral reserves and involvement in specifically gold and platinum mining and beneficiation since the 1800s.

It thus follows that the major 'traditional' industries in which Chemical Engineers are found in South Africa are petrochemical and minerals processing. The development of the economy and the maturation of the chemical-processing industry have given rise to several other industries from which graduate Chemical Engineers are pooled. Increasing labour and utility costs have also led to the employment of Chemical Engineers to optimise processes by reducing waste.

For reference, industry examples are given below.

INDUSTRY	SECTOR	APPLICATION
Beverages	Wine, beer, spirits	Anaerobic digestion, fermentation
Chemicals	Primary chemicals, fertiliser	Air liquefaction, evaporation, crystallisation
Effluent treatment	Acid mine effluent, municipalities	Membrane processes, thermal evaporation
Food	Human and animal food	Drying, mixing
Mineral beneficiation	Extraction of precious metals and base metals	Solvent extraction, electrowinning
Mining	Underground or above-ground primary mining industry	Cooling, heating, ventilation, effluent treatment, water treatment
Petrochemical	Refinery, polymer production	Distillation, refining
Power generation	Industries co-generating power – pulp and paper, sugar	Steam or gas turbine integration
Solvents and paints	Production of paint	Reactors, mixing

6.1 Investigation

The investigation phase of a project, which may be labelled formally as pre-feasibility, concept or feasibility, is a significant part of the chemical engineering design process. Investigation in its most fundamental form is a process whereby a stated objective or mandate is explored in terms of the parameters of the specific situation, perhaps more aptly referred to as *'Investigation of the Engineering Problem'.*

Graduate engineers are often exposed to the detailed area of the investigation under the supervision of an experienced Chemical Engineer. It is useful for the purpose of this guide to separate the investigation phase into two distinct categories:

1. Optimisation or modification of existing projects
2. New projects

Candidates could either be tasked with improving or modifying an existing (brownfield) process with a very specific mandate or become involved in a new (greenfield) project that has a more open-ended mandate.

For example, consider a graduate Chemical Engineer working at a refinery who has been tasked with investigating a cooling water circuit. The cooling water circuit is demonstrating a lack of performance during the summer months, indicated by a cooling water supply temperature of 28°C instead of 24°C as designed. The project manager sets up a small team of engineers to investigate. In this example, the investigation stems from a known and well-defined problem. The Candidate Chemical Engineer needs to consider many aspects and follow certain steps in the investigation process, which include

- obtaining a process flow diagram (PFD) of the circuit with a mass and energy balance and determining the users of the cooling water supply; and
- verifying the design inputs and outputs against the installation –
  - Has anything changed such as equipment being upgraded without considering the cooling water capacity?
  - Are there additional or temporary cooling water return streams entering the cooling tower circuit?

- What are the system parameters (i.e. pumps, fan speed, air velocity, distribution pattern) and how do the current measured parameters compare with the design?
- Have maintenance items such as filters, cooling tower packing, strainers, old valves been considered?
- Has the control philosophy and operation of the cooling tower been considered? Is it against design?

The investigation phase is critical to the development of Candidate Chemical Engineers because it provides an opportunity to identify real-world scenarios. Employers often test graduates by assigning them low-risk or non-critical items that could be solved in the space of a few weeks or months.

6.2 Research/Development

While Chemical Engineers gain a vast amount of fundamental and first-principle knowledge in their tertiary education, industry problems require taking that knowledge one step further. After having identified a problem and investigating it, the research and development phase is the next step towards implementing a rational design to solve the problem.

Research/development is often assumed to be a task reserved for academic researchers or industry-partnered research institutions such as the Council for Scientific and Industrial Research (CSIR). However, the graduate Chemical Engineer will be confronted with the development of solutions based on collecting the information during the investigation phase, irrespective of the environment.

Research/development constitutes a myriad of available options, depending on the industry and application:

- consulting peer-reviewed academic journals in respect of novel technology – for example, specialised anaerobic digestion of industrial wastewater;
- conferring with technical representatives of industry associations such as in the cement industry when confronted with specific issues;
- consulting with industry specialists who may be equipment vendors; and

- conducting a literature review of published text books on the subject matter – for example, Coulson and Richardson's *Chemical Engineering Volume1: Fluid Flow, Heat Transfer and Mass Transfer* and *Perry's Chemical Engineers' Handbook* for mass transfer operations.

Sometimes, development requires testwork to be done to verify the concepts identified in the research. Many clients insist on proving a process on the bench or on a pilot scale since ultimately, vast amounts of money are to be spent on the construction.

6.3 Process design

Process design in this guide refers to the synthesis of a solution to an engineering problem. An ill-posed problem has been posed and investigated, and all available tools are utilised to obtain a solution to it. In the chemical engineering field, the process design is the hallmark of an experienced Chemical Engineer. The success of the engineering approach to this step is directly dependent on the preceding investigation and development/research steps.

The process synthesis would naturally follow the sequence:

1. Block flow diagram – define fundamental process steps involved
2. PFD – select the unit operations and define the inputs and outputs of the process
3. Mass and energy balance in conjunction with the PFD – reagent consumption, utility requirements, economics of the plant
4. Piping and instrumentation diagrams – the process is defined in detail, and accurate pricing can be obtained

6.4 Risk and impact mitigation

A key developmental aspect of a Chemical Engineer is the identification and mitigation of risks in the design of a process. Formally, the Hazard and Operability (HAZOP) technique, developed by Imperial Chemical Industries (ICI), is employed to identify process and operational risks during the design phase. Other risks to be considered are plant economics, including the availability of reagent, logistics and selling price/market sensitivity of a product or by-product. Directly linked to the feasibility of a process is cost. One can design a technically sound process, but if the economics such as capital costs and running costs are not favourable, a client will not approve the project.

The concept selection of a process design is probably the most significant risk for a Chemical Engineer. Consider the design of an effluent treatment evaporation system. If a falling film evaporator is selected based on the client's feed specification of having a low scaling potential and that specification significantly changes over the course of the project development, then no matter how well the project is executed, the evaporator tubes will scale. In this example, a forced circulation would be more appropriate.

The rationale is the same for detailed applications. Consider pump sizing and selection in a slurry system. Too low a velocity causes settling and endless blockages, and too high a velocity causes wear and abrasion. Or consider the selection of a standard centrifugal pump for a highly viscous fluid instead of a positive displacement pump. The shear forces at the impeller would render the fluid not pumpable.

In conclusion, risk, or more appropriately, process design risk, is perhaps the Chemical Engineer's most important consideration.

6.5 Engineering project management

The completion of a process design to the detailed stage and the project approval phase signals the stage of engineering project management and project engineering. The Chemical Engineer may be involved in procurement in situations where equipment (e.g. pumps) needs to be specified to vendors. The vendor recommendation needs to be checked and ratified for suitability regarding the application – Does it fulfil the standards required, that is, the process operating parameters and safety requirements?

It is advisable for candidates to gain exposure to project management, but it should be noted that the focus should remain on problem-solving work related to Chemical Engineering.

6.6 Implementation/Commissioning

Many Chemical Engineers start their careers by being exposed to a site environment. This could be the construction, completion and commissioning of a new plant or the upgrading of an old plant. Site experience in implementing designs and commissioning of unit operations provides candidates with excellent exposure to the realities of the industry. Early exposure to a site and the commissioning of process equipment enables the candidate to understand the impact of their future designs and provides context in terms of a construction and commissioning timeline.

During commissioning, ill-posed problems often arise that need to be solved quickly. For example, Chemical Engineers may encounter a pump that does not produce the required flow rate. During the process of troubleshooting, the candidate should consider many practical aspects. For example:

- Is the correct pump installed with the correct impeller?
- Are there any valves in a throttled position?
- Are there obstructions in the piping such as debris from construction?
- Are there non-return valves that have failed or been installed incorrectly?
- Are there control valves that have not been properly calibrated?

One can see that the troubleshooting process creates tremendous value early in a candidate's career. The 'softer' side of implementation and commissioning is that the candidate works with people in a team environment, which requires patience and an understanding of team dynamics. Management of time and schedules is critical during implementation and is a valuable skill for Chemical Engineers.

6.7 Production

The production environment in the industry refers to new or well-established operations in which the objective is to ensure that the plant performs according to its design intent. Similar to commissioning/implementation, opportunities for troubleshooting and optimisation exist in this space and should form part of an ideal training programme for candidates.

6.8 Operations and maintenance

Although many processes are automated to a large extent, process plants still need human intervention and monitoring. Additionally, process equipment requires maintenance. Exposure of candidates to the aspects of operations and maintenance contributes substantially to their development as professionals. In industry, plants that operate poorly are often the result of a design that is not sufficiently robust or that is too 'ideal'. Due consideration must be given to the operation and maintenance of processes during the design phase. Experience in operations and maintenance could result in

- knowing when to use a duty/standby configuration or other method for rotating equipment;
- understanding the interface between the control system and operators;
- downtime considerations for blockages of piping or tanks; and
- developing robust and sound control and operating philosophies that result in the simple operation of a plant rather than over-complicated, cumbersome functioning.

7. DEVELOPING COMPETENCY: ELABORATING ON SECTIONS IN THE GUIDE REGARDING COMPETENCY STANDARDS (DOCUMENT R-08-PE)

7.1 Contextual knowledge

Contextual knowledge refers to the specific design environment in which the candidate is working. For example, a Chemical Engineer working in the field of distillation column design should become familiar with technology advancements and developments. Engineering standards are critical in ensuring that the output of a design is sound. In specifying distillation equipment, pressure regulations play an important part of the HAZOP study. For example, Chemical Engineers need to be familiar with the general provisions of the Tubular Exchanger Manufacturers Association (TEMA) in heat exchanger design, and ASME VIII Div.1 and API 520 in pressure safety requirements and design considerations.

The onus is on candidates to participate in the industries in which they are involved.

7.2 Functions performed

The functions in which Chemical Engineers need to be proficient are required to a greater or lesser extent in all the areas of employment. These functions are listed below. The parallels with the generic competence elements required by the Competency Standard (document R-02-PE) should be clear.

- Investigation/troubleshooting
- Process plant and equipment design
- Process safety and environmental considerations
- Project management
- Plant construction, support, hand-over and commissioning/de-commissioning
- Plant operation

Applicants need to gain experience in these functions, even if they are not part of their core job function.

7.3 Statutory and regulatory requirements

The Candidate Engineer who aspires to become professionally registered must be familiar with all the legal requirements of practising as a Professional Engineer in the Republic of South Africa. The legal requirements can be grouped into three main categories:

- Code of Conduct for Professionally Registered Persons
- The Occupational Health and Safety Act, No. 85 of 1993 and the Mine Health and Safety Act, No. 29 of 1996
- Industry-specific legislation

The Engineering Profession Act, No. 46 of 2000 is a mandate from government to the ECSA to provide regulatory oversight of the industry. The mandate is as follows:

"To provide for the establishment of a juristic person to be known as the Engineering Council of South Africa; to provide for the registration of professionals, candidates and specified categories in the engineering profession; to provide for the regulation of the relationship between the Engineering

Council of South Africa and the Council for the Built Environment; and to provide for matters connected therewith" (Republic of South Africa, 2000:2).

The ECSA, in turn, established a document known as the ECSA Code of Conduct and entitled "Code of Conduct for Registered Persons: Engineering Profession Act, 2000 (Act No. 46 of 2000)". The ECSA Code of Conduct sets out the ethical rules of conduct for professionally registered persons in terms of the following categories:

1. Competency
2. Integrity
3. Public Interest
4. Environment
5. Dignity of the Profession

Further administrative considerations are also set out in the Code of Conduct. The onus is on candidates to familiarise themselves with these concepts.

Depending on the working environment, the provisions of the Occupational Health and Safety Act, No. 85 of 1993 (OHS Act) and/or the Mine Health and Safety Act, No. 29 of 1996 (MHS Act) must be followed by employers and employees. Candidates should obtain a functional understanding of these provisions in their specific workplaces.

Industry-specific regulations and requirements may or may not be applicable in all fields of Chemical Engineering. However, candidates may find that each industry or aspect of design has developed 'good engineering practices' or has mandated statutory requirements. The onus is, once again, on candidates to familiarise themselves with these practices in the South African industry-specific context.

7.4 Desirable formal learning

Formal learning in the context of this guide refers to the continuous development of a candidate's skills-base by making use of formal programmes, courses, academic research and literature reviews. The candidate should adopt an approach of continuous learning after graduating. The formal learning chosen will depend on the environment in which the candidate works. Consider, for example, a

Candidate Chemical Engineer working for a water treatment company. The candidate could engage in water industry-specific courses, attend workshops and study academic or industry literature on water-treatment subjects.

It is recommended that candidates engage with their employers or sponsors to select formal learning that is cost-effective and appropriate for their roles in the organisation.

As a general guide to desired formal learning for Chemical Engineers, consider the following options:

- HAZOP study methods and techniques
- Layer of Protection Analysis (LOPA)
- Root Cause Analysis (RCA)
- Training in the use of simulation tools such as Aspen, SimSci, ChemCAD, AFT, Metsim
- Training in safety-related legislation such as the OHS Act and the MHS Act
- Formally registered Continuing Professional Development (CPD) courses in Chemical/Process Engineering and associated disciplines
- Value Engineering and other Value Improvement Practices (VIPs)
- Preparation of specifications
- Environmental aspects of projects
- Professional skills such as report writing and presentations
- Project and operational planning methods

Some large companies offer significant training opportunities, particularly companies that are specialists in their field. In companies where such opportunities are few, candidates are advised to consider joining the Voluntary Association, SAIChe/IChemE. The South African Institute of Chemical Engineers, in conjunction with a dual membership agreement with the Institution of Chemical Engineers in the United Kingdom, provides considerable opportunities for formal learning and informal learning.

8. PROGRAMME STRUCTURE AND SEQUENCING

8.1 Best practices

There is no ideal training programme structure or unique sequencing that constitutes best practice. The training programme for each candidate depends on the available work opportunities assigned to the candidate by the employer. Thus, each candidate will effectively undertake a unique programme in which the various activities carried out at the discipline-specific level must be linked to the generic competency requirements demonstrated in document R-08-PE.

The onus is on candidates to take responsibility for their own development.

8.2 Realities

There are particular considerations that candidates must bear in mind when navigating the path to professional registration. Many companies in South Africa that employ Chemical Engineers are small in size, with a relatively flat reporting structure. In such cases, candidates have the advantage of being exposed to many more activities than in a large, more rigid corporate structure. However, such candidates may eventually experience insufficient responsibility and management opportunities and should make themselves available to lead a team or take on additional responsibilities.

Larger corporate structures often have different approaches compared with smaller companies – every engineering discipline has its role. In a small company, a candidate may quickly become a specialist in a single area of engineering and fail to gain cross-discipline exposure. The candidates should request exposure opportunities and discuss these with their employers or supervisors. In addition, the chemical engineering industry in South Africa is relatively small, and candidates should consider this when changing jobs or industries.

Experienced Chemical Engineers often make very good project managers because of their exposure to the entire lifecycle of a project and their interaction with other disciplines. The ‘big picture’ is gained in this way and should be considered by candidates interested in project management as their future careers.

Finally, there is no fixed recommendation for the timeline for registration application. Candidates need to consider the realities of the industry and acknowledge that they are ultimately responsible for their own development.

8.3 Generalists, specialists, researchers and academics

The working environment in which Chemical Engineers receive their formative training can sometimes be very specific rather than general. For candidates who work in academia, research institutions or directly enter highly specialised fields, it may be challenging to gain the level of experience required for registration. Although there is no ideal training programme or path to follow, the experience of the ECSA has shown that candidates working in a more general work environment experience a broader exposure to the facets of competencies required for professional registration.

A generalist Chemical Engineer could be considered as an engineer who during candidacy was adequately exposed to all phases of the engineering design cycle. Candidates who specialise or focus during the early stages of their career must still obtain the necessary experience to enable them to demonstrate that they have met the competencies specified in document R-02-PE at the level expected of a Professional Engineer. It is expected that this will take longer than it would for candidates working in more general areas. Candidates are advised that in such circumstances, options should be discussed with their employers such as moving temporarily to different departments or business units, spending some time on site or joining a commissioning team.

8.4 Moving into or changing candidacy training programmes

This guide assumes that the candidate enters a structured programme in a work environment after graduation and continues with the programme until ready to submit an application for registration. The guide also assumes that the candidate is supervised and mentored by persons who meet the requirements stated in document R-04-P, section 7.2. In the case of a person changing from one candidacy programme to another or moving into a candidacy programme from a less structured environment, it is essential that the following steps are completed:

- The candidate must complete the Training and Experience Summary (TES) and the Training and Experience Reports (TERs) for the previous programme or unstructured experience. In the latter case, it is important to reconstruct the experience as accurately as possible. The TERs must be signed off in the appropriate manner.

- On entering the new programme, the mentor and supervisor should review the candidate's development while being mindful of the past experience and the opportunities and requirements of the new programme. At minimum, the mentor and supervisor should plan the next phase of the candidate's programme.

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Rev 2	23 Oct 2017	Reviewed and checked	J Cato, B Collier-Reed
Rev 2	19 Nov 2017	Approval	PDSGC

The Discipline-Specific Training Guide (DSTG) for:

Registration as a Professional Engineer in Chemical Engineering

Revision 2 dated 16 November 2017 and consisting of 22 pages has been reviewed for adequacy by the Business Unit Manager and is approved by the Executive: Policy Development and Standards Generation (PDSG).

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Business Unit Manager — Date

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Executive: **PDSG** — Date

The definitive version of this policy is available on our website.