

An investigation into the relevance of a first year primer course in engineering graphics for chemical engineering students

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DECLARATION

I, **Dieketseng Maria Kotole**, hereby declare that this study, *An investigation into the relevance of a first year primer course in engineering graphics for chemical engineering students*, is original and my own work. I further declare that the information used was referenced appropriately and that this dissertation was not previously in its entirety or partially submitted by me or any other person for degree purposes at this or any other university.

DM Kotole

Date

*Praise be to You, O Lord, God of our
father Israel, from everlasting to
everlasting. Yours is the greatness
and the power and the glory and
the majesty and the splendour, for
everything in heaven and earth is
Yours. Yours O Lord is the kingdom;
You are exalted as head over all.
Wealth and honour come from You;
You are the ruler of all things. In
Your hand are strength and power
to exalt and give strength to all.
Now my God, I give You thanks, and
praise Your glorious name.*

1Chronicles 29:10-13

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Soli deo Gloria! (Glory to God alone!)

ABSTRACT

In chemical process industry (CPI) projects the responsibilities of chemical engineers can generally be split into two categories, namely, plant and equipment sizing; and piping and instrumentation diagram (P&ID) development. In these projects chemical engineers usually work with other departments such as mechanical and civil engineering, piping engineering, instrumentation engineering, and project engineering. Communication in such projects is done through various mediums. These include communication of the plant layouts as well as equipment and P&ID layouts by means of technical engineering drawings. Given this background it is important that chemical engineers should have adequate knowledge to understand the work being communicated by the other departments through means of technical drawings. This makes it necessary for the chemical engineers to obtain training in this field of knowledge. As the literature suggests, this training will benefit chemical engineers by enhancing their spatial visualization ability – which literature points out to be crucial for all engineers, as well as in being able to transpose from 2-D to 3-D drawings, and vice-versa.

Technical engineering drawings used to be offered at university entry level for all engineering disciplines. Currently only 33% of South African universities still offer technical engineering drawings for chemical engineering. This raises the question of whether the lack of training in technical drawings for chemical engineers is not a limiting factor in the industry. As a result, this research aimed to establish whether the removal of this subject would not have a negative impact on the chemical engineering students once they are in the industry.

The study employed a mixed-method approach to the investigation. A questionnaire containing both quantitative and qualitative questions, and semi-structured interviews were used as the measuring tools for the study.

The sample used for this study comprised chemical engineers with varying years of experience who have worked in different offices as chemical engineers in the industry.

The findings of this research revealed that chemical engineers do work with technical drawings. The extent and the frequency with which they use drawings is dependent on

the type of office (design, process control, management, etc.) as well as the magnitude of the project in which the chemical engineer is working.

For the chemical engineers who had the technical engineering drawing subject in their undergraduate studies, the subject yielded benefits with regard to the fundamental engineering thinking abilities. The findings also indicated, however, that the large part of the content presented for the subject is not relevant for chemical engineers.

The study therefore recommends that chemical engineers should acquire the necessary technical engineering drawing skills, preferably at the early stages of their university programme. It is also recommended that the subject content should be customized for chemical engineers to address the typical applications of technical engineering drawings in the chemical engineering field, i.e. to read and interpret, and be able to communicate the information on the drawings.

KEYWORDS

Technical engineering drawings, chemical engineers, undergraduate curriculum, chemical engineering industry, spatial visualization.

OPSOMMING

In chemiese prosesindustrie (CPI) projekte kan die verantwoordelikhede van chemiese ingenieurs hoofsaaklik in twee kategorieë verdeel word, naamlik aanleg en toerustingbepaling; en pypwerk en instrumentasiediagramontwikkeling (P&ID). In hierdie projekte werk chemiese ingenieurs gewoonlik met ander departemente soos meganiese en siviele ingenieurswese, pypwerkingenieurs, instrumentasie en projekingenieurswese. Kommunikasie in sulke projekte word deur verskillende media gedoen. Dit sluit in kommunikasie oor die uitleg van die aanleg sowel as toerusting en P&ID-uitlegte deur middel van tegniese ingenieurstekeninge. Teen hierdie agtergrond is dit belangrik dat chemiese ingenieurs voldoende kennis moet hê om die werk te verstaan wat in ander departemente gedoen word en wat by wyse van tegniese tekeninge gekommunikeer word. Dit beteken dis nodig vir chemiese ingenieurs om kennis van hierdie veld te hê. Soos blyk uit die literatuur sal sulke opleiding vir chemiese ingenieurs tot nut wees as gevolg van die versterking van hulle ruimtelike visualiseringsvermoë. Literatuur dui aan dat hierdie vermoë van groot belang is vir alle ingenieurs, wat ook van toepassing is op hulle vermoë om te kan transponeer tussen 2-D en 3-D tekeninge en vice-versa.

Tegniese ingenieurstekeninge is vroeër aangebied by alle universiteite op die intreevlak van ingenieurswese. Tans bied slegs 33% van Suid-Afrikaanse universiteite nog tegniese ingenieurstekeninge aan vir chemiese ingenieurswese. Dit laat die vraag ontstaan of die gebrek aan tegniese tekeninge vir chemiese ingenieurs nie 'n beperkende faktor in die industrie is nie. Hierdie navorsing is dus daarop gemik om vas te stel of die verwydering van hierdie vak uit die kurrikulum nie 'n negatiewe impak sal hê op die werk van chemiese ingenieurstudente as hulle die bedryf betree nie.

In die studie is gebruik gemaak van 'n gemengde-metode benadering tot die ondersoek. 'n Vraelys met beide kwantitatiewe en kwalitatiewe vrae sowel as semi-gestruktureerde onderhoude is gebruik as meetinstrumente vir die studie.

Die steekproef wat vir die studie gebruik is het bestaan uit chemiese ingenieurs met verskillende aantal jare diens in die bedryf.

Die bevindinge van die navorsing is dat chemiese ingenieurs wel met tegniese tekeninge werk. Die omvang en gereeldheid hiervan hang af van die soort kantoor (ontwerp, prosesbeheer, bestuur, ens.) sowel as die grootte van die projek waaraan die betrokke chemiese ingenieur werk.

Die bevindinge het ook aangedui dat vir diegene wat tegniese ingenieurstekeninge in hulle voorgraadse studies gehad het, die vak voordele ingehou het met betrekking tot fundamentele ingenieursdenkvaardighede.

Hierdie studie beveel dus aan dat chemiese ingenieurs die nodige tegniese ingenieurstenen vaardighede bekom, verkieslik tydens die vroeë stadium van hul universiteitsopleiding. Dit word ook aanbeveel dat die inhoud van sodanig kursus aangepas sal wees vir chemiese ingenieurs wat blootstelling sal gee aan tipiese toepassings van ingenieurstekeninge in die chemiese bedryf soos om tekeninge te lees en te interpreteer en die inligting daarin te kan kommunikeer.

SLEUTELWOORDE

Tegniese ingenieurstekeninge, chemiese ingenieurs, voorgraadse kurrikulum, ingenieursindustrie, ruitemilike visualisering.

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LIST OF ABBREVIATIONS

2-D – Two-dimensional

3-D – Three-dimensional

AIChE – American Institution of Chemical Engineers

CAD – Computer-Aided Drawing/Design

CE – Chemical engineer(s)

DWG – Drawing(s)

ECSA - Engineering Council of South Africa

Eng. - Engineering

FD – Flow diagrams

ICE – Integrated Chemical Engineering

CPI – Chemical Process Industries

MFD – Mechanical Flow Diagrams

PFD – Process Flow Diagrams

P&ID – Piping and Instrumentation Diagram

R&D – Research and Development

RQ – Research Question

SA – South Africa

SAIChE – South African Institution of Chemical Engineers

GLOSSARY

Engineering graphics is used synonymously with *technical engineering drawing(s)*.

Engineering graphics – technical drawing, including freehand sketching, 3-D modelling (by hand or computer), and creating drawings.

Working with drawings – doing the actual drawing or just having to read and interpret a technical drawing.

CHAPTER 1

BACKGROUND, PROBLEM FORMULATION, AND OBJECTIVES

1.1 INTRODUCTION

This chapter provides background to the topic, discusses the purpose, problem statement, and research objectives of the study, and provides an overview of the research. The chapter also introduces the method of investigation followed in order to achieve these objectives, as well as the layout of the study.

1.2 BACKGROUND

Chemical engineering is practised in various industries such as pharmaceuticals, petrochemicals, pulp and paper, and manufacturing, design and construction, to mention but a few. Given the wide spectrum in the application of chemical engineering, chemical engineers are tasked with various responsibilities ranging from research to design to development of chemical products and chemical processes. In addition, chemical engineers are also responsible for the design and development of plant and equipment (Exforsys, 2006).

In the manufacturing, design, and construction fields of chemical engineering an interdisciplinary approach is employed to generate and maximise solutions (Miller, 1999). In such environments it is expected of the chemical engineers to:

- Understand and follow equipment installation manuals;
- Assess and interpret the sizes of new equipment for installation by taking the measurements from the scale drawings (blue prints or maps) and comparing it to the actual plant or equipment;
- Make use of sketches to communicate proposed solutions;
- Make use of Computer Aided Drawing/Design (CAD) software for simulations and flow diagrams; and
- Do plant and equipment designing (Xie & Ma, 2015; Exforsys, 2006; Toghraei, 2015; Kidam & Hurme, Design as a Contributor to Chemical Process Accidents, 2012b).

It can be appreciated that technical design ideas cannot be easily described verbally except by means of an object or a visual image (Belofsky, 1991). Therefore this necessitates that engineering offices should create means to communicate these ideas. For this purpose most chemical engineering companies have drawing technicians employed specifically to prepare the engineering drawings, mostly by means of a computer-aided design (CAD) software. In such instances the chemical engineer can communicate with the technician by only generating hand sketches and have them updated by the technician. However, in some companies the chemical engineer is the person responsible for the drawing and the updating of the equipment, and piping and instrumentation diagrams (P&IDs). These tasks require life-like visualization and the ability to manipulate a drawing from 2-D to 3-D, and vice versa. For both cases it is necessary that the chemical engineer be adequately conversant with the discourse used in the operation.

Chemical engineers design and develop the systems, equipment and facilities that use chemical reactions to produce products. Typical phases involved in a design project include research and development (R&D), basic engineering, detailed engineering, and construction and start-up phases (Kidam & Hurme, 2012b). During the detailed engineering phase 3-D plant layouts are developed as part of the design for the construction of the mechanical, civil, and electrical engineering features of the plant (Kidam & Hurme, 2012b). In a study they conducted Kidam and Hurme (2012b) found that 29% of the design errors are committed during this phase. Of this percentage, 34% is found in the internal layout design of equipment and piping (Kidam & Hurme, 2012b). These failure during the detailed engineering design phase, connected to failures during the procurement/fabrication phases can be attributed to, inter alia, inappropriate piping layout, inappropriate internal shape of equipment/component, as well as miscommunication between the designer and the fabricators (Kidam & Hurme, 2012b). Statistics show that most chemical plant accidents are due to piping systems (Hussin, Johari, Kidam, & Hashim, 2015). It is therefore important for chemical engineers to have sufficient knowledge to be able to verify the feasibility of solutions proposed to them. In another study they conducted Kidam and Hurme (2012a) found that 69% of the errors attributed to the detail engineering in piping systems is found in the piping layout, specifically. These errors (in the piping systems) constitute 24% of the accident-causing equipment types in the chemical process industries (Kidam & Hurme, 2012a). During the detail engineering phase the mechanical designs and piping isometric drawings are done based on the process data determined in the preliminary phases (Kidam & Hurme, 2012a). Since this phase contributes such a significant part in

accidents related to designs, it becomes important for chemical engineers to be able to not only understand the process flow, but to possess a mechanical and layout viewpoint ability, i.e. be able to translate the flow diagrams in 2-D to 3-D and vice versa.

In today's competitive industry companies are looking to provide effective solutions within minimal lead times. As a result, technical drawings are no longer the business of a drawing office only. They now form part of all other engineering disciplines, be it in production or services (Uçan *et al.*, 2012). Taking this into account Uçan *et al.* (2012) see it as befitting that technical drawing and drafting courses should be taught in all engineering departments. They suggest that all engineering students should start with technical drawing right from the beginning of their degree. They reckon that technical drawing and design will aid in the methods of "orderly thinking" onto which they can add more knowledge as they progress with their studies (Uçan, Ercan, & Ercan, 2012).

1.3 ENGINEERING DRAWING AS A DISCOURSE

Engineering Drawings is a technical language used by engineers and other technical people to convey technical ideas and guide the manufacture, fabrication, and assembly of products (Miller, 1999; Lee & Han, 2005). The purpose of engineering drawing is to communicate the external as well as the internal characteristics of objects with regard to form and size (Dulevicius & Nagineviciene, 2005; Dori & Tombre, 1995). Engineering drawings consist of different types of lines, each with a different meaning and purpose. The different types of lines, their meaning, symbols, and constructions are to engineering drawings what letters, words, and phrases are to a language. A solid line, for instance, represents the visible edges of an object, a dashed lines represent hidden edges, a combination of long and short broken lines represents centre lines, and continuous arrow headlines represent dimension lines, etc., including extension, construction, and section lines (Dori & Tombre, 1995; Jordaan, 2010; Tombre, 1995; Wen, Zhang, Sun, & Paul, 2011)

In the past, engineering drawings were generated by means of instruments such as a drawing board, a drafter, a compass, divider, drawing pencil, eraser, and drawing paper, but with the rapid development of technology these equipment have been reduced to CAD programmes (Ault & John, 2010; Dori & Tombre, 1995; Barr, 2012). These programmes, however, still work on the same theoretical principles and require the same basic understanding of technical drawings. For instance, a technical drawing,

whether done by means of free-hand sketching or CAD, cannot be complete unless important detail such as dimensions, title, dates, revisions, as well as additional notes, where applicable, are included. Therefore, standards and conventions for layout, line thickness, text size, symbols, projection views, descriptive geometry, dimensioning, and notations are used to create drawings that can be interpreted in only one way (Wen, Zhang , Sun, & Paul, 2011). As a result the same discourse is used interdisciplinarily as well as internationally (Çayıroglu, Çavusoglu, & Veli, 2007; Dori & Tombre, 1995; Uçan, Ercan, & Ercan, 2012; Miller, 1999).

Since this is a specialised discourse, the above factors necessitate that lessons be obtained in order to be conversant with the meaning behind every aspect of technical drawings. At universities where technical engineering drawing is given as a primer subject, the course does not teach alphabets and number for annotations and dimensions *per se*, but rather how to write them in a clear, legible, and uniform manner. What is important is to understand how these are used and interpreted. For example, a drawing without dimensions has no meaning except just to show the form of the object (Gupta & Roy, 2008). Dimensioning is used to indicate the various sizes of an object, such as the width and length, thickness of material, diameter of holes, angles, etc. Since the size of a drawing is usually smaller than the actual object, it is important be able to interpret the scales used to represent the actual object. The scale of a drawing indicates a ratio between the dimensions of the drawing and those of the actual object. In order to get as much detail as possible these object parts (or assembly thereof) are usually displayed in various projection views, or zoomed in to focus on parts with more complex or hidden detail.

According to Agrawal and Agrawal (2008) all drawings used in the discipline of engineering apply the principles of projections. A projection is an image of an object put forth on a plane surface. The purpose of all projection techniques is to outline a 3-D object on a 2-D surface (Belofsky, 1991). The intention is to give more detail by providing auxiliary views of oblique angles and supplementary cross-sections where details cannot otherwise be clearly shown (Gupta & Roy, 2008; Belofsky, 1991). This facilitates a better understanding of the designer's instructions to the person who will be manufacturing the object. The types of projections discussed in Engineering

Drawing 1¹ are orthographic projections - multi-views; and pictorial views – perspective, isometric, and trimetric views.

Orthographic projections (multi-views)

“Orthographic projections” is the written language through which design ideas of engineers and architects are transmitted to technicians and builders” (Belofsky, 1991, 23). An orthographic projection is a multi-view projection by means of which only one face (side) of an object can be viewed at a time (Agrawal & Agrawal, 2008; Jordaan, 2010). In an orthographic projection, the features of the object are displayed in their true size and form, without foreshortening or distorting some of the lines, i.e. the edges of the projected object are identical to the outline of the projection on the projection plane, irrespective of the distance between the object and the plane of projection (Jordaan, 2010; Gupta & Roy, 2008; Agrawal & Agrawal, 2008; Belofsky, 1991). Orthographic projections are, to many engineers, almost as natural as their native language (Belofsky, 1991). Its rules are the same universally (Belofsky, 1991 (Wen, Zhang , Sun, & Paul, 2011). These projections are obtained on two reference planes i.e. two-dimensional (2-D), namely, the vertical plane and the horizontal plane (Agrawal & Agrawal, 2008). In this way a design is “worked out” in the form of multi-view projections by putting together the different views of the same object simultaneously in order to put together a three dimensional (3-D) model (Belofsky, 1991). This enables the designer to work back and forth between views. In their study Kidam and Hurme (2012b) found that causes leading to human error in designs can be attributed to poor communication, misunderstanding or misinterpretation of technical instructions, and lack of sufficient knowledge of the discourse used. In their other study (2012a) they found that one of the causes leading to failure in piping systems and process vessels in the chemical plants is poor fabrication/construction. This can be due to, inter alia, incorrectly stipulated or inadequate detail on the design drawings for example, missing dimensions, the type of welding to be used on a particular type of vessel, etc. Therefore, it is important that chemical engineers clearly understand the standards governing orthographic projections as these serve as the authoritative design documentation that bears the instructions to the manufacturing, fabrication, and assembly of products (Lee & Han, 2005). Clear communication in this regard will save time on sending the drawings back and forth for clarity between the designer and the

¹ Primer technical engineering drawing subject taken in the first semester of the four-year engineering degree at university. The Engineering Drawing curriculum discussed for the scope of this research is based on the module content of the course as given by the South African universities that offer engineering drawing to chemical engineering students.

manufacturer or constructor and also reduce the likelihood of human errors in construction and manufacturing (Kidam & Hurme, 2012b).

Pictorial views

Pictorial views on the other hand, such as isometric views and perspective views, are 3-D models used primarily as a means of illustration to merely render the object as perceived by the naked eye. Measurements can only be estimated, but cannot be accurately measured from a pictorial view (Belofsky, 1991).

A 3-D model is a transformation of an idea or a concept into reality. Therefore 2-D drawings are converted into 3-D solid models to give a clearer picture of the object and to improve the product design and manufacturing efficiency. A 3-D model is usually created from three orthographic projections (front, side, and top views) of a model. During this process all views must be considered simultaneously in order to comprehend the shape of the 3-D object (Singh *et al.*, 2014). The ability to transform a 2-D drawing into a 3-D object, and vice versa, is a necessity for engineers (Adanez & Velasco, 2004). This also requires the ability to mentally rotate objects in space which, according to Sorby (2007), is crucial to the engineering practice. Sorby (1999) suggests that these skills require training and, as a basis for this, the traditional universities of South Africa (SA) used to offer Engineering Drawings as a first-year primer to all engineering students (chemical, electrical, and mechanical).

1.4 PROBLEM FORMULATION AND PURPOSE OF THE RESEARCH

International statistics gathered in the year 2014 revealed that of twenty (20) universities that ranked the highest in the world in 2014 (QS Top Universities, 2014) only one university offered technical drawings for their students. The curriculum content of three universities ranking 7, 8, and 12 could not be accessed. As a result, the top twenty-three (23) universities were considered for this purpose.

At the universities that do offer engineering drawings to chemical engineering students this course is given in the first semester of the first year of the engineering degree and is not a prerequisite for any other subject (University of Cambridge, 2014 - 2015) (University of Pretoria, 2014; Stellenbosch University, 2014). Furthermore, it is said to serve a useful purpose in follow-up design courses (University of Cambridge, 2014 - 2015). The subject is usually given through the School/Department of Mechanical Engineering, and as said, covers the same course content as for mechanical engineering students (University of Pretoria, 2014; Stellenbosch University, 2014).

It has been indicated in a number of studies that spatial visualisation skills, which is the ability to translate visual images (from 2-D to 3-D, and vice versa), are essential in engineering (Ault & John, 2010; Sorby S.A., 2009; Leopold C., 2005; Adanez & Velasco, 2004;). Uçan *et al.*, 2012 postulate that it is necessary that engineering students be equipped with the ability of orderly and spatial thought as soon as possible in their engineering studies. They reckon that this ability will assist in incorporating further knowledge the students will acquire in their engineering studies (Uçan *et al.*, 2012). Sorby (2009), Leopold (2005), and Ault and John (2010) all agree that these visualisation skills can be significantly enhanced by means of engineering drawing practice.

In South Africa, only two out of six universities that offer a four-year chemical engineering still offer Engineering Drawings as a primer for chemical engineering students (University of the Witwatersrand, 2014; University of Pretoria, 2014, p. 21; University of Kwa-Zulu Natal, 2015, p. 91; North West University, 2013, p. 31; University of Cape Town, 2014, p. 24; Stellenbosch University, 2014, p. 26). This only makes up 33.3% of the local chemical engineering universities. The problem with this situation is that if the skills acquired in this primer subject are necessary or even beneficial for chemical engineers in the industry, then the graduates currently being produced by 77% of the relevant South African universities might be disadvantaged. This lack of qualified skill may have a limiting effect on the careers of these students as they might lack the necessary fundamentals to read and understand the work of their co-designers or drafting technicians.

The purpose of this research is therefore to investigate whether the decision made by the universities that have terminated Engineering Drawings for chemical engineering students has no negative impact on the students when they start practising in the industry, or whether the subject should be reinstated. This purpose leads to the discussion on the focus and objectives of the research.

1.5 FOCUS AND OBJECTIVES

The main objective of this research is to determine whether it is necessary for chemical engineers to have technical engineering drawings as a compulsory subject in their undergraduate university studies in South Africa. This chapter has highlighted some literature on the uses of technical engineering drawings in chemical engineering projects and has also suggested the benefits of understanding the discourse for engineers. However, the literature does not detail much on the direct involvement of chemical engineers. Therefore, there is a need to understand the direct involvement of chemical engineers with engineering drawings.

Given the objective of the study, the investigation serves to answer the following research questions (RQ):

RQ1: To what extent do chemical engineers in the industry work with technical engineering drawings?

RQ2: Does the Engineering Drawings subject, as had been taught at university, benefit and benefit the type of work done by chemical engineers in the industry?

To address these questions, this dissertation focuses on understanding the individual experiences of chemical engineers who have been working in the industry. Particularly, it focuses on:

- The type of drawings chemical engineers work with on a frequent basis; and
- The link between engineering drawings, as had been taught at university and the type of engineering drawings generally used by chemical engineers in the industry.

The above points of focus helped to answer the research questions in addressing the relevance of Engineering Drawings to chemical engineering practices in the industry. The researcher chose to focus the investigation on the practical experience of chemical engineers who are, or have worked in the industry for a minimum of three years. The reason for this is that upon graduation, engineers must be subjected to a minimum of

three years as Engineers-in-Training (EIT) to be trained on the core elements of chemical engineering to an acceptable level of competence (ECSA, 2001). These elements involve technical problem-solving; management of materials, equipment, costs, manpower, and methods; as well as communication in the technical, scientific, and financial fields. In this way the target sample for the research will have experience in several aspects of the field.

1.6 HYPOTHESIS

Not all chemical engineering companies have drawing facilities or resources on site. Those that do not, outsource the work to a drafting technician or another consulting company to do the plant designs and other technical drawings for them. From the literature reviewed, and based on general conversations and discussion forums engaged in by the researcher, it is hypothesised that although the engineer him/herself might not need it, having background knowledge of engineering graphics (including CAD) will be to the chemical engineer's advantage as it will enable them to thoroughly communicate their ideas and clearly understand the work of the drafting technician. It is also helpful as the engineer might need to quickly make minor changes on the drawings when no drafting technician is available.

1.7 METHOD

The results of this study were obtained by making use of theoretical and empirical investigations. A literature review, informal and semi-structured interviews, and questionnaires consisting of both closed and open-ended questions were used for this purpose. Current trends in the local and international academia were also investigated to determine how many universities are still offering engineering drawings to first year chemical engineering student.

1.7.1 Literature review

The literature review, which forms the theoretical exposition of this study, was conducted in order to review the results/research done in this field with regard to chemical engineers needing the engineering drawing skill. The literature sources that were reviewed included:

- Books
- Journals
- Internet
- Periodicals

1.7.2 Empirical study

According to Sumser (2001) empirical research is the process of accumulating knowledge by means of observations, data collection, and content analysis rather than by a theoretical, conceptual or logical approach. In an effort to meet the objectives of this research quantitative and qualitative methods of investigation were utilised. Data were collected by means of questionnaires, interviews, and emailed comments. The empirical study comprised the research design, which informed the sampling strategies, data-collection techniques, and the data analysis strategies.

1.7.2.1 Research design

In order to determine whether chemical engineers need to have technical engineering drawing skills this study employed a mixed-methods approach of investigation. The quantitative research method was used as a measuring tool to test the theories and the hypothesis, while the qualitative research method was used to verify and support the results obtained from the quantitative method (Maree & van der Westhuizen, 2009; Welman, Kruger, & Mitchell, 2011), and also to gain further insight on matters that could have not been properly addressed by the quantitative questionnaire.

1.7.2.2 Sampling of sites and respondents

The sample used for this research was obtained on the basis of convenience sampling (Gilham, 2007; Struwig, Struwig, & Stead, 2001). Both the interviews and questionnaire were executed with conforming participants who could accord the researcher their time for the investigation. The sample involved chemical engineers from different chemical industries, having worked in different departments, and who obtained their bachelor's degree in engineering from different universities. The purpose for this was to have a varied background in terms of the type of education obtained, as well as variety in the work experience. Different South African traditional universities were also consulted to determine the trends in the South African engineering academia.

1.7.2.3 Data-collection techniques

Data collection involved searching for sources, accessing the sources, collecting the information, and studying it (Sarantakos, 1998, p. 203). This study made use of questionnaires, email comments, and semi-structured interviews.

1.7.2.4 Data analysis

Struwig *et al.* (2001) point out that data analysis helps to bring meaning to large amounts of data. The quantitative part of the questionnaire was measured with a Likert scale and consisted of 19 items rated on a scale of 1 to 5, with 1 being the extreme negative and 5 being the extreme positive. These quantitative data were analysed by means of descriptive statistical techniques, while the qualitative data were analysed by making use of constant comparative method (Maykut & Morehouse, 1994).

1.7.2.5 Reliability and validity

The validity of the measuring instruments was assured by asking questions that directly address research questions (Gray, 2004). For the qualitative study, interviews were conducted until no further new information emerged (Gray, 2004). The reliability and internal consistency of the quantitative measuring instrument, on the other hand, was measured by means of Cronbach Alpha coefficient (Field, 2013). Triangulation of the data was used to enhance the validity of the whole research enterprise (Creswell & Plano Clark, 2007).

1.7.2.6 Ethical issues

All participants were informed about the project and its purpose. No person was forced or intimidated in any way to take part in the study. It was made clear to the participants that participation was out of free will and that no incentives would be given as a result of taking part in the study. No personal information was required from the participants. To ensure anonymity and confidentiality no names or contact information were linked to any data received. For the purpose of documentation and record-keeping participants were assigned random numbers in order to protect their identities (Kelley, Clark, Brown, & Sitzia, 2003).

1.8 DEFINITIONS AND CLARIFICATION OF TERMS

The following terms are used as the key concepts of this research:

Chemical engineer

A university graduate professional with a four-year bachelor's degree (B.Eng.) or a bachelor of science (B.Sc. (Eng.)) degree in chemical engineering who works (or has worked) in the chemical industry.

Formal and informal training

Formal training refers to when a person has to attend a class or go through a structured programme to acquire a certain skill or knowledge. Informal training on the other hand is a process of teaching oneself a particular skill without having a structured programme.

Engineering drawing

The term engineering drawing refers to technical drawings that include various types of lines, dimensions, lettered notes, sectional views, and symbols. For the purpose of this study, the term also refers to three-dimensional models (computational and physical) translated from two-dimensional drawings, and assembly models. The terms "engineering drawings" and "technical drawings" are used interchangeably throughout this dissertation.

Use of technical engineering drawings (or engineering graphics)

Use of technical engineering drawings (or engineering graphics) pertains to dealing with technical drawings either in terms of creating the actual drawing, or even just having to read and interpret drawings.

1.9 CHAPTER DIVISION

Chapter 1 provides an overview of the study by describing the nature and scope of the research. The problem statement, research objectives, research methodology, and the layout of the study further contribute to this chapter.

Chapter 2 investigates how chemical engineering is defined and described in the literature survey. This chapter further looks at the uses of technical engineering drawings by chemical engineers. The benefits of engineering drawings for chemical engineers are discussed.

Chapter 3 discusses the research design and chosen methodology of the inquiry.

Chapter 4 presents and discusses the findings of the research.

Chapter 5 summarizes and presents the conclusion of the study. The chapter also demarcates any limitations of the study and makes recommendations based on the study of literature review and on the mixed-method style of inquiry for the improvement of practice.

1.10 SUMMARY

This chapter provided an overview of the research and discussed the purpose of the research. The problem statement and research objectives were stated. The method of investigation that was followed to achieve these objectives was also discussed.

CHAPTER 2

LITERATURE STUDY

2.1 INTRODUCTION

This chapter investigates how chemical engineering is defined and described in the literature study. The chapter looks at the current trends within the chemical engineering curriculum at universities and further investigates the uses of technical engineering drawings by chemical engineers. The benefits of engineering drawings for chemical engineers are also investigated.

2.2 ENGINEERING DRAWINGS

“An engineering drawing is a graphic product definition” (Dori & Tombre, 1995, p. 243). The purpose an engineering drawing is to accurately and unambiguously capture all the geometric features of a product, thereby fully and clearly describing the engineering requirements of the product.

Technical engineering drawings are the most important documents at the design, production, and cataloguing stages of a project (Singh *et al.*, 2014). The drawings are used as a graphical language by technical people to share ideas from one mind to another with the purpose of construction of a product (plant or equipment) (Barr, 2012). They are also used interdisciplinarily for the purpose of analysis and making deductions in the industry, as well as communicating product information among designers, manufacturers, subcontractors, customers, and quality assurance professionals (Weiss-Cohen, 2007; Sorby, 1999; Toghraei, 2014). The drawings are created and reproduced to be distributed to vendors, company archives, workshop floors, etc.

In most cases 2-D drawings still serve as the main design documentation that give instructions for manufacturing, fabrication, and assembly of products (Lee & Han, 2005). These types of drawings are usually a combination of three orthographic projections (top, front, and right views) that show the object’s edges, as well as the descriptive information such as dimensions, tolerances, manufacturing requirements, and textual annotations (Weiss-Cohen, 2007). Therefore a complete engineering drawing will include detailed drawings of all parts, all the necessary descriptive detail, as well as a drawing of the assembled unit.

The detailed format of the drawings is regulated by certain standards to ensure that the drawings can be interpreted in only one way in order to convey the intended message or idea, irrespective of the location of the initiator or the end-user (Wen *et al.*, 2011). Therefore different manufacturing fields use different types of layout depending on the purpose of the drawing. A plant layout drawing, for instance, outlines the building, work areas, isles, and equipment, all to scale, whereas an assembly drawing indicates the position and clearances of parts in an assembly. Assembly drawings also vary according to their application; i.e. design assemblies, working drawing assemblies, general assemblies, installation assemblies, and check assemblies. As a result this necessitates knowledge and a good understanding of the types and applications of the engineering drawings as the engineering disciplines are becoming more and more synchronised.

In today's age technical engineering drawings are done by means of Computer Aided Drawing/Design (CAD) programmes. CAD is a set of computer tools that aid in the drafting and design process. These tools are important as they form the basis of all engineering fields (Uçan, Ercan, & Ercan, 2012). These sets may include:

- CID – computer-integrated drafting;
- CAM – computer-aided manufacturing;
- CAE – computer-aided engineering;
- MRP – material requirement planning; and
- TTD – technical drawing and design, to list but a few.

These types of drawings (CAD drawings) are much more convenient to work with in that they can be easily manipulated for modifications and redesigns. But like any other language skill, engineering drawing requires some training in order to be properly comprehended. In many cases the engineering drawings can be used as a legal contract specifying what is expected from the contractors or manufacturers who have to commit resources in order to bring the idea into reality. In this regard a proper understanding of engineering drawings becomes crucial as these drawings can be used to protect either the engineer/designer or the manufacturer should the product not come out as expected. Consequently, all the relevant parties must be conversant with the relevant standards that are used so that the drawings can communicate the same message to all parties involved (Singh *et al.*, 2014).

Before the advent of CAD programmes in the 1980s technical drawings used to be done by hand and saved as hardcopies for reference and/or maintenance purposes. As today's trend is shifting more towards reverse engineering of products, i.e. old designs have to be remodelled in order to improve the existing product, it is inevitable that old design drawings will somehow need to be recreated. There are cases, however, where an old design has to be modified and an organisation finds itself with old drawings that are only available as hard copies. In some cases the CAD programme that was used to make the original drawing is not resourced by the organisation. In such cases the drawings would have to be read, accurately understood and interpreted, and redrawn from scratch by means of CAD. This task requires "skilled" personnel (Weiss-Cohen, 2007; Dori & Tombre, 1995). It therefore becomes crucial to be able to transform 2-D drawings to 3-D models, and vice versa (Dori & Tombre, 1995).

The ability to transform 2-D to 3-D, and vice versa, is sometimes compromised by failure to comprehend and visualise the engineering drawings. This inability to comprehend and visualise technical engineering drawings comes mostly due to their dual nature, i.e. the outline of the object itself, and the annotations including dimensions, instructions, etc. (Dori & Tombre, 1995). Therefore the successful interpretation and transformation of an engineering drawing can be achieved by considering both the graphics and the text together (Dori & Tombre, 1995), i.e. putting together the elements of knowledge retrieval and variation geometry (Weiss-Cohen, 2007). These elements involve understanding of the nature of 2-D engineering drawings and being able to analyse the dimensional scheme and topological relations (Weiss-Cohen, 2007). This means the engineer would first have to extract vital information from each view and then reconstruct the object by combining the orthographic views in her mind. This extraction process can be achieved as follows (Weiss-Cohen, 2007):

- Each view undergoes a mental "layer separation"
- Dimension-sets are aggregated from primitive components
- Annotation is further analysed
- Resulting dimension-sets are then associated with the corresponding object contours, or geometry sites.

According to Uçan *et al.* (2012) in order to master this extraction process and thereby be able to transpose between 2-D and 3-D, the technical engineering drawing subject must be taught at first-year level in all engineering departments. They suggest that the first term should be focused on teaching drawing and terminology in technical drawings as well as

introduction to computer usage in engineering, and in the second term the transformation of 2-D and 3-D in using CAD, CID, and CAE, etc. should be covered.

2.3 SPATIAL VISUALISATION

The transformation from 2-D to 3-D, and vice-versa, requires a spatial thought exercise whereby the person working with the drawing is able to extract the object from the whole drawing by separating the graphics from the text, but not neglecting the information, and combining the views in his mind (Dori & Tombre, 1995; Weiss-Cohen, 2007).

According to Sorby (1999) spatial ability differs from spatial skill in that the latter can be acquired by means of training, whereas the former is inborn. In the articles consulted for this research these terms are used as equivalents. Therefore, for the purpose of this dissertation the two terms are also used interchangeably.

Maier (1994) (as cited by Sorby, 1999) suggests that spatial skill is made up of five components, viz. spatial perception, spatial visualisation, mental relations, spatial relations, and spatial orientations. Tartre (1990) on the other hand, takes the spatial skill concept and divides it into two, viz. 3-D spatial visualisation and 3-D spatial orientation. She defines the construct of spatial visualisation as being able to mentally take an object, as a whole or only a portion of it, and rotate it in space, and she explains spatial rotation ability as the ability to fix an object in space and to be able to view it from different angles (Tartre, 1990).

It is highly likely that most engineering faculties may take for granted the importance of spatial training by making the assumption that a person is either born with or without the spatial ability (Sorby, 1999). However, research shows that this skill can be worked on and improved through engineering drawings (Sorby, 1999; Ault & John, 2010; Leopold, 2005).

A number of studies have indicated that working with 3-D CAD alone is not very effective in developing the visualisation skills of students (Sorby S.A., 1999; Leopold C., 2005; Ault & John, 2010). In a study conducted at Michigan Technological University (MTU), Sorby (1999) concluded that in order to develop 3-D spatial skill students need plenty of exercise in sketching hand-held models. He claims that the brain comprehends better with sight and touch combined, than with only seeing the model on a computer screen.

In 2004 Sorby (2009) conducted an empirical study with non-engineering students as sample to investigate what methods of learning technical engineering drawings were more effective in developing better spatial skills. The test lasted for ten weeks. The sample was made up of an experimental group and a control group. The experimental group was divided into three groups, viz. the software only, the workbook only, and the software and workbook group. Both the workbook and the software courses were composed of nine modules viz. (Sorby, 2009):

- Isometric pictorials from coded plans,
- Multi-view drawings,
- Paper folding/2-D to 3-D transformations,
- Object rotations about one axis,
- Object rotation about two or more axes,
- Object reflections and symmetry,
- Cutting planes and cross-sections,
- Surfaces and solids of revolution, and
- Putting together solid bodies (assemblies).

The outcomes of the study indicated that the group that used the workbook only performed significantly better than the control group, whereas the group that used the software only performed essentially the same as the control group. The group that used the workbook only and the workbook and software group did not show a significant difference (Sorby, 2009). This study supports previous studies which indicated that sketching of physical 3-D models is the key element of spatial visualisation skills development (Ault & John, 2010; Sorby, 1999; Sorby, 2009; Adanez & Velasco, 2004).

When following up on grades in other subjects that followed in the undergraduate studies, the results of this study showed that the average grade point average (GPA) for the experimental group showed a statistically significant difference (Sorby, 2009).

In longitudinal studies, it was shown that students who initially exhibited poor spatial skills and who participated in the spatial skills development course earned higher grades in a number of introductory engineering, mathematics, and science courses at the university when compared to students with weak spatial skills who did not participate in the course (Sorby, 2009, p. 477).

In another study conducted by Adanez and Velasco (2004) to assess whether engineering drawing has any positive effect on spatial visual ability, a visualisation test was given to a group of first year engineering graphics students. The tests took place at the beginning and at the end of the semester. The outcomes of the test showed that one-third of the sample increased their spatial visualisation ability (Adanez & Velasco, 2004).

An observation by Ault and John (2010) indicated that since the dawn of CAD programmes in the 1980s, most engineering schools have been paying less and less attention to the traditional descriptive engineering graphics to the extent that, in some cases, free-hand sketching has been completely eliminated. This, regrettably, has led to a significant diminution in spatial visualisation skills of engineering students (Ault & John, 2010), which Adanez and Velasco (2004) and view as crucial for engineers. For this reason the spatial visualisation skill development should receive attention, especially in cases where a person might need to use free-hand drawings to communicate and convey ideas (Sorby, 1999).

The spatial visualisation skills are thought to be an indicator of success in a variety of careers, particularly in engineering and science (Ault & John, 2010). In their study Adanez and Velasco (2004) concluded that technical engineering drawing is the suitable and relevant tool for improving spatial visualisation skills. Uçan *et al.* (2012) therefore suggest that the module must be offered to all engineering departments in the first semester of the first year of their engineering degree. The module can be distributed to cover the terminology and basic aspects of computer drawing in the first quarter, and in the second quarter the focus can be on transposition from 2-D to 3-D, and *vice versa* (Uçan *et al.*, 2012).

According to Sorby (1999) the acquisition of spatial visualisation skill is not necessary unless it is a requirement in the professional industry. Given this suggestion it is therefore necessary, for the purposes of this study, to determine whether chemical engineers in the industry do work with engineering drawings, and if so, for what applications.

2.4 CHEMICAL ENGINEERING AND TECHNICAL ENGINEERING DRAWINGS

As part of their job specification, chemical engineers can work as process engineers as well as plant and equipment designers. The responsibilities of a chemical engineer in chemical process industry (CPI) projects can be generally divided into two categories viz. equipment sizing and piping and instrumentation diagram (P&ID) development (Toghraei, 2014). While equipment sizing has got more to do with the determination of acceptable size for specific equipment components, depending on the application in the industry segment, piping and

instrumentation describes all process design features of a plant (Toghraei, 2014). This includes, but is not limited to, minor and major equipment; valves – including bleeders, safety relief, vents, etc.; instrumentation – gauges for flow rate, viscosity, pressure, etc.; stand-alone controllers; control buttons; and piping – all the tubes and pipes in the plant, including the utility pipes such as air, steam, fuel, etc. (AIChE ChEnected, 2010).

P&IDs are regarded as the touchstone for proper designs and maintenance of plants in the chemical process industries (Toghraei, 2014). These diagrams are used for the plant manufacturing and installation of piping, equipment and machinery, and efficient operation of the plant. P&IDs are usually created and used by various engineering disciplines working together. The following disciplines will have the following responsibilities and involvement with a P&ID in a CPI (Bhattacharyya, Shaeiwitz, Turton, & Whiting, 2012):

- Mechanical and civil engineers – design and install individual equipment;
- Instrument engineers – specify, install and check control systems;
- Piping engineers – develop plant layout and elevation drawings; and
- Project engineers – develop plant and construction schedules

These diagrams (P&IDs) are also frequently used in technical meetings for procuring equipment and hazard and operability (HAZOP) studies (Toghraei, 2014).

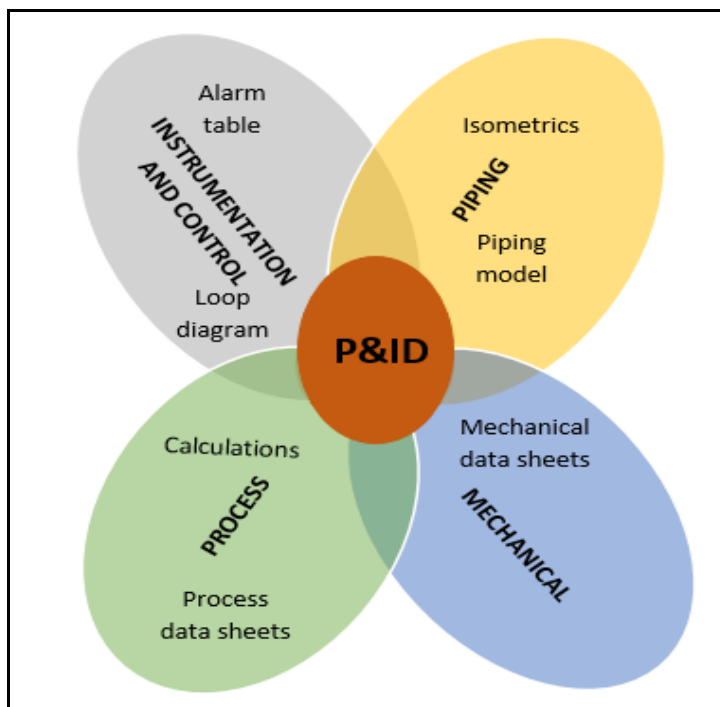


Figure 1 below shows the interrelations among other functions sharing essential engineering information in plant design.

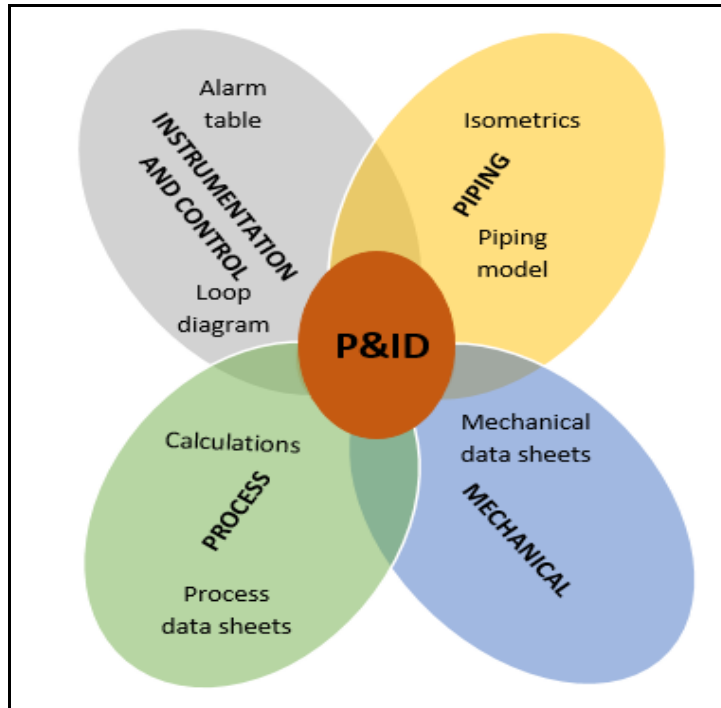


Figure 1: Central repository of essential engineering information (Toghraei, 2014)

The essence of plant design can be divided into two activities, viz. process design activities, which is the behavioural aspect of production, and engineering design activities which involves the plant layout and equipment design (Han *et al.*, 1999), see Figure 2 below. The arrows in the figure represent information being transferred from one office (department) to another.

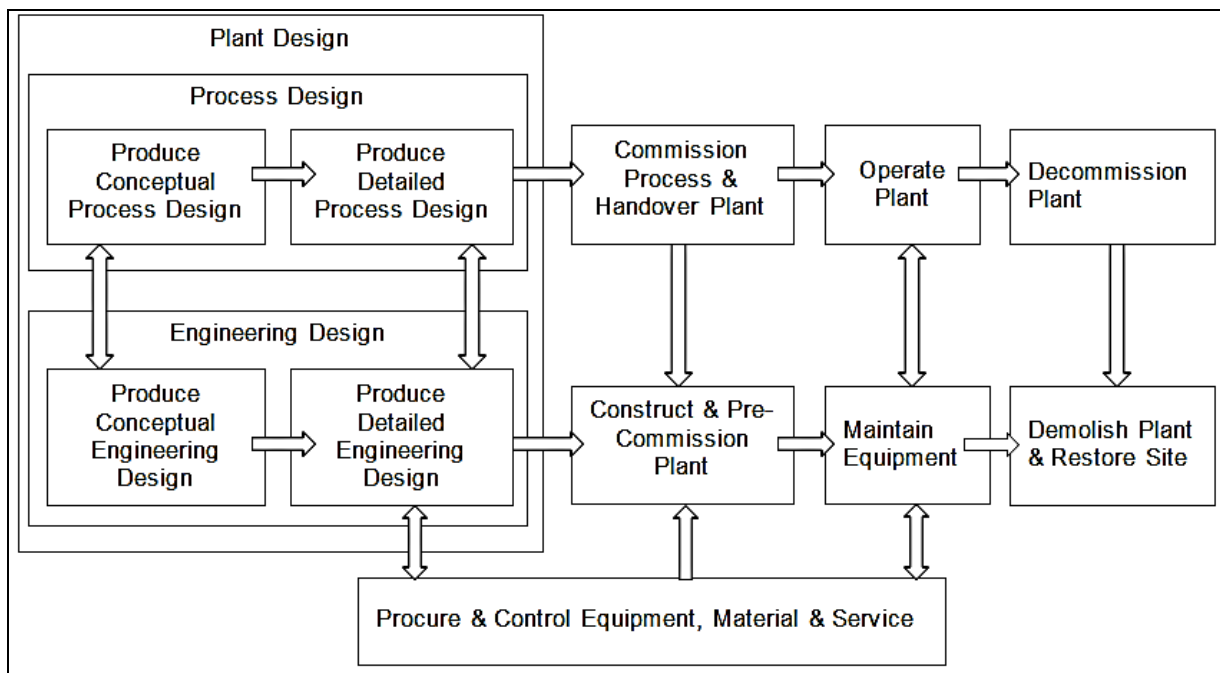


Figure 2: Plant Design - Process and Engineering Design Activity (PISTEP) modified from (Han *et al.*, 1999)

A plant design is composed of a facility model, which is a model that combines both the physical and the behavioural aspects of plant design, and enables the designer to manage both the topology and the geometrical information simultaneously (Han *et al.*, 1999). Therefore, when planning a facility model one should consider the process design requirements, which focus more on the product, as well as the engineering design activities which focus on the hardware of the plant (Han *et al.*, 1999).

Figure 3 below shows a facility design feature, which is divided into process design feature and engineering design feature. The process design feature, which focuses on pressures, temperature, production rate, etc., generates information in 2-D format (process flow diagrams, P&IDs) (Han & Lee, 1999). This 2-D information is required for the activities of the engineering design feature, which focus on the physical equipment and plant layout to produce other 2-D (layouts) and 3-D (solid models) information (Han & Lee, 1999). The dual arrow between the two features symbolises information transference (back and forth) between the process design and the engineering design features.

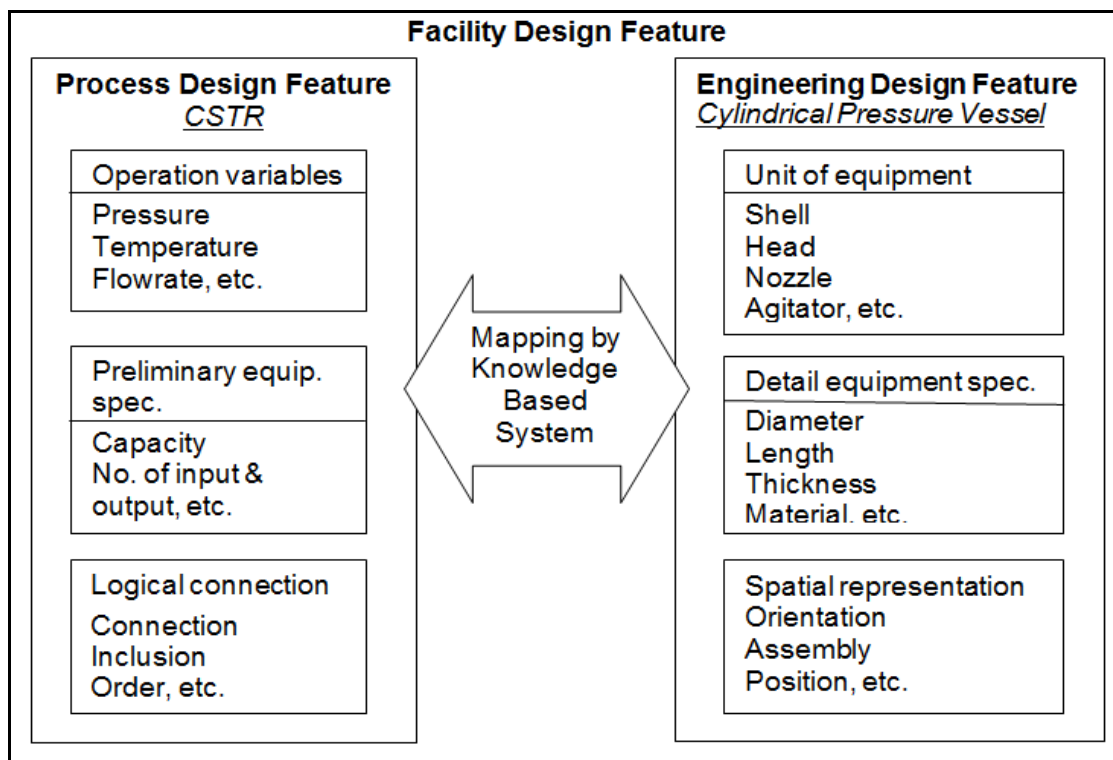


Figure 3: Facility design feature modified from (Han *et al.*, 1999)

It can be seen from Figure 2 and Figure 3 that communication between the two activities is crucial. However, Han *et al.* (1999) point out that information-sharing between process and engineering design activities introduces a challenge in the system as information generated

from process design, which is in 2-D, is not consistent with the 3-D information required for engineering design activities. Therefore this calls for the application of concurrent engineering which, according to Han and Lee (1999), is achieved by integrated information management.

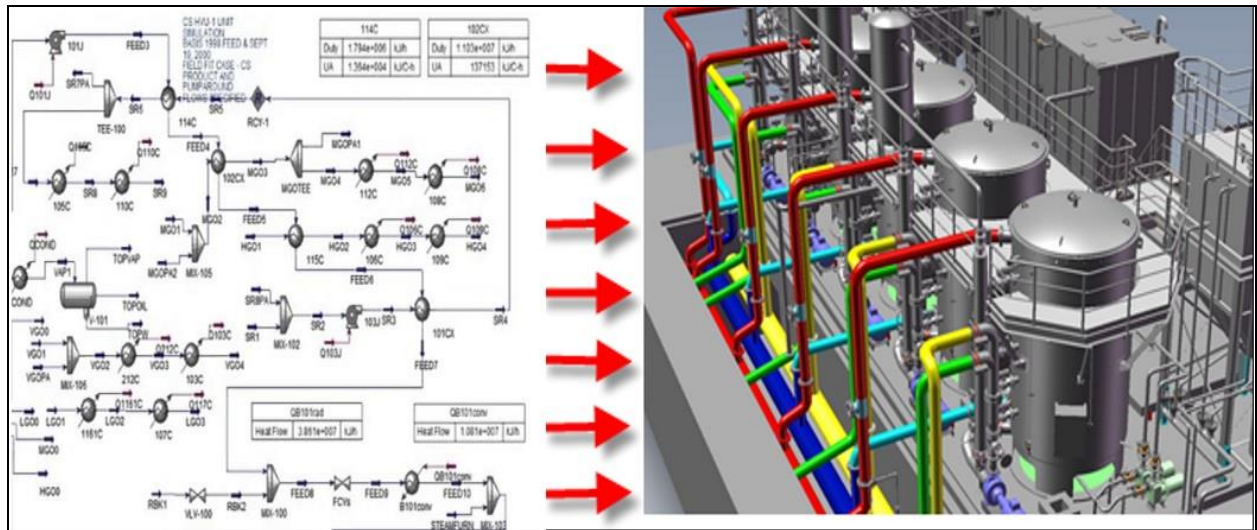


Figure 4: An example of a process design (left) and a 3-D design model (right)

As engineering disciplines are now becoming more and more synchronised, the increased use of computer design tools should be considered (Uçan *et al.*, 2012). Han *et al.* (1999) and Uçan, *et al.* (2012) both suggest that all activities involved in the process of plant designing should be in the form of CAD for the purpose of information management and effective communication between the two features. Figure 4 above shows a 2-D expression of a process design created in Aspen Hysys depicted on the left, and on the right is a 3-D model of an engineering design created in SolidWorks. This shows that an engineer working on either side of the facility design feature, i.e. process design feature or engineering design feature, must at least have a basic knowledge and understanding of the communication language i.e. technical engineering drawings, as well as the complementary programmes used (Uçan *et al.* 2012).

2.5 CHAPTER SUMMARY

This chapter looked at the current curriculum trends in chemical engineering at university level, both locally and internationally. The chapter also looked at the applications of technical engineering drawings, how they relate to chemical engineering, and what benefits could be gained from receiving training in engineering drawings, as well as how it should be offered.

In summary, this chapter has indicated that:

- Very few top chemical engineering universities offer engineering drawings for chemical engineering students;
- Chemical engineers work with drawings, especially in plant and equipment design, and therefore need to understand engineering drawings for communication purposes;
- Working with technical engineering drawings helps to develop and enhance spatial thought, which is deemed necessary for all engineering fields; and
- The technical drawing should be offered in a structured way – beginning with free-hand sketching and 2-D drawings to 3-D solid modelling of objects.

CHAPTER 3

RESEARCH DESIGN

3.1 INTRODUCTION

This chapter presents the research design of the study. The study employed both quantitative and qualitative methods (mixed-method) and in particular made use of a non-experimental survey design with self-designed questionnaire and semi-structured interviews. Further, the chapter gives a detailed overview of the selection of sites, sampling of respondents, and techniques for data collection and data analysis. Steps taken to ensure reliability and validity of the study are dealt with. Attention is given to ethical issues and the role of the researcher in this study is also described.

3.2 CHOICE OF RESEARCH DESIGN

Thomas (1998:172) in his book on classical methodology defines research design as:

...the arrangement of conditions for collection and analysis of data in a manner that aims to combine relevance to the research purpose with economy in procedure. It refers to the outline plan or strategy to be used in seeking an answer to the research question(s)...

The following section describes the research design adopted in this study.

The mixed method

The mixed method has been selected as a best-suited method for this study because using the qualitative approach together with elements of the quantitative research methods approach provided the researcher with the opportunity to capture the details about the problem under investigation and to add depth and context to the study. Mixed method design is an interactive method where both qualitative and quantitative methods are used, one before the other (irrespective of the order), or simultaneously (McMillan & Schumacher, 1993). The approach proved beneficial because it allowed the researcher to draw from the strengths of the quantitative approach and qualitative approach, and it minimizes the weakness of doing one-method studies (Johnson & Onweugbuzie, 2004). The mixed-method approach attempts to find a workable solution to the problem at hand by one method making up for the shortcomings in the other method (Johnson, Onwuegbuzie, & Turner, 2007; Ridenour & Newman, 2008; Winter, 2008). In addition, Mouton (1996) suggests that using multiple methods and techniques is most

effective for improving the quality of research. Mixed-method research can be classified into three categories, namely (Ridenour & Newman, 2008):

- Non-integrative method - the qualitative research is carried out first, followed by the quantitative research, or *vice versa*. During these processes the two methods do not inform each other as they serve different purposes.
- Simultaneous attempt - both the quantitative method and the qualitative method are used simultaneously towards the same end. Research, however, indicates that interpreting data from such a method may pose a huge challenge as these two methods operate on different assumptions and these different assumptions cannot apply simultaneously when interpreting data (2008; Welman, Kruger, & Mitchell, 2011; Morse, 2006; Morse, Marrett, Mayan, Olson, & Spiers, 2002).
- Interactive continuum method - both the qualitative method and the quantitative methods are necessary to “conceptualise research holistically” (Ridenour & Newman, 2008:29). In this type of mixed method the results obtained from the quantitative study can be used to determine which questions should be asked in follow-up interviews in the qualitative study, and feedback from the qualitative study can be used to determine which questions to focus on for the quantitative study, and *vice versa*. This enhances the validity of the research.

When using both qualitative and quantitative methods it is important to understand that each one gives a different angle to knowing about the world (Palinkas, *et al.*, 2013) and as such Ritchie (2003) and Layder (2013) caution that it should not be expected that the evidence generated from the one method will assimilate that which is generated from the other. Gardner (2009) notes several strengths of mixed-methods research which he states as follows:

They help to clarify and explain relationships between variables, they allow researchers to explore the relationships in depth, and they can help to confirm or cross-validate relationships discovered between variables. A quantitative study can identify if relationships exist between variables, but doing a mixed methods study adds the qualitative piece to help the researcher understand why the relationships exist (Gardner, 2009:142).

This research firstly attempted to determine whether chemical engineers in the industry are using engineering drawings and if so, to what degree. But since companies differ, experiences might also vary. Therefore the research had to also explore the “immeasurable” experience. Consequently, the Interactive Continuum method was followed for this research.

Quantitative research

Welman *et al.* (2011) describe quantitative research as an effort to ‘understand the facts of an investigation from an outsider’s perspective’. Quantitative research is used to test a theory or hypothesis (Ridenour & Newman, 2008). The rationale for using quantitative methods is described as using a non-experimental, survey method by using a questionnaire as an instrument of data collection (Creswell, 2009), to allow the research to focus on the relationships between the dependent variable (which, in the case of this research, is the exposure and experiences of chemical engineers in the industry) and the independent variable (the extent of use of technical engineering drawings in the industry).

Questionnaires are research tools used to elicit different perspectives on the same subject (Gray, 2004) by asking the same set of questions presented in the same order. There are benefits in using a questionnaire. A questionnaire has a short turnaround time in both data collection and data processing (Creswell, 2009). Depending on the purpose and the objective of the study some questionnaires may contain either one or both open-ended and closed-ended (selection) questions.

Closed-ended questions, or selection questions, are easier to analyse; however, they may limit the richness of alternative responses (Gray, 2004). Open-ended questions, on the other hand, present a potential for richness of response, that is, information that the researcher could not have otherwise thought of (Churchill & Iacobucci, 2002). To enhance the richness of the data the questionnaire contained both open-ended and closed-ended questions. The purpose of the questionnaire was to measure the objectives of the study (Gillham, 2007). Careful attention was given to the following elements when constructing the questionnaire (Gillham, 2007; Welman, Kruger, & Mitchell, 2011):

- The language and context of the questionnaire could be clearly understood by chemical engineers in the industry,
- Personal questions that could elicit any negative emotions were avoided,
- The questionnaire was short and mainly consisted of ‘select an option’ type of questions,
- Jargon and abbreviations were avoided and general terms were clarified in relation to this study to avoid confusion and misunderstandings,
- Clear instructions were given on how to answer each question,
- All the items addressed only one point per question. Twofold questions were avoided,

- All questions were relevant to the objectives of the study. No answer to any question could be found from any existing questionnaire,
- The questionnaire was neatly and clearly structured, all items were clearly indicated and sufficient space was provided for open-ended questions, and
- All the items of the questionnaire were constructed positively. No negative statements or questions were used.

The questionnaire used for this study was divided into five sections. The first section (Section A) captured the biographical information of the respondents. Section B focused on the experiences of the respondents with respect to working with technical engineering drawings in their daily jobs. Section C enquired on the type and method of training relevant for chemical engineers working with drawings in the industry. Section D aimed to conclude the questionnaire by determining the necessity of technical engineering drawings for chemical engineers. At the end of each section an open ended provision was made for any comment on the particular section. The last section, Section E, aimed to solicit any other information/topic relevant to the subject of this study that might have not been covered in the other sections by requesting any other comment, suggestions, or recommendations. Sections A to D of the questionnaire contained both closed questions measured on a Likert scale of 1 to 5, and open-ended questions. See APPENDIX B: QUESTIONNAIRE for the questionnaire.

Qualitative approach

The purpose of qualitative research is to gain an understanding of the nature of reality, extract meaning from phenomena, and draw up concepts and explanations (Ritchie, *et al.*, 2003). In this sense, qualitative research is used to build theory (Ridenour & Newman, 2008). Qualitative researchers try to make an analysis of the real world by getting the perspectives of the people that participate in that world (Welman, Kruger, & Mitchell, 2011). In a qualitative research method, data are first collected in a language format instead of numbers, and then analysed (Ridenour & Newman, 2008; Welman, *et al.*, 2011). From the analysis conclusions are drawn. A theory or hypothesis is then created based on these conclusions (Ridenour & Newman, 2008).

3.3 SELECTION AND DESCRIPTION OF SITES

The site considerations for this study focused on chemical industries within South Africa that employed chemical engineers with a four-year university degree. Taking the purpose of this research and the research questions into consideration, a research site with varied chemical engineering applications was sought (levels and types of experience). The rationale behind this is that different job requirements require different levels and applications of technical engineering drawings. The sample used for this study was obtained using a combination of

purposeful and convenience sampling (see Section 3.4.1). Due to logistics and time constraints the site selected for the purpose of interviews was in the areas of Vaal, Johannesburg, Pretoria, and Rustenburg.

3.4 THE RESPONDENTS

The participants for this study were engineers who are in possession of a B.Eng. (chemical) degree or a B.Sc. (in chemical engineering) degree – both four-year degrees, and who are working or have worked in the industry as chemical engineers.

3.4.1 Sampling strategy

A sample is chosen on the basis of it being representative of the whole population, that is, the sample must have similar characteristics to those of the population (Gray, 2004). Although the sample would ideally be hundred per cent identical to the population, practicality does not provide for this given the time and cost associated with the research, and also as the population could be made up of different sub-groups in one population. As a result this calls for a sample that will represent the actual population.

Non-probability sampling was used to select the sample used for the study. The respondents were selected on the basis of convenience sampling. Convenience sampling allows the researcher to interview respondents that are easiest to access (Welman *et al.*, 2003). Welman *et al.* (2003) suggest that the sampling process be carried out until the required sample size is reached, however, Layder (2013) urges that the required sample size is reached when new insights no longer emerge from the data. Care was taken to ensure that the available respondents conformed to the sample criteria defined for the purpose of this study. The researcher is aware that there are several sectors within the chemical engineering industry that may require different application levels of technical engineering drawings. The population focus of this research is chemical engineers who are working or have worked in the industry.

3.4.2 Sample

To achieve a balance between higher education curriculum and the industry needs, it is important that the concept of process versus product engineering be understood (Favre, *et al.*, 2008). Therefore to determine the current status of technical engineering drawings with regard to chemical engineers, traditional universities of South Africa offering a four-year chemical engineering degree were consulted for the trends in the South African engineering academia. This did not include Universities of Technology.

For the findings of a study to be generalised to a larger population the sample must share similar characteristics with the actual population (McMillan & Schumacher, 1993; Layder, 2013). To understand what the relation of chemical engineering to technical drawing is in the industry, the target population for this study was identified as chemical engineers who are working, or have worked, in the industry. The sample included engineers from different sectors in the industry. These participants were in possession of a B.Eng. (chemical) degree or a B.Sc. (in chemical engineering) degree – both four-year degrees. The reason for this requirement is that the universities involved in this study offer either one of the two degrees as a minimum for an engineering degree. Participants needed not be registered as professional engineers.

Contact list

The researcher sent the questionnaire to a list of 144 participants who fitted the description of the desired sample, acquired from a certain South African university. However, from this list only 23 responses were received. As suggested by Layder (2013), the researcher had to find other ways to get more participants for the study until no 'out of the ordinary' information emerged.

SAIChE

To increase the number of participants the questionnaire was sent to the South African Institution of Chemical Engineers (SAIChE) to distribute to its members. It was indicated that this questionnaire had been forwarded to all members of SAIChE. However, due to privacy and confidentiality regulations, it could not be confirmed that indeed the questionnaire had been sent to all SAIChE members. From this group only 20 responses were received. This brought the research sample to a total of 43 participants.

3.5 DATA COLLECTION

Data collection involves searching for sources, accessing the sources, collecting the information, and studying the information (Sarantakos, 1998). Mouton (1996) suggests that a choice of technique is determined by the research purpose. It is also generally accepted that when conducting research, the use of multiple sources of data collection will likely increase the reliability of the data as the findings are corroborated by the next source (Layder, 2013; Mouton, 1996; McMillan & Schumacher, 1993; Winter, 2000).

If the same measuring instrument is used under the same conditions, then the measured data should be the same in all the situations (Mouton, 1996). Many researchers argue that the data should have the same character, but in different situations (Golafshani, 2003; Ridenour & Newman, 2008; Palinkas, *et al.*, 2013; Field, 2013). Struwig *et al.* (2001) and (Winter, 2000) ascribe such an instrument to be “reliable” and Mouton (1996) and Welman *et al.* (2003) simplify it as “stable and consistency over time”. This research made use of the following data collecting methods: questionnaires, emails, and semi-structured interviews.

3.5.1 Questionnaire development

This research employed a questionnaire as a measured variable tool to test the hypothesised relationship in a more controlled way and to also give the distribution of the quantitative responses. In the same questionnaire, open-ended questionnaires were used for the qualitative part of the study to further gain the immeasurable insight into chemical engineering practices in the industry with regard to technical engineering drawings. The questionnaire is displayed in APPENDIX B: QUESTIONNAIRE of this dissertation.

In their book Churchill and Iacobucci (2002) prescribed a process for developing a questionnaire. Figure 5 below outlines the steps necessary for this process. For the purpose of this study the development of the questionnaire was summarized and implemented as follows:

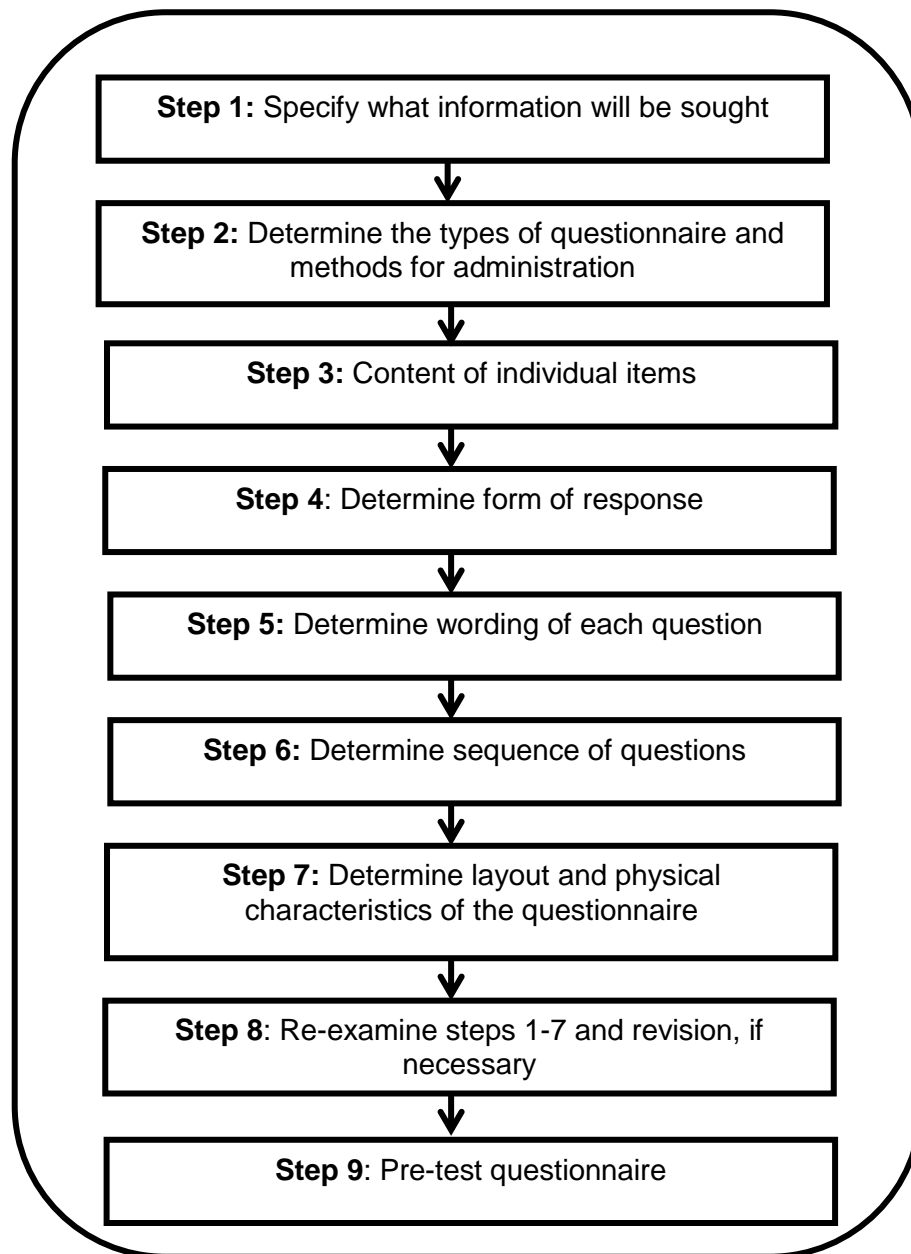


Figure 5: Questionnaire development process (Churchill & Iacobucci, 2002, p. 315)

3.5.1.1 Information sought

The aim of the questionnaire was to establish the involvement of chemical engineers with technical engineering drawings. To compile the questionnaire items a series of open-ended and unstructured interviews were conducted with chemical engineers who have worked in the industry. The aim of the unstructured interviews was to elicit key issues that have to be addressed with regard to the involvement of chemical engineers with technical drawings. No specific questions were posed to the interviewees. Instead, the background and purpose of the study were explained to prompt possible and relevant topics that should be addressed in the questionnaire so that the researcher could guard against designing a subjective questionnaire (Gray, 2004). Topics that emerged from these discussions were as follows:

- Chemical engineers work in functional teams and therefore do work with technical engineering drawings, but indirectly;
- Chemical engineers are not responsible for creating technical drawings;
- Not all chemical engineers have to make or edit engineering drawings;
- Chemical engineers mainly work with flow diagrams;
- Not all topics covered in the first-year curriculum of engineering drawings are relevant to chemical engineering;
- Engineering improved spatial thought ability;
- The need for engineering drawing application depends on where the chemical engineer works, and the type of work they do;
- Technical engineering drawings are more applicable when working in CPI projects;

When no more new ideas were received the questionnaire was then carefully constructed. From the above general points the following themes and questions emerged and are discussed further in Section 3.5.1.3:

- Work experience,
- Benefits of engineering drawing,
- Module content, and
- Training.

3.5.1.2 Distribution method

Contact between the researcher and the participants was done telephonically and electronically, and the questionnaires were sent out and back via email. A cover letter giving the background orientation of the study and assurance of anonymity and confidentiality was also attached (APPENDIX A: COVER LETTER). The questionnaire form was in PDF format and the completed form could be returned directly to the researcher by clicking the “submit” button on the form itself.

3.5.1.3 Format of the questionnaire

A total of 31 questions constituted the questionnaire. The questions included both closed- and open-ended questions. Of these 31 questions, 25 were multi-choice questions (APPENDIX B: QUESTIONNAIRE). The document was formatted in such a way that only one option could be selected. The questionnaire was divided into five sections (A-E) and each of the first four sections included an open-ended question for comments or recommendation on the section in discussion. However, based on the factor analysis the items were rearranged, grouped, and renamed as follows:

Biographical information

(Questions on the questionnaire: A1-A8)

This section inquired into the background of the participants. Information requested here was essential to determine how much influence each item had on the follow-up questions. Questions in this section relate to the type of degree, post-level qualification, years in the industry, experience in specific divisions, and whether the respondents had engineering drawing in their undergraduate studies or not.

Work experience

(Questions on the questionnaire: B9, B10, B11, B12, B15, B16)

This section looked into the experience of the respondents with regard to technical engineering drawings. The section sought to determine how involved chemical engineers are with the type of technical drawings discussed for this study. Based on reliability testing and assumptions, items B9, B15, and B16 were further grouped into one construct and named "Involvement with engineering drawings" which focused on the direct involvement of chemical engineers with technical drawings. Items B10, B11, and B12 were grouped and named "Responsibility of working with technical engineering drawings" with the aim of determining who usually creates technical drawings for chemical engineers.

Benefits of technical engineering drawings

(Questions on the questionnaire: B13, B14, D25, D26, D28, D29)

This section aimed to investigate whether there could have been any benefit in having done technical engineering drawings at university undergraduate level.

Module content

(Questions on the questionnaire: C20, C21, C22, C23)

The aim of this section was to establish how relevant the current module content being offered is with regard to the responsibilities of chemical engineers in the industry.

Training

(Questions on the questionnaire: C18, C19, D27)

This section sought to elicit recommendations on whether chemical engineers need to be learn technical engineering drawings, and if so, what the best method of training would be.

3.5.1.4 Pre-test questionnaire

After compiling the questionnaire items, the questionnaire was taken to four chemical engineers to ensure that the questionnaire was easily readable, understandable, interesting, and that it could be completed within the estimated time frame. The questionnaire was then improved and

randomly sent out to 50 respondents on the “contact list” with the intention of pilot testing. Only six responses were received over a period of approximately three weeks. Therefore the researcher decided to send the questionnaire to the rest of the list. When only a total of 43 responses were received from the whole sample the researcher decided to use the received responses as the main data for the study.

3.5.2 Interviews

An interview is a method in which the researcher or interviewer asks questions of the interviewee or participant while aiming at entering the inner world of the respondent and gaining an understanding of that person’s perspectives. Moris in his book (*A Practical Introduction to In-Depth Interviewing*, 2015) suggests that constructing an interview that is too detailed may limit the interviewee from sharing important information that may be significant to the research, but not directly included in the interview questions. At the same time interview questions that are too general may end up not addressing the research aims. Therefore the interview questions must be directed by the research questions and the general topic of the research (Moris, 2015).

The researcher chose one-on-one, semi-structured interviews to collect rich data, as an interview is one of the most essential sources of information (Neuman, 1997; Doody & Noonman, 2013). The semi-structured interviews allowed the researcher to vary the wording and order of the questions and gave the interviewee the opportunity to express more within the boundaries, while giving the interviewer the opportunity to dig deeper into areas she could have not thought of (Doody & Noonman, 2013; Moris, 2015; Gray, 2004). The respondents were given an option to choose an interview location that will be comfortable and convenient for them. The interviews were scheduled for thirty minutes to an hour.

The interview schedule (See APPENDIX C: INTERVIEW SCHEDULE) was guided by the research questions, and as semi-structured in nature, did not have too much detail. To ensure that the respondents could answer the questions asked the interview was centred on the following types of questions (Moris, 2015): background questions, experience, and opinions and values. The following themes constituted the core of the interview:

- Biographical information;
- Work experience;
- Chemical engineering and technical engineering drawings;
- Training; and
- Module content.

3.5.2.1 Test interviews

After the construction of the interview schedule test interviews were conducted with two respondents to ensure that the questions were clear and easy to understand, and also to establish the average time it took to complete the interview. When constructing the interview schedule careful attention was given to ensure that (Moris, 2015):

- Jargon was avoided;
- All questions were open-ended; and
- All the respondents could answer the questions posed.

3.6 DATA ANALYSIS AND QUALITY ASSURANCE

Data analysis involves breaking data down into smaller units, grouping it according to themes, and extracting meaning out of the data (Struwig & Stead, 2001; McMillan & Schumacher, 1993). The reliability of a data analysis is subject to 'clean' data, that is to say that data have to be captured accurately (Gray, 2004). Gray (2004) also suggests that, although it might require extra resources, it is recommended that two people enter the data separately and compare the results. The quantitative and qualitative data, however, are analysed and presented differently and it should be noted that the aim of the data strategies is to cross-validate the data obtained (McMillan & Schumacher, 1993). The different analysis strategies followed in this study are discussed below.

3.6.1 Quantitative data analysis

The statistical data collected by means of the questionnaire were analysed using SPSS (Statistical Package for the Social Sciences). Assistance with regards to guidance of tests to be conducted and confirmation of the data analysis was obtained from Statistical Consultation Services of the North-West University, South Africa. The data obtained were analysed by means of descriptive and inferential statistical techniques. These methods are described in detail in sections 3.6.2.1 and 3.6.3.2 below. The quantitative data were measured using a Likert scale of 1 to 5, with 1 being totally negative (i.e. totally disagree, very unlikely, or never) and 5 being totally positive (i.e. totally agree, most likely, or always) as applicable to the question, and consisted of 19 items.

3.6.2 Validity in quantitative data

The quantitative data were analysed using descriptive and inferential techniques. The purpose with the descriptive analysis technique was to give a clearer and more consistent picture of numeric data, i.e. depiction of the distribution, central tendency, or the skewness of the data (Struwig & Stead, 2001; Field, 2013), whereas the inferential analysis technique aimed to determine relationships among items and to draw conclusions beyond the data (Field, 2013; Gray, 2004). The following statistical analysis methods were used for the purpose of validating the quantitative data:

3.6.2.1 Descriptive statistics

The descriptive analysis organised and summarised the data so that it can be easily understood (Anthony, Onwuegbuzie, & Julie, 2012). The following descriptive analytical tests were conducted:

Mean

The mean, which is also known as the average, was determined for each item to give a central tendency of the data (Field, 2013).

Standard deviation

The standard deviation (s) measured how widely spread or how close the data points are to the mean (Field, 2013). For example, if a certain concept is measured and the standard deviation is high, this would mean that the opinions of the respondents on the matter are widely varied. The statistics consultant advised that, based on the sample size and the purpose of this study, a standard deviation of 1.8 would be acceptable. The items of this questionnaire obtained an average standard deviation of 1.1, with a maximum of 1.4.

Frequency distributions

Frequency distributions determine the number of occurrences of each score per item (Field, 2013) (see Table 6 in section 4.4.1 of chapter 4).

3.6.3.2 Inferential statistics

Inferential statistics are used to make conclusions about a population based on the characteristics of the sample (Anthony, Onwuegbuzie, & Julie, 2012). The following inferential analyses were conducted:

Cronbach's Alpha

The reliability and internal consistency of the measuring instrument for this study was measured by means of Cronbach's Alpha coefficient (McMillan & Schumacher, 1993). This test measures two parameters, namely: "variance within the item" and covariance between an item and any other item on the questionnaire (Field, 2013). A minimum acceptable value for the Cronbach's Alpha test is 0.7 (Field, 2013). Anything below 0.7 means the scale is statistically unreliable. The results for reliability analysis of the constructs of the questionnaire are discussed in Chapter 4.

Mann-Whitney

The Mann-Whitney test was used to compare two independent variables, that is, the p-value. There are two ways of calculating the p-values for this test viz. i) the asymptotic method - for large samples (>50), and ii) the exact method – for small samples (≤ 50) (Field, 2013). Since the sample obtained for this study was fairly small (43 participants) the exact method was used. According to Ridenour and Newman (2008) the outcomes of a quantitative study can be used to generalise from a sample to a population depending on the estimate of confidence. This study worked on a 95% confidence. Therefore a critical significance (p-value) value is 0.05. A p-value less than 0.05 is considered statistically significant, i.e. there is less than 5% chance that the conclusion is wrong (Field, 2013). Anything more than 0.05 is considered statistically non-significant, meaning that the results can be attributed to chance (Field, 2013). The practicality of the significance will be verified through in-depth investigations by means of interviews.

Spearman's rho

The Spearman's correlation (or Spearman's rho) looks at the strength and the relationship between items to see how they move together. This correlation also measures the effect size (Field, 2013). If the correlation between items is positive it means as one item increases (agrees) so does the other item. If the correlation is negative it means that as one item increases (agrees), the other one decreases (disagrees). The effect of the correlation is measured on the following scale (Field, 2013):

- r = 0.1 – weak correlation
- r = 0.3 – moderate correlation
- r = 0.5 – strong correlation

The purpose of the Mann-Whitney and the Spearman's rho tests was to compare how certain aspects of the respondents' background influenced their responses to other questions. The following aspect was of particular interest:

- **Years in the industry** – the comparison of the years spent in the industry with other constructs of the questionnaire will seek to determine whether there is any significant difference in response between respondents who have more years of practice and those who have less.

Effect size

The effect size was calculated to determine the extent of the experimental effect. The scale of the effect size is measured the same as the Spearman's rho correlation (Field, 2013):

- $r = 0.1$ – small effect
- $r = 0.3$ – medium effect
- $r = 0.5$ – large effect

The results and discussion on the tests conducted to ensure reliability and validity of the data obtained are presented in Chapter 4.

3.6.3 Qualitative data analysis

One of the most common approaches to analysing qualitative data is by objectively and systematically distinguishing similar characteristics within the data (McMillan & Schumacher, 1993). According to Maykut and Morehouse (1994) and Struwig and Stead (2001) qualitative data analysis begins with tabulation or categorising and coding of the data to find themes and patterns in the data. This process of categorising and coding the data helps the researcher to reasonably reconstruct it.

The qualitative data were analysed by making use of a constant comparative method (Maykut & Morehouse, 1994; Struwig & Stead, 2001). In this method each response was compared with the rest and classified accordingly. The items were then colour-coded and thereafter analysed. For this study a deductive method of coding was used, that is, the data was coded and categorised according to the themes of the quantitative data (Anthony, Onwuegbuzie, & Julie, 2012; Gray, 2004; McMillan & Schumacher, 1993). The next section discusses methods employed to validate and ensure the reliability of the data.

3.6.4 Validity in qualitative data

Since it was not possible to determine the total number of chemical engineers in the country to determine an appropriate sample (as the Engineering Council of South Africa (ECSA) could not provide such records, and neither did SAChE), the researcher accepted the questionnaires and conducted the interviews until no new or "out of the ordinary" responses to the open-ended questions became evident (Layder, 2013; Brenner, *et al.*, 1985). As Gray (2004) and McMillan and Schumacher (1993) suggest, these qualitative data are verified by the quantitative data.

In addition, the following criteria were implemented on the data collection and the data analysis strategies in order to increase the validity and reliability of the research (Morse *et al.* 2002; Maree & van der Westhuizen, 2009; Winter, 2000). Table 1 below describes how the following strategies were carried out during the data collection to ensure the validity of the research.

Table 1: Validity in qualitative data collection technique

Dada collection	
Strategy	Description
Respondents' checks	During each interview the summarized transcripts were read to the interviewee to confirm accuracy of the notes.
Multi-method strategies	This study makes use of triangulation (refer to section 3.7).
Participants' expressions	<ul style="list-style-type: none"> • Notes from interviews • Quotations from open-ended questionnaire questions and emailed comments were used
Negative cases or discrepant data	Any irregular or discrepant data were captured and recorded.

Source: Adapted from (McMillan & Schumacher, 1993)

To ensure validity in the qualitative data, Table 2 below describes the strategies that were carried out during the data analysis to ensure the validity of the research.

Table 2: Validity in qualitative data analysis technique

Data analysis	
Strategy	Description
Averting poor coding of qualitative data	The data were reviewed and sent to external coders for verification. The services of two colleagues (mechanical and chemical engineers) were obtained to assist in coding and categorising of the data (Morse <i>et al.</i> , 2002). For the items that were coded and categorised differently each coder had to motivate and a consensus was reached. This was done to verify the data classification and minimise sources of bias and also to obtain a varied view and interpretation of the data (Ridenour & Newman, 2008).
Averting researcher bias	Bias in information collection is a distortion in the data collected so that it does not represent reality. This can occur as a result of, for example, "leading questions that cause the interviewee to believe one answer would be preferred over another or questions posed in an unsystematic fashion" (Rubin & Rubin, 2005, 17) Precautions were taken against the expectations, and the need to find data that would confirm to the supposition of the study.
Averting selective use of data	Data were not exclusively picked to verify or falsify the outcomes.
Averting unsupported inferences	Generalisations were made solely on the research findings obtained and no inferences were made beyond raw data (Mouton, 1996).

Source: Adapted from (Maree & van der Westhuizen, 2009; Brenner, Brown , & Canter, 1985; Layder, 2013; McMillan & Schumacher, 1993)

3.7 RELIABILITY AND VALIDITY

The quality of the data analysed is, to a very large extent, determined by issues of validity and reliability of the instruments used to gather the data (Gray, 2004; Layder, 2013). Maree and van der Westhuizen (2009) further add that with data verification the output of the research must be consistent regardless of the time the data was collected or the application of the measuring method used. The following verification strategies were used as guidance to know “when to continue, stop, or modify” the research process for enhanced research validity and reliability (Morse *et al.*, 2002; Seale, 2004):

- *Methodological coherence*
The study was designed in such a way that there is a direct link and flow between the research questions and the components of the selected method of research (Winter, 2000; Welman, *et al.*, 2011).
- *Sample appropriateness*
Respondents who took part in the study were B.Eng. (chemical) and B.Sc. (chemical engineering) degree holders. The research inquiry was further extended to the ECSA committee, which is the board responsible for the undergraduate development of engineers in South Africa, and SAChE committee whose aim is to “promote high standards in the profession by enhancing the professional competence” (SAChE, 2013) and also to monitor chemical engineering education in South Africa and provide continuing education programmes for its members.
- *Concurrent collection and analysing of data*
The qualitative data were analysed as soon as being obtained in order to keep tabs on, and address any interesting aspects that may emerge, and also to avert repeating errors and weaknesses in the instruments (Layder, 2013; McMillan & Schumacher, 1993). The quantitative data had to be analysed only when all the responses had been received to give a complete descriptive picture.

According to Little (2011) research is verified if there is a body of evidence and an inference that supports the hypothesis, that is, the ‘jump’ from the evidence to the conclusions. The validity or acceptability of this ‘jump’ is dependent, not on whether the premises are true or not, but rather on the ability of the premises to support the conclusions (Mouton, 1996). Verification is therefore a process of ‘checking, confirming, and ensuring’ reliability and validity of a study by means of empirical data, observations, tests, or experiments (Little, 2011; Morse, *et al.*, 2002).

3.7.1 Reliability

One type of truth (validity) is reliability (Hammersley, 1992; Winter, 2000) which, according to the WordWeb Dictionary (version 7.03), is defined as the quality of being dependable. Even though according to literature inferences made from the qualitative data need not be validated, the research needs to generate a reliable data set, that is, data that are consistent and replicable over time (Welman, *et al.*, 2003)

Reliability has been explained by many researchers as the ability of the research results to have a consistent character across different situations, and over time (Golafshani, 2003; McMillan & Schumacher, 1993; Field, 2013). Reliability is essentially used to measure validity of research (Ridenour & Newman, 2008). Without reliability there cannot be a claim of validity, and without validity a research is as good as never been done. (Ridenour & Newman, 2008; Morse, 2006; Morse, *et al.*, 2002). This research used chemical engineers from different companies and different offices (different situations), and also considered different years of experience (over time) to determine whether the need for engineering drawing could be situational or perhaps experience-based.

To establish reliability in the research findings one has to ask the following question: “will the evidence and conclusions stand up to the closest scrutiny?” (Welman, *et al.*, 2011). The research instruments for this study were developed to address the objectives of the study, which answer to the research questions.

3.7.2 Validity

Wolcott (1973) cited by (Ridenour & Newman, 2008) recounts the sequential development of validity over the past three decades prior to his writing as having started from “test validity” to “validity of test data” to “validity of test and measurement data” to “validity of the research data on test and measurement”, and finally, the “validity of research” itself, which is what this study aims to achieve.

Winter (2000) and McMillan and Schumacher (1993) explain that the main cause of invalidity in many researches, both quantitative and qualitative methods, is the incompatibility of the research methodology to the purpose of the research. Table 3 below attempts to link the data collection techniques with the purpose of the study through the breaking down of the research questions.

Table 3: Linking research questions to data collection techniques

Questions	Technique	Purpose
To what extent do chemical engineers need the technical engineering drawing skills?	Questionnaires; Interviews	Explore the fields / divisions of the chemical engineering industry to determine how much the skill is required.
Does the Engineering Drawings subject, as was taught at university, benefit the type of work done by chemical engineers in the industry?	Questionnaires; Interviews	Find out if the formal training received is a matter of necessity and if it was beneficial in any way.

Measurement validity evaluates how well the instrument measures what it intends to measure whereas the design validity focuses on internal and external validity (Winter, 2000; Welman, *et al.*, 2011; Field, 2013). With validation of a measuring instrument the inferences and conclusion of the study can be accepted as valid (Shultz & Whitney, 2004).

Validity in quantitative research necessitates both internal and external validity as well as measurement validity, and reliability to assure that the test, data, or design do measure or reflect that which it intends to measure or reflect (Layder, 2013; Morse, *et al.*, 2002; Gray, 2004).

3.7.2.1 Internal and external validity in quantitative research

The internal validity of the design is directly dependent on the measurement validity of the research and its reliability (Ridenour & Newman, 2008). Internal validity looks at whether the findings of the study were influenced by any other factor being investigated (Winter, 2000; McMillan & Schumacher, 1993). This study made use of the Mann-Whitney test and the Spearman's rho correlation test (refer to section 3.6.3.2 above). External validity, on the other hand, is the extent to which the data of the research can be generalised to a larger population (McMillan & Schumacher, 1993; Maree & van der Westhuizen, 2009). Since it can be argued that the generalisation of the data is only relevant to a particular setting or group, Gray (2004) suggests that in order to make argument for generalisation stronger, studies should be taken out with different participants under different conditions. He reckons that if the findings can be replicated it will enhance the external validity of the study. The sample considered for this research comprised chemical engineers who work in different sectors within the chemical

engineering industry. In this regard, the field may be the same but the job requirements and the application of technical engineering drawings may differ from company to company.

3.7.2.2 Validity in qualitative research

When using structured and semi-structured interviews, the validity of the research can be increased by ensuring that that questions asked directly address the research objectives (Mouton, 1996). In cases of very few interviews a survey should be used to verify the data (Gray, 2004). Mouton (1996) suggests that to strengthen the validity of the research the premises or evidence used to support the truth or likelihood of a conclusion highly probable, if not true, must also be relevant to the conclusion made.

3.7.3 Triangulation (quantitative and qualitative research)

Triangulation involves using two or more strategies of collecting data in the same design. This method is used in mixed-methods to verify the results of one method by comparing it to the outcomes of the other (Maree & van der Westhuizen, 2009; Welman, *et al.*, 2011; Moris, 2015). Triangulation, in this research, was used to compare the outcomes of the questionnaire (quantitative) to the open-ended questions, emailed comments, and the interview responses (qualitative). The data from all these strategies is expected to positively correlate (Maree & van der Westhuizen, 2009).

3.8 ROLE OF THE RESEARCHER

The researcher is considered the main role player in any research process. Therefore the roles of the researcher included, but are not limited to:

- Developing the measuring instruments which, in this case, are the questionnaire and interview schedules;
- Administering the questionnaire;
- Conducting the interviews; and
- Analysing and interpreting of data.

3.9 ETHICAL ISSUES

Ethics in social research is meant to protect the rights and welfare of the research subjects. Ryen (2004) describes ethical considerations as centred on the following main issues (see Appendix A: Cover Letter).

3.9.1 Informed consent

All participants were informed about the nature of the research and its purpose. No person was forced or intimidated in any way to take part in the study and the subjects were made aware of their right to withdraw at any time without any negative consequences. Participation was out of free will.

3.9.2 Confidentiality

No personal information was required from the participants. To ensure anonymity and confidentiality no names or contact information were linked to any data received. For the purpose of documentation and record-keeping participants were assigned random numbers and letters in order to protect their identity (Mouton, 1996).

3.10 SUMMARY

This chapter discussed the research design chosen for this study. The study followed a mixed-method research design and made use of self-designed questionnaire and semi-structured interviews. The selection of sites and sampling was described as well as the techniques applied to collect and analyse data. Measures taken to ensure reliability and validity of the study were discussed, and attention was also given to the ethical issues pertinent to the data collection. The next chapter deals with the results obtained from the study.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The purpose of this investigation was to determine whether the decision taken by some of the local universities to terminate technical engineering drawings for chemical engineers is something all universities can consider, or whether the decision needs to be revisited. The empirical investigation was carried out to answer the two research questions stated in section 1.4 of this dissertation.

The empirical investigation revealed that it is generally important for chemical engineers to be able to read and understand technical engineering drawings ($\bar{x} = 4.70; s = 0.636$). This is because chemical engineers often have to read and interpret technical drawings ($\bar{x} = 4.24; s = 0.983$). The background acquired in this subject helped to develop the spatial visualisation skill of chemical engineers ($\bar{x} = 4.28; s = 0.826$) and consequently this helps when working with P&IDs ($\bar{x} = 4.21; s = 1.001$).

To put the picture together this chapter presents and discusses the findings of both the quantitative and qualitative investigations - in the order of the research questions (Gillan *et al.*, 1998). Extracts of the qualitative data are presented in the qualitative sections to give grounds for the interpretation. These excerpts are presented in *Italics* and are separated using inverted commas “ ”. Square brackets [] are used within the excerpts to include explanatory text and make sense.

In the sections that follow, the chapter first gives the biographical data of the respondents. The frequency and correlations analysis are done next, followed by the qualitative analysis. The last section is a summary of the findings corresponding to the particular research question. The results and findings are based on a questionnaire survey and interviews conducted with chemical engineers working in the industry. The frequency analysis of the data collected was analysed using SPSS (Statistical Package for the Social Sciences) with help from the Statistical Consultation Services of the North-West University, South Africa. Percentages in brackets are rounded off to the nearest whole number.

4.2 BIOGRAPHICAL DATA

This section presents background information of the respondents. Questions were asked to establish the type of training and qualification the respondents had and to also determine how long they have been practising as chemical engineers in the industry. The purpose of this section was to establish whether there are patterns or relationships between the responses and the background of the respondents.

Type of degree

Eighty-four percent (84%) of the respondents indicated that they have a Bachelor's degree, while 12% indicated a Bachelor of Science (in Engineering) degree. Only 5% of the respondents selected "other" qualifications. Of these two (5%) respondents one indicated having an M.Eng degree which would mean that the undergraduate qualification had been a B.Eng degree, while the other one is registered with ECSA as a professional engineer (PrEng) which according to ECSA is attainable with a minimum of a four-year degree in engineering. Table 4 below gives a summary of the type of degree held by the respondents.

Table 4: University qualifications

Type of degree	%
B.Eng.	84
B.Sc.	12
Other	5

Year obtained

The data show that the earliest degree was obtained in 1982 and the most recent was in 2007. This indicates that the sample obtained graduated before the engineering drawing subject was taken away by some of the universities. This presented a limitation for the research as experiences of chemical engineer who have never had the subject at university could not be explored. However, since this is an explorative study, the aim is to determine whether chemical engineers do work with engineering drawings to the extent that they need to do it in their undergraduate studies.

Other qualifications

The aim of this question was to see whether the respondents had obtained additional qualifications that could perhaps influence their involvement with engineering drawings. Forty-nine per cent (49%) of the respondents had post-graduate qualifications. These additional qualifications ranged from M.Sc. Eng., M.Eng., PhD, and other management qualifications.

Years in the industry

This question was aimed at determining the respondents' years in the industry in order to see whether the time spent in the industry had any effect on the participants' experience and involvement with engineering drawing. Twenty-one percent (21%) of the respondents had six to eight years' experience, while only 7% had nine to ten years', and 72% had more than ten years' experience. As a result of the data distribution and for the purpose of statistical analysis and inferences this question was divided in "less than 10 years' experience" and "greater than 10 years' experience". The summary of years spent in the industry is given in Table 5 below.

Table 5: Years spent in the industry

Years in the industry	%
6 – 8	21
9 – 10	7
More than 10	72

Did you have Engineering Drawing in your undergraduate studies?

This question aimed to determine how many of the respondents had had engineering drawing in their undergraduate studies. Ninety-eight percent (98%) did have engineering drawing in their undergraduate studies. Only 2% (1 respondent) of the participants did not have the subject. Interestingly enough, this 2% respondent has never taken an extra drawing class, and indicated further on in the questionnaire that they work with engineering drawings very often.

Have you ever taken any extra class for engineering drawing?

To follow up on the previous question respondents were asked if they have ever taken any additional course for engineering drawing. Twelve per cent of the respondents agreed to having had an extra class while 88% said no, they did not.

All participants had had a minimum of six years working in the industry. Of all 43 respondents only one person did not have engineering drawing over the course of undergraduate studies. Twelve per cent (12%), however, indicated having taken an extra class for drawing. This percentage does not include the one person who indicated not having had drawing at undergraduate level.

4.3 RELIABILITY RESULTS

To work with the mean scores of constructs each item of the questionnaire must be tested for homogeneity or internal consistency. When tested, items forming a single construct should give a high correlation, which reflects the internal consistency of the items. Since the sample size for this study is small it is critical that only the reliable constructs of the measuring instruments be considered. To test the construct reliability of the questionnaire this research made use of the Cronbach's alpha coefficient as discussed in section 3.6.3.2 in chapter 3 of this dissertation.

For the reliability of the questionnaire, items that had negative correlations with other items of the same construct were removed and therefore only correlating items were considered and the results are as follows:

Involvement with technical engineering drawings (9, 15, 16)

This section obtained α of 0.71, which indicates that the construct was reliable and therefore an average score could be considered.

Responsibility of working with technical engineering drawings (10, 11, 12)

This section obtained α of -1.09, which violates the reliability model assumptions. This means that the construct was not reliable as it could only obtain a maximum Cronbach's Alpha of 0.27 if an item was removed. As a result, this whole construct was removed. Items constituting this construct will therefore be considered individually.

Benefits of technical engineering drawing (13, 14, 25, 26, 28, 29)

This section gave α of 0.858, which indicates that the construct was reliable, and therefore an average score can be considered for each response.

Module content (20, 21, 22, 23)

The *module content* section obtained α of 0.828, which indicated that the section was reliable and therefore an average score could be determined for each respondent.

Training (18, 19, 27)

This section, with all three items considered, obtained α of 0.133, which is too low for the construct to be considered reliable. When item C19, which had a negative correlation with other items, was removed, α increased to 0.838. However, this leaves too few items to make up a construct. Because this study intends to determine what type of training is required for chemical engineers, the items of this construct were addressed individually.

4.4 MEAN SCORES AND CORRELATION OF CONSTRUCTS AND ITEMS

4.4.1 Mean scores of items

Table 6 below presents the frequency distribution and mean scores of the individual items of the questionnaire. The data presented in this table are discussed in section 4.5.1 and section 4.6.1 below.

Table 6: Frequency distributions

Item	Question	1 (negative)	2	3 (neutral)	4	5 positive	Mean	Std. Deviation
B9	How often have you had to read and interpret technical drawings?	0.0	7.1	16.7	21.4	54.8	4.24	0.983
B10	In the companies I have worked for, the chemical engineer does the drawings.	19.5	36.6	24.4	9.8	9.8	2.54	1.206
B11	In the companies I have worked for, specialized drafting technician does the drawings.	2.3	7.0	11.6	27.8	51.2	4.19	1.052
B12	In the companies I have worked for, drawings are outsourced.	44.2	18.6	14.0	16.3	7.0	2.23	1.360
B13	The background knowledge of engineering drawing helps when doing P&IDs.	2.4	4.8	11.9	31.0	50.0	4.21	1.001
B14	Background knowledge of engineering drawing helps when doing flow diagrams.	2.3	9.3	11.6	25.6	51.2	4.14	1.104
B15	Chemical engineers work with drawings at management level.	4.7	14.0	18.6	30.2	32.6	3.72	1.202
B16	Chemical engineers work with drawings at non-management level.	4.7	2.3	4.7	34.9	53.5	4.30	1.013
C18	The drawing skills required for chemical engineers require formal training.	2.3	11.6	9.3	46.5	30.2	3.91	1.042
C19	The drawing skill required for chemical engineers can be acquired by self-training.	23.3	23.3	25.6	25.6	2.3	2.60	1.178

C20	Chemical engineers need to learn about geometric tolerances as required in detail design.	7.0	14.0	34.9	27.9	16.3	3.33	1.128
C21	Chemical engineers need to learn about assemblies (how individual parts fit and operate together).	2.4	17.1	17.1	39.0	24.4	3.66	1.109
C22	Orthogonal projections are relevant for chemical engineers.	15.4	25.6	10.3	30.8	17.9	3.10	1.392
C23	Computer generated 3-D models are relevant for chemical engineers.	0.0	12.2	9.8	26.8	51.2	4.17	1.046
D25	I acquired some fundamental engineering thinking skills from doing engineering drawing during my undergraduate studies.	2.3	11.6	11.6	44.2	30.2	3.88	1.051
D26	Engineering drawing helped me to develop a higher level visualization skill (spatial thought).	0.0	2.3	16.3	32.6	48.8	4.28	0.826
D27	I would recommend that chemical engineers should have the engineering graphic skill to create drawings.	11.6	4.7	9.3	23.3	51.2	3.98	1.371
D28	It is important to be able to work with computer generated 3-D models.	2.7	7.0	16.3	37.2	37.2	4.00	1.024
D29	It is generally important to be able to read and understand technical drawings.	0.0	2.3	2.3	18.6	76.7	4.70	0.638

4.4.2 Mean scores of constructs

Table 7 below gives the results of the mean factor of each construct. The mean of the constructs that were considered not reliable, i.e. obtained a Chronbach's α of less than 0.7, were not considered. However, items in those constructs were considered separately. The findings of Table 7 below are discussed in section 4.5 and section 4.5.4 of this dissertation.

Table 7: Mean scores of constructs

Construct	Mean	Std. dev.
Involvement with technical engineering drawings	4.1	0.85
Module content	3.6	0.94
Benefits of technical engineering drawings	4.2	0.73

4.4.3 Correlation between items and constructs

The Spearman's rho test was conducted to compare independent variables to see how two items relate and influence each other (see section 3.6.3.2). Table 8 below gives correlations between selected items of the questionnaire and constructs.

Table 8: Spearman's rho correlations

	Years spent in design	Years spent in process control	Years spent in management	Years spent in R&D	Years spent in other offices	Formal training	Self-training	CEs to create drawings	Involvement with technical drawings	Benefits of drawing
The drawing skills required for chemical engineers require formal training	0.1	-0.1	0.1	0.1	0.3	1.0				
The drawing skills required for chemical engineers can be acquired by self-training	0.2	-0.1	0.001	-0.2	-0.1	-0.394**	1.0			
I would recommend that chemical engineers should have the engineering graphics skill to create drawings.	0.337*	0.01	0.02	0.04	0.02	0.657**	-0.2	1.0		
Involvement with technical engineering drawings	0.378*	-0.1	0.04	-0.1	0.1	0.657**	-0.1	0.677**	1.0	
Benefits of technical engineering drawings	.328*	0.1	-0.1	0.01	0.1	.653**	-0.3	.641**	.715**	1.0
Module content	0.2	0.2	0.1	-0.1	0.1	.426**	-0.2	.474**	.578**	.616**

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

4.4.4 Mann-Whitney significance results

The Mann-Whitney test was conducted in order to determine whether there is any significant difference in response between respondents who have more years of practice in the industry and those who have less.

Question A4 in the questionnaire (see APPENDIX B: QUESTIONNAIRE) was aimed at determining the respondents' years in the industry to see whether the time spent in the industry had any effect on the participants' experience and involvement with engineering drawing. The collected data showed that 28% of the respondents had less than ten years' experience while 72% had more than ten years' experience. Table 9 below gives the results of the statistical significance between the two to see whether the results obtained were not dependent on chance, and the effect size to determine the extent to which the results are applicable to the actual population.

Table 9: Significance results for years spent in the industry

Construct	Mean rank		P-value	Effect size
	Less than 10 years	More than 10 years		
The drawing skills required for chemical engineers require formal training.	18.5	23.4	0.27	0.19
The drawing skills required for chemical engineers can be acquired by self-training.	23.6	21.4	0.60	0.08
I would recommend that chemical engineers should have the engineering graphics skill to create drawings.	19.8	22.9	0.48	0.12
Involvement with technical engineering drawings	19.2	23.1	0.34	0.14
Benefits of technical engineering drawing	20.9	22.4	0.72	0.06
Module content	20.3	22.7	0.58	0.09

It is observed from Table 9 above that there is no statistical difference between respondents who indicated having worked in the industry for less than ten years and those who have worked for more than ten years. The lack of statistical significance and the effect size measured among variables that were tested enabled the researcher to understand the respondents' variances based on the number of years spent in the industry. Therefore, it is safe to say that the need for engineering drawings for chemical engineers and the use thereof, is the same throughout all levels of years' experience.

4.5 FINDINGS OF RESEARCH QUESTION 1:

The findings of the respective constructs and items of the questionnaire that were aimed to answer to the first research question have been analysed according to the methods described in Chapter 3 and are both represented and discussed below.

RQ 1: To what extent do chemical engineers in the industry work with technical engineering drawings?

To determine the relevance of technical engineering drawings to the type of work done by chemical engineers it was necessary to first establish whether chemical engineers in the industry do work with technical engineering drawings, and also whether the requirement of working with these types of drawings was dependent on anything else besides being qualified as a chemical engineer.

4.5.1 Frequency analysis

This section gives the distribution of the responses to the individual items of the questionnaire. The alpha-numeric references in the brackets refer to the questionnaire items presented in Table 6 of this chapter.

4.5.1.1 Involvement with technical engineering drawings

From the sample that took part in the questionnaire 7% of the respondents indicated that they seldom worked with drawings. Seventeen per cent (17%) said occasionally, 21% frequently, and 55% indicated that they work with drawings very frequently. No respondents indicated never having worked with drawings (B9).

A mean score of 3.72 with a standard deviation of 1.20 suggested that chemical engineers work with technical drawings at management level (Q: B15), while a mean score of 4.30 with a standard deviation of 1.04 suggested that chemical engineers work with technical drawings at non-management level (B16).

The mean score of 4.1 as reported in Table 7 for the construct of *Involvement with Technical Engineering Drawings* indicates that chemical engineers frequently work with technical engineering drawings and as suggested in the literature the results of this construct indicate that the requirement to work with drawings extends to both management and non-management chemical engineers. The standard deviation of 0.85 shows that the responses to the questions in this construct were close to the mean score of the construct. This means that a large percentage of the respondents tended to agree that chemical engineers are involved with technical drawings both in management and non-management.

4.5.1.2 Responsibility of working with technical engineering drawings

When asked which division mostly works with engineering drawings (A6), 88% of the respondents selected design to be the division that works with drawings the most, while 5% selected process control, and the remaining 7% selected other.

This construct indicated that chemical engineers may be responsible for creating drawings, but to a very small degree. Question A6 revealed with 88% that technical engineering drawings are mostly utilised in the design office. These results indicate that even in the design office the responsibilities of a chemical engineer do not largely extend to creating technical drawings. However, only 20% agreed that in the companies they have worked for the chemical engineers do the drawings (B10). It was observed that most companies rather prefer to have their own drafting technicians who are responsible for the drawings (B11) – 28% agree and 51% totally agree to this statement. Sixteen per cent (16%) agreed and 7% totally agreed that in the companies they have worked for the technical drawing services are outsourced (B12).

4.5.2 Correlation between items and constructs

In an attempt to answer the first research question, the following correlations between constructs and items of the questionnaire were analysed.

4.5.2.1 Strong correlation results

A strong correlation of 0.677 was observed between the construct (Involvement with technical engineering drawings) and item (I would recommend that chemical engineers should have the engineering graphics skill to create drawings) (see Table 8). This correlation gives evidence that the skill acquired from engineering drawings subject is necessary for the type of work required in the industry. Technical engineering drawings seem to be utilised more in the design office. The mean of 3.98 with a standard deviation of 1.37 (see Table 6) for the item (I would recommend that chemical engineers should have the engineering graphic skills to create drawings) suggests that it is necessary for chemical engineers to have some level of engineering drawing knowledge, even if it is at a basic level.

The item (The drawing skills required for chemical engineers require formal training) showed a strong correlation with construct (Involvement with technical engineering drawings), (Benefits of technical engineering drawings), and item (I would recommend that chemical engineers should have the engineering graphics skill to create drawings).

The correlation of 0.657 with the construct (Involvement with technical engineering drawings) (see Table 8) shows that the way in which chemical engineers learn engineering drawing has an influence on the type of skill they acquire with regard to what is expected of them in the industry. The mean of 3.91 and a standard deviation of 1.04 (see Table 6) therefore suggest that the level of skill required in the industry does require formal training.

Another strong correlation of 0.657 observed in Table 8 between the item (The drawing skill required for The drawing skills required for chemical engineers require formal training) and item (I would recommend that chemical engineers should have the engineering graphic skills to create drawings) tells that the way in which the subject is offered has an influence on the recommendation for the subject. With the mean of 3.91 and standard deviation of 1.04 (see Table 6) for the item (The drawing skills required for chemical engineers require formal training) it is safe to say that engineering drawings is better offered in a formal class setting.

The implications of the strong correlation between the item (The drawing skills required for chemical engineers require formal training) and the construct (Benefits of technical engineering drawings) are discussed in an attempt to answer research question 2 (see section 4.6.2.1 below).

4.5.2.2 Moderate correlation results

A moderate correlation was observed between the construct (Involvement with technical engineering drawings) and item (Years spent in design office). Literature has indicated that chemical engineers are responsible for various tasks and as such, they also work with various types of drawings. The type of drawings the engineer works with is dependent on the industry as well as the department/project they are involved in. The moderate correlation of 0.38 with a statistical significance of 0.01 observed in Table 8 between this construct and item indicates that the use of technical engineering drawings is more prevalent in the design office as compared with most offices/departments. This can be verified by the lack of correlation with other types of engineering offices the respondents have worked in (see Table 8).

The item (I would recommend that chemical engineers should have the engineering graphics skill to create drawings) with a moderate correlation of 0.337 as reported in Table 8 to the item (Years spent in design office) indicated that the office in which the chemical engineer operates has an influence on their need for engineering drawing. In this case engineering drawing is recommended more if the engineer works in the design office.

4.5.3 Qualitative analysis

This section discusses the qualitative data that were obtained with the purpose of getting answers to the first research question.

4.5.3.1 Involvement with technical engineering drawings

In industry projects chemical engineers usually work in multi-disciplinary teams which will include, among other functions, mechanical, electrical, and/or civil engineers (see

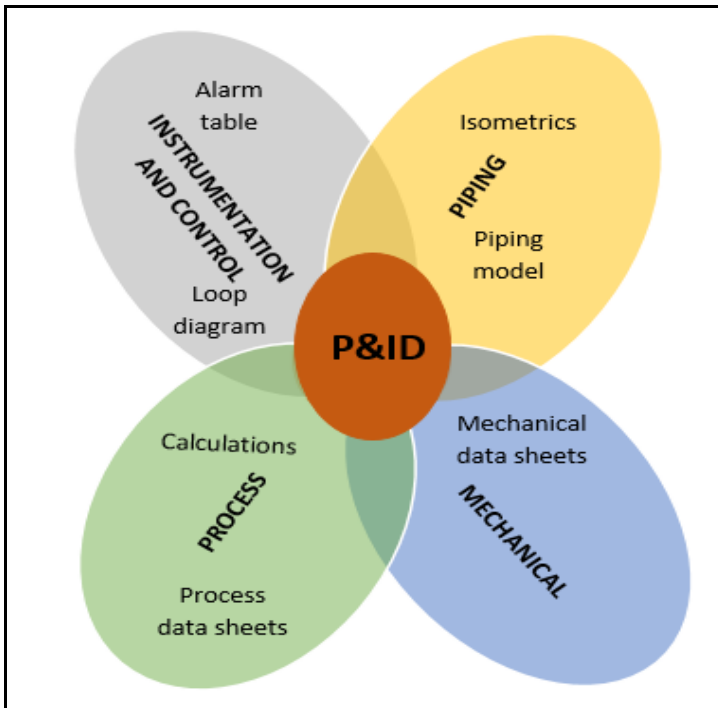


Figure 1: Central repository of essential engineering information (Toghraei, 2014) in chapter 2 of this dissertation). Depending on the project size, the chemical engineer may be expected to give more input in terms of designs. Chemical engineers also have to do fault findings in the plants and/or design verifications. Both these activities are more often communicated by means of technical drawings. The excerpts below illustrate this point.

“...In most cases, in my experience, when there is a change that's happening, new design systems that are happening in the what you call, in the factory, you [as a chemical engineer] will always have to have the final say in terms of what is your... if you approve it, you know, or if you are against that particular change. And in most cases they come in a drawing. So the importance of knowing the drawing is also important.”

“Being a Chemical Engineer in a small firm, 80% of my engineering work is mechanical engineering.”

Generally, chemical engineers work with P&IDs and PFDs. These are the types of drawings they use to design and define the plant process flow. But from time to time chemical engineers are confronted with design decisions that require understanding of technical drawings.

On the question “What type of drawings are typically used by chemical engineers?” respondents made the following comments:

"Process flow diagrams [and] P&IDs. Mostly I work with those drawings".

"PFDs & PIDs... that's most of the time."

"I received this [questionnaire] while I was actually busy reconciling a P&ID with the routing of piping on a 3-D-Plant model on my computer. I enclose a photo I took showing the P&ID on the left hand side and the 3-D Plant model on the right hand side [see Figure 6 below]. I believe these graphical skills are vital for any chemical engineer involved in real engineering."



Figure 6: Translation from P&ID (2-D) to a 3-D plant model

In most cases the chemical engineer never has to create drawings from the beginning as most companies have a mechanical engineering department or a drawing office, or both, to create their drawings. In other companies the drawing services are outsourced. Therefore the extent of working with technical drawings may also depend on the size of the company and how well-resourced that company is.

On the question “When working with plant designs and layouts do you ever have to transpose your layout from 2-D P&ID to 3-D models?” one responded as follows:

"Ya [yes] if you doing it [then] it's for aesthetic reasons, for it to look nice. But it's not necessary. Coz it's just for you to understand where what goes... if it's [you] really wanna [want to] make it nice it's through [Microsoft] Visio, or something. But I won't sit and work on AutoCAD, nah."

Even though it is not may not be necessary for chemical engineers to draw the plant and equipment from 2-D to 3-D graphics, it is very important that they are able to connect the components of the one drawing with those of the other drawing, i.e. be able to visualise an elevated 3-D plant from the 2-D P&ID drawings.

It is expected that technical engineering drawings are most often utilized in the design office than any other department. Although the drawings may in most cases originate from the design or drawing offices their use is applied throughout several departments and sections of chemical engineering. This is how some of the respondents articulated this:

"It's always cross-sectional. It always cuts through every dept."

4.5.3.2 Responsibility of working with technical engineering drawings

The use of technical engineering drawings by chemical engineers is applicable in both management and non-management levels. For some, this can be a daily requirement while for others it can be required for fault findings during maintenance and rebuilds. In most cases when working on projects the responsibilities of the chemical engineer with regards technical drawings is dependent on their function in the team. Chemical engineers in the design office are most likely to work with technical drawings to a larger degree. The same is also true for project leaders as they are responsible for seeing to it that all the requirements of the project are met, including technically. As observed in paragraph 4.5.1.2 most companies have drawing offices or they outsource services for drawing. Therefore the responsibility of chemical engineers with regards to technical drawings mainly extends to just reading and interpreting the drawings. This fact can be identified in responses such as these that follow:

"It is not often that Chemical engineers are required to draw detail drawings"

“Chemical engineers not required to do [create] drawings but must be capable to read and interpret drawings”

“Drawings are an essential part of the day to day work of process engineers on the plants. Although we are not responsible for drawing it ourselves we are responsible for redlining.”

The extent of involvement of chemical engineers with technical drawings is also influenced by the type and the size of a project the chemical engineer is working on. Details of the design drawings such as tolerances and assemblies of machine components are not required when working large projects like building a new process plant because in most cases such big projects will include a mechanical engineering department and/or a drawing office which will be responsible for such fine details. On the question “Have you ever had to create or modify a drawing from scratch?” respondents had the following to say:

“No. Because we have a draftsman that does that job for us. So you can draw it in rough and give the dimensions but because you have a draftsman who's dedicated to doing AutoCAD drawings.”

“No... [If change is needed] I will tell you that this is what I want then someone maybe a draftsman or anyone or mechanical engineer will do that for me. And then that's when I can come in and say - yes, can I approve, yes or no. But depending on how eh well that person has done the job such that it's clear to me. I'll tell you all the requirements.”

When working on a small project such as developing a certain part of equipment the chemical engineer will need to understand the detail drawings to some extent. In both cases (big or small projects) it is never a real necessity, at least in most cases, for chemical engineers to generate or create computer generated models or drawings from scratch. However the engineer must be able to understand and communicate through the drawings and be able to suggest the necessary changes to the design. There are several reasons why the chemical engineer must be able to understand technical drawings. The following are some of the reasons stated by respondents:

“Because we usually do our own conceptual design of certain things [and] they need to also meet certain requirements, we have certain estimates that we make. So that's how [when] we have to go back and go through the details of the drawing.... Then I

would do a rough drawing and the draftsman would do it [professional/CAD drawing]. And if it needs special work then we would outsource it."

"I do not work with drawings on a daily basis, but there are critical instances where the knowledge of drawings was vital."

Literature pointed out that communication between process design office and engineering design office requires information-sharing by means of 2-D and 3-D drawing formats. The chemical engineer will specify all the requirements relating to the design, and specify the process using P&IDs and PFDs. The mechanical engineer or drafting technician will then put the specified requirement into a technical drawing. After the design drawing has been completed the chemical engineer must be in a position to approve or make changes or recommendations where necessary. This makes it necessary for the chemical engineer to understand both the 2-D and 3-D information communicated between the departments/divisions. This fact can be identified in the following responses:

"GA's [general arrangements] and 3-D model reviews form part of chemical / process engineers' duties. [Chemical engineers] should thus have this ability and need formal training for this."

You have to understand the drawing first of all. What is it about? Say you designing a thicker and they give you a 3D drawing and different types of section drawings then you analyse that drawing and question from that drawing... You have to really understand how the drawing works so that you can make certain assumptions."

4.5.4 Summary of RQ1

This section presents a summary of the findings that were investigated to answer the first research question of this study.

4.5.4.1 Involvement with technical engineering drawings

From the data gathered for this study one can assume that chemical engineers work with engineering drawings to a great extent. However, the involvement of chemical engineers with engineering drawings as explained in the context of this study mainly extends as far as reading and interpreting the drawings.

4.5.4.2 Responsibility of working with technical engineering drawings

Communication still remains a vital aspect in engineering projects as most engineering companies employ drafting technicians to create drawings and the chemical engineer is only left with the responsibility of editing them. This shows that it is crucial that the chemical engineer have a technical understanding of the work done by the drafting technician.

The following two statements “*I do not work with drawings on a daily basis*” and “*Drawings are an essential part of the day to day work of process engineers on the plant*” are an indication that the requirement of the use of engineering drawing by chemical engineers varies. It can therefore be expected that chemical engineers who are working in the design office will be more likely to work with drawings on a daily basis than any other office.

4.6 FINDINGS FOR RESEARCH QUESTION 2:

This section will deal with the findings of both the quantitative and the qualitative data with the main focus being on answering the second research question.

RQ 2: Does the Engineering Drawings subject, as was taught at university, befit the type of work done by chemical engineers in the industry?

4.6.1 Frequency analysis

The following section presents the frequency of responses related to the second research question as stated above. The alpha-numeric references in the brackets refer to the questionnaire items presented in Table 6 of this chapter.

4.6.1.1 Benefits of technical engineering drawings

This section presents a description of how chemical engineers regard technical engineering drawings in terms of it being helpful or not to with respect to specific requirements relating to their duties at work. Fifty per cent (50%) of the respondents totally agreed that the background knowledge of technical engineering drawings helps when working with P&IDs (B13) and 31% agreed. Even though the technicality of P&IDs and flow diagrams differ the mean score of 4.14 with a standard deviation of 1.10 (B14) indicated that the background knowledge of technical drawings is deemed beneficial when working with the latter as well.

Literature has shown that working with technical engineering drawings enhances the spatial visualisation ability which is an essential tool for an engineer. It further suggested that the exposure to working with technical drawings will help to incorporate further knowledge that

the students will acquire as they progress in their learning path. The mean scores of 3.88 (s=1.05) and 4.28 (s=0.826) indicate that learning to work with technical engineering drawings enhanced the fundamental engineering thinking skills (D25) as well as helped to develop a higher level spatial visualisation ability (D26).

The mean score of 4.2 reported in Table 7 for this construct of *Benefits of Technical Engineering Drawings* indicates that having the subject at university helped to develop some fundamental engineering thinking skill and enhances a higher level visualization skill in chemical engineers. The background knowledge of the subject is found to be helpful when working with P&IDs and PFDs. The standard deviation of 0.73 shows that most of the responses to this construct are close to the mean.

4.6.1.2 Training

Literature revealed that training students to work with technical engineering drawings has some benefits. However, the experiments that were conducted to come to this conclusion were conducted in a formal setting and included general engineering and non-engineering students, not specifically chemical engineering students. Therefore questions in this section of the questionnaire sought to establish the type of training necessary to acquire the drawing skills essential for chemical engineers.

Forty-seven per cent (47%) and 30% agreed and totally agreed, respectively, that the skills required for chemical engineering require formal training (C18). This result is strengthened by 23% that totally disagreed, and another 23% that disagreed that the drawing skill required for chemical engineers can be acquired by self-training (C19). Only 2% totally agreed and 26% agreed to this statement. Furthermore, in terms of this construct of training, 51% totally agreed that they would recommend that chemical engineers should have the engineering drawing skill to create drawings. Twenty-three per cent (23%) agreed to the statement while 5% agreed and 12% totally disagreed (D27).

4.6.1.3 Module content

To determine the relevance of the subject for chemical engineers this section of the questionnaire looked at some key topics that form the core² of technical engineering drawings. Thirty-five percent (35%) of the respondents were neutral regarding the need for chemical engineers to learn about geometric tolerances as required in detail design (C20). Twenty-eight percent (28%) agreed and 16 % totally agreed that chemical engineers need to learn about tolerances as applicable in detailed designs. On the other hand, 14% disagreed and 7% totally disagreed to the statement (C20). On the topic of assemblies 2% totally disagreed and 17% disagreed that chemical engineers need to learn about assemblies. Thirty-nine per cent agreed to the statement, and 24% totally agreed, leaving 17% as neutral (C21). A mean score of 3.1 regarding the relevance of orthogonal projections for chemical engineers with a standard deviation of 1.4 indicated a varied opinion of the relevance of multi-views. Fifteen per cent (15%) totally disagreed and 26% disagreed while 31% agreed and 18% totally agreed that orthogonal projections are relevant for chemical engineers (C22).

Twelve per cent (12%) of the respondents disagreed that computer-generated 3-D models are relevant for chemical engineers, 10% were neutral, while 27% agreed and 51% totally agreed to the statement (C23). Of all the respondents no one totally disagreed with the statement. On the same topic of computer-generated 3-D models 2% indicated that working with computer generated 3-D models was not at all important to chemical engineers, 7% said it was of little importance, 16% said it was moderately important, while 37% said it was important, and another 37% said that it was very important (D28).

Looking at the general importance of being able to read and understand technical engineering drawings 2% of the respondents indicated that it was of little importance, another 2% said it was moderately important, while 19% said it was important, and 77% said it was very important for chemical engineers to be able to work with technical drawings (D29).

The mean score of 3.6 for this whole construct of *Module Content* indicates that topics such as geometric tolerances, assemblies of parts, orthogonal projections, and computer generated 3-D models may be relevant to chemical engineers, but not to a large extent. The

² Based on the general subject content as obtained from various yearbooks offered by South African Universities

standard deviation of 0.94 indicates that a lot of the responses are close to the mean (see Table 7: Mean scores of constructs).

4.6.2 Correlations between items and constructs

This section discusses the correlations among items and constructs of the questionnaire observed in Table 8.

4.6.2.1 Strong correlation results

The construct (Benefits of technical engineering drawing) showed a strong correlation of 0.715 with item (Involvement with technical engineering drawings) in Table 8. When this skill is required the background knowledge of the subject acquired at university comes in handy. The background knowledge of technical engineering drawing enables the chemical engineers to visualise and mentally transpose between 2-D and 3-D objects. This ability, as established in Chapter 2 of this dissertation, is crucial for any engineer working in the industry. These results also highlight that, at a minimum, being able to generally understand engineering drawings is a benefit that will help to efficiently function in their required position. A strong correlation of 0.653 was also observed in Table 8 between item (Chemical engineers require engineering drawing) and construct (Benefits of engineering drawing). The correlation indicates that the way in which the subject is offered has an influence on the benefits that will be gained from the subject. The mean scores of 3.91 for the item (The drawing skills required for chemical engineers require formal training) as observed in Table 6 and 4.2 for the construct (Benefits of engineering drawing) observed in Table 7 simply imply that having attended lectures for this subject yielded benefits with regard to the skill acquired.

Another strong correlation observed with the construct (Benefits of technical engineering drawing) is with the item (I would recommend that chemical engineers should have the engineering graphics skill to create drawings) (see Table 8). Findings of a strong correlation between these construct and item suggest that having the engineering drawing skill has benefits for chemical engineers in the workplace. This means that the knowledge and skill acquired in the undergraduate engineering drawing class can be applied when working with P&IDs and engineering flow diagrams.

A strong correlation of 0.578 for the construct (Module content) with construct (Involvement with technical engineering drawings) observed in Table 8 gives evidence that the content of engineering drawing as described throughout this report is necessary for the understanding of, and the ability to work with engineering drawings in the industry. Being able to

understand geometric tolerances and orthogonal projections is not necessary to be able to do the job required for chemical engineers. This information indicates that the job application requires chemical engineers to work more with part assemblies and generating computer 3-D models than they do with tolerances and projections. Finer details such as tolerances may be left to the drafting technician or the responsible drawing office. This suggests that more focus should rather be placed on the former than the latter.

The construct (Benefits of technical engineering drawings) also showed a strong correlation with construct (Module content). A correlation of 0.616 as observed in Table 8 signifies that the benefits of the subject are influenced by the topics addressed in the subject. As the literature highlighted, doing engineering graphics in undergraduate studies help the chemical engineers to be able to mentally visualise and adequately size the elements they are working on. It has also enhances the fundamental engineering thinking skills of the participants. It can therefore be accepted that when working with P&IDs and technical engineering drawings the background knowledge acquired in engineering drawing class plays a role.

4.6.2.2 Moderate correlation results

A moderate correlation was observed between construct (Benefits of technical engineering drawing) and item (The drawing skills required for chemical engineers can be acquired by self-training). A negative but linear correlation of -0.3 (see Table 8) indicates that to reap more benefits chemical engineering students should rather have a formal training in engineering drawing. The mean of 2.6 (see Table 6) for the item (The drawing skills required for chemical engineers can be acquired by self-training) implies that chemical engineers should rather have the engineering drawing training in a formal setting.

The item (Years spent in design office) also showed a moderate correlation with the construct (Benefits of technical engineering drawings). A correlation of 0.641 observed in Table 8 suggests that the benefits gained from doing engineering drawing have an influence when working in the design office. This may be due to the fact that engineers in the design office work with drawings almost on a daily basis. This also highlights the fact that the content presented for the subject may be applicable for the requirements of the design office.

The item (The drawing skill required for chemical engineers require formal training) showed moderate correlations with construct (Module content), and items (Years spent in other

offices) and (The drawing skills required for chemical engineers can be acquired by self-training).

A moderate correlation of 0.426 observed in Table 8 between item (The drawing skills required for chemical engineers require engineering drawing) and construct (Module content) points that the topics addressed in the subject can have an influence on whether student need to be seated in a class or whether they can learn the subject on their own. The mean of 3.91 with a standard deviation of 1.04 for the item (The drawing skills required for chemical engineers require engineering drawing) suggests that for the type of content addressed in the subject, the subject is better given in a class setting. The mean of 3.6 as reported in Table 7 for the construct (Module content) suggests that the content presented in the subject is not optimal for chemical engineering students. It can be deduced from the two means that the class should be offered in a formal setting, however, the content should be customised to for chemical engineers to suit the current trends in the industry.

A moderate significance of 0.3 observed in Table 8 between the items (The drawing skills required for chemical engineers require formal drawing) and (Years spent in other offices) denotes that the years spent in other offices has an influence on the type of training required for chemical engineers. The average years over the 17 participants who indicated that they have worked in other offices is 6 years, with a standard deviation of 3.84. The mean on the total sample is too little and the standard deviation is too widely spread to make valid inferences from. However, this correlation gives an indication that irrespective of the type of office the chemical engineer works in (design, process control, management, etc.), having engineering drawing in the foundational studies is necessary for chemical engineers.

Whilst a correlation of 0.474 observed in Table 8 between construct (Module content) and item (I would recommend that chemical engineers should have the engineering graphic skills to create drawings) was less than 0.5 for this correlation to make a strong correlation, it highlights the fact that chemical engineers in the industry endorse the subject. The mean score of 3.6 as reported in Table 7 for the construct (Module content), however, indicates that the topics discussed in the subject are not necessarily crucial for chemical engineers in the work place. The content offered for chemical engineers needs to be aligned to suit the industry needs of chemical engineers.

4.6.3 Qualitative analysis

This section looks at the qualitative responses in an effort to answer the second research question for this study.

4.6.3.1 Benefits of technical engineering drawings

When working on a plant design or analysing with technical engineering drawings it is important to have in one's mind an idea of the spatial relations being referred to in the drawings. Literature suggested that this ability is crucial for all engineers. Literature also indicated that working with, or being able to work with technical engineering drawings can enhance these spatial visualization skills. These postulations are emphasised by the following responses:

"I recall that several of my engineering class could not "see" in 3-D but by the end of the course they were able to do so"

"What I want and what I like about drawing is that it creates that visual, what you call... it makes me to see everything combined. That spatial (visualization). Things must make sense, let put it like that. Roughly if you are talking about a meter of this it should be like this size (demonstrating)."

Having a background in technical drawing makes it easier to understand and be able to communicate when presented with technical drawings from other departments like mechanical engineering or drawing office. The experience that one gets from using a certain technical drawing package at university lays the necessary foundation to understand and further enables one to manoeuvre through similar packages used in the industry. Respondents agree that there is a need to understand technical engineering drawings by highlighting the following:

"When working on a plant, we [will] have the whole plant drawn on pieces of paper, and you should be able to understand that sheet. I think my understanding came from technical drawings."

"Most drawings are now done via CAD systems so awareness of how they work is probably enough on how to draw."

To the question "Does the background of technical engineering drawings make it easy (now) to read and understand?" the respondents replied as follows:

"Ya [yes], relatively. Some are difficult to understand of course. But that background also assists in terms of getting a quick understanding [of the drawing presented]."

"No it's much easier. It's very easy"

"Chemical engineers need to be able to understand and interpret the drawings. If they have done some technical drawing it is easier to understand what and how the drawings can be read and modified."

4.6.3.2 Training

Not all students who enrol for a chemical engineering degree at university are previously from technical high schools, and for such students chances are that they have no technical drawing background at all. Literature has shown that in order to have the benefits mentioned in section 4.6.3.1 above engineering students require a lot of 2-D and 3-D drawing exercises. Nonetheless, it does not suggest what the best way to offer the subject to chemical engineering students would be.

The findings of this construct revealed that all the respondents of this questionnaire had had engineering drawing in their undergraduate studies, except for one participant. This one participant, who did not even have an extra class for engineering drawing, as indicated in section 2, disagreed with the statement that *Chemical engineers require formal training*. On the contrary, as indicated in the excerpts below, one respondent who had the engineering drawing subject but did not have the CAD training reckons that it is necessary to have such training at university.

It would have been even more interesting to establish from more chemical engineers who did not have the primer subject at university if they would recommend that the subject be taught in a formal setting or not.

Respondents were asked to reflect on the question "Given the extent to which chemical engineers work with technical engineering drawings, is it necessary for one to go through formal training or can one acquire the required skill by self-training?" The following are responses they gave:

"I haven't had formal AutoCAD training - I had to learn that myself. AutoCAD training in varsity would be very useful for engineers later on in a design ICE (Integrated Chemical Engineering)."

“As far as my opinion is concerned, I believe that it is important that chemical engineers do a course Engineering Drawing in their undergraduate studies”

Even though the level of skill required for chemical engineers is not the same as for mechanical or civil engineers, the question “How easy or difficult would it be for someone who does not have the university engineering drawing background to function in the industry?” aimed to establish whether it would be easy to function in the industry without a formal technical background of technical engineering drawings. The findings indicate that the best option is to have a structured learning environment in order comprehend what is necessary for chemical engineers. This deduction can be identified in the following responses:

“Ya [yes] they’ll learn it but eventually it will take longer, obviously. Because everything... I think you can learn everything. It’s just going to take longer as compared to something that you specifically sat in class for and wrote your exams on. It won’t take a semester. It will take five years maybe.”

“They can. But it will have been difficult, hey. [It would have taken] more energy and more time, rather than [unlike] if they were being taught right from the word go [from university level].”

4.6.3.3 Module content

The drawing offered at university is in most cases offered by the mechanical engineering department. As such the subject caters more for the needs of mechanical engineers than the rest. Although it is accepted that when working on CPI projects chemical engineers often work with other people from different departments on the same project, not all chemical engineering students end up in the design office. Therefore the technical engineering drawing curriculum for chemical engineers needs not be as detailed as it is for mechanical engineering students. The subject should instead be tailor-made for chemical engineers. This proposition is supported by responses such as these that follow:

“For me I have found it much useful. But the extent in which it’s being taught at varsity I think they [are] somehow overdoing it. For me I just need the basics of knowing, or of interpreting the drawing... We just need the basics of interpreting the drawing, you know when you say a diameter should be something like this be able to interpret because in most cases I’ve been in situations where you really start a plant from scratch and you have to interpret it in terms of drawings per se... However, my

solution could have been [to] create a chapter that only speaks to chemical engineers and their relative drawings.”

“The drawings used in industry are very basic, and is not the same as the subject presented at first year level.”

“Detailed knowledge to do what a draughtsman [drawing technician] is supposed to do, is too much”.

It is evident that chemical engineers do not necessarily have to create the drawings themselves but rather only need the basic knowledge to read and interpret drawings. However a study conducted by Sorby (1999) concluded that students need more sketching exercises in order to develop and enhance the spatial visualisation skills since the brain apprehends better in doing than in just seeing. The following responses suggest, in addition to the findings of the study conducted by Sorby (1999), that learning to learning to create the drawings also serves an important purpose. This impression can be identified in the following statements:

“Engineers need to be able to put their ideas on paper for others to understand. Drawing is one of them [one of the ways in which ideas can shared].”

“A basic knowledge of engineering drawings is necessary, such that the [chemical] engineer can do hand drawings.”

“A Good understanding of drawings is required, both being able to do the drawings, as well as interpreting the drawings”

Asked specifically whether “Chemical engineers need to learn to create drawings?” the respondents answered as follows:

“No I don’t have to. You are there for that as a mechanical engineer.”

“Chemical engineers need to read drawings, but will never do [create] them”

4.6.4 Summary of RQ2

This section presents a summary of the findings that were obtained to answer the second research question of this study.

4.6.4.1 Benefits of technical engineering drawings

Engineering drawing is necessary for chemical engineers in order to develop the skills necessary to be able to comprehend and interpret instrumentation diagrams and design plans. Working as a plant designer, a chemical engineer needs to understand some basics such as dimensions (length, mass, etc.) and how to use annotations in a universally standardised manner. In addition, the fundamental engineering thinking skills and the spatial visualisation skills are necessary to interpret and be able to manipulate drawings so that appropriate measures can be implemented.

The findings of this construct conform to the literature which suggested that engineering graphics help to develop and enhance spatial visualisation skill which is considered essential for all engineers. However, the findings of this study also suggest that chemical engineers themselves do not particularly need to create the drawings. These skills are also helpful when working with P&IDs and plant layouts because one needs to be able to connect the two together mentally before it can be physically implemented. Without the ability to spatially visualise in 3-D it will not be simple to work with P&IDs and plant design drawings. The knowledge of engineering graphics enables the chemical engineer to understand how drawings can be read and modified.

4.6.4.2 Training

The outcomes of this investigation have revealed that technical engineering drawings can be self-taught to a certain extent. This, however, is a technical subject and some topics need to be elaborated in detail by an expert. Given the type of technical drawings chemical engineers get involved with, it would be more beneficial to learn the subject under formal instruction and supervision.

4.6.4.3 Module content

No literature was found to propose what needs be included in the subject content especially for chemical engineers. However, based on the analysis of this research it is clear that chemical engineers require mainly to understand and be able to interpret the drawings. Even though literature indicated that during the engineering design of a facility design feature the engineer would be expected to design equipment, tolerances and projections do not seem to be part of this requirement. This finding may be emanating from the finding that most companies employ the services of drafting technicians or outsource the function. This also suggests that in order to sign off for equipment and plant design drawings services of qualified mechanical engineers may be employed.

Since the major responsibility of chemical engineers with regard to engineering drawings is to red-line and update, it only makes sense that the key requirement for them be to be able to read and interpret the drawings.

4.7 CHAPTER SUMMARY

This chapter presented and discussed the data analysis of the investigation that were gathered by means of questionnaires and interviews. The reliability of the constructs and the correlations among the constructs and selected items were also discussed. The discussions of these findings were organised and presented to answer specific research questions. The next chapter renders a conclusion to the study and makes some recommendations.

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 INTRODUCTION

The aim of this research was to establish whether it is necessary for chemical engineers to have Technical Engineering Drawings as a compulsory subject in their undergraduate university studies. To achieve this aim an investigation was executed to answer the following two research questions:

RQ1: To what extent do chemical engineers in the industry work with engineering drawings?

RQ2: Does the Engineering Drawings subject, as had been taught at university, benefit and benefit the type of work done by chemical engineers in the industry?

This chapter presents a summary of the research work, the conclusion that was reached, and makes recommendations based on the findings of the research. Lastly, the chapter concludes by making proposition for future research. Limitations to the research are also highlighted at the end of this chapter.

5.2 SUMMARY

Chapter 1 of this dissertation introduced the research by giving background to the topic and discussing the purpose, problem statement, and research objectives of the study. The chapter also introduced the method of investigation that was followed to achieve the identified objectives. And lastly, the chapter presented the layout of this dissertation.

Chapter 2 followed with a literature study to establish what is already available within the body of knowledge with regard to the objectives of this study. The chapter investigated the current curriculum trends in chemical engineering across local and top international universities. The chapter also focused on the applications of technical engineering drawings in the chemical engineering field, the impact that the university subject has on chemical engineers in the workplace, as well as the most efficient way in which the subject should be offered.

The literature study revealed that not much research has been done on the subject of chemical engineers and technical engineering drawings. Research directed at the subject dates as far back as 1999. With the changing trends in technology and practices in the industry, this lack of research presents a gap in the body of knowledge.

The literature that was available revealed that very few top chemical engineering universities offer technical engineering drawings as a compulsory subject for chemical engineers. The chapter also revealed that chemical engineers do work with technical drawings especially in plant and equipment designs, and therefore need to understand these types of drawings to be able to communicate effectively with other departments/divisions. Technical drawings are also said to help develop and enhance spatial visualization ability which is deemed crucial for all engineers. Lastly, the technical drawing subject should be given in a structured way beginning with free-hand sketching and 2-D drawings, then progressing to 3-D modelling of objects.

Chapter 3 presented the research design chosen for the study. The study employed a mixed-method research design and made use of self-designed questionnaire and semi-structured interviews. The selection of sites and the sampling were described as well as the techniques applied to collect and analyse the data. Measures taken to ensure reliability and validity of the study were discussed, and attention was also given to the ethical issues regarding the data-collection methods.

The sample used for the investigation was made up of chemical engineers who are in possession of a four-year university degree in chemical engineering (B.Eng. or B.Sc.). The participants were chemical engineers who are, or have practised, in the industry as chemical engineers. The sample had a minimum working experience of six years.

The questionnaire used for data collection contained both quantitative and qualitative questions. The qualitative inquiry was used to elicit information that might have not been addressed by the quantitative inquiry. The statistical data collected was analysed using SPSS (Statistical Package for the Social Sciences). The findings of the questionnaire were followed up with interviews.

Chapter 4 presented and discussed the findings of both the quantitative and the qualitative investigations. The quantitative data were discussed based on the frequency analysis, reliability analysis, mean scores of constructs, correlation analysis, as well as the significance test analysis. The outcomes of the qualitative data were then correlated with the qualitative findings. The next section presents the conclusion reached based on the findings of the data analysis.

5.3 CONCLUSION

To achieve the main objective of this research, which has been to determine whether it is necessary for chemical engineers to have technical engineering drawings as a compulsory subject in their undergraduate university studies in South Africa, an investigation was executed to answer the following research questions:

- To what extent do chemical engineers in the industry work with engineering drawings?
- Is the technical engineering drawing, as was taught at university, befitting the work done by chemical engineers in the industry?

RQ1: To what extent do chemical engineers in the industry work with technical engineering drawings?

The outcomes of this research have established that chemical engineers do work with technical engineering drawings. The requirement to work with technical drawings cuts across various offices, and applies to both management and non-management positions alike. The extent of utilisation, however, differs. Depending on the department/division as well as on the size and type of project one is working on the requirement to work with technical engineering drawings can be a once in a while activity with basic requirement of understanding, while for the design office it can be a daily activity with an extensive requirement. From this it can be inferred that chemical engineers need to have at least a basic knowledge of engineering drawings.

This study also revealed that even for chemical engineers who work with drawings on a daily basis, it is rarely expected of them to create parts or the detailed technical drawings themselves. Most companies rather have a mechanical engineering department or a drawing office responsible for such. The chemical engineers' main involvement with technical engineering drawings is that of recommending modifications where necessary. With respect to this, it is crucial that they are able to understand and interpret the drawings.

A major finding that emerged from the data collected is that chemical engineers are responsible mainly for updating the drawings and therefore the most important skill required for them as far as engineering drawing is concerned, is to be able to **read** and **interpret** the drawings.

RQ2: Does the Engineering Drawings subject, as had been taught at university, benefit and benefit the type of work done by chemical engineers in the industry?

Not all the content presented for the subject is relevant for chemical engineers. However, the basics that are relevant to chemical engineers enabled them to be able to read, understand, and interpret universal technical engineering drawings. The subject is much more relevant and applicable to chemical engineers working in the design office, even so, not all of it. With regard to working with parts and models chemical engineers only go as far as reading and modifying, and not creating. The finer details such as tolerances are left to the responsible mechanical or drawing office.

Since it is not always known in which department or division a chemical engineering student will end up working in the industry, and since the use of technical engineering drawings is applicable in several departments in chemical engineering, it remains prudent for all chemical engineering students to acquire the technical engineering drawing skill.

The skills acquired in doing technical engineering drawing at university develop the fundamental engineering thinking ability and also enhanced the spatial visualisation level of chemical engineers. With this the chemical engineer is easily able to understand technical drawings and to transpose from 2-D drawings to 3-D drawings when doing P&IDs and general designs.

5.4 RECOMMENDATIONS

Based on the findings and the conclusions reached this research makes the following recommendations regarding the training of chemical engineers:

- Instead of terminating the subject altogether, the credit points for the technical engineering drawing subject should be reduced to include only topics applicable to chemical engineering. This may also reduce the allocated contact sessions with the students, allowing them more time to focus on other chemical engineering subjects.
- Given the technicality of the subject content it will be in the chemical engineer's best interest to be taught the subject in a formal and structured setting. Also considering the benefits discussed in the text, the subject must be given as early as possible in their programme of studies. The content of the subject, however, needs to be custom-made to suite the industry need for chemical engineers.
- Since the application of engineering drawings in the chemical engineering industry is not as extensive as for other disciplines such as mechanical or civil engineering, the subject curriculum should be revised and emphasis be placed on reading and interpreting the drawings. This, however, must still include learning to create drawings using both freehand sketching and computer programmes as literature and the findings of this research indicated that this will improve the spatial visualization abilities of the students.
- Other topics relevant to chemical engineers such as working directly from P&ID to 3-D plant model, as depicted in Figure 6, section 4.5.3 of Chapter 4, should be included in the engineering drawing curriculum specified for chemical engineering.

5.5 POSSIBILITIES FOR FURTHER RESEARCH

Further research should be done specifically with chemical engineering graduates who have not done Engineering Drawings in their undergraduate studies to determine what impact the lack of technical engineering drawings background has on the type of work they do when they get into the industry.

5.6 LIMITATIONS TO THE RESEARCH

Because of the sample size and the fact that the total population of chemical engineers in South Africa could not be determined the inferences made from this research are based on the sample obtained for this research.

Another limitation was that the study only had one participant who had not had engineering drawings in undergraduate studies, so in that way the data collected seem to be biased since almost all of the respondents had the subject at university.

END.

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APPENDIX A: COVER LETTER



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Date

Dear Participant

RESEARCH: DO CHEMICAL ENGINEERS NEED TO DO ENGINEERING DRAWING IN THEIR UNDERGRADUATE STUDIES?

In past years Technical Engineering Drawing used to be offered to all engineering first year students at the North-West University but has now been discontinued for the chemical engineering students since 2010. I am therefore doing a study to determine the need, and the frequency of the use of engineering graphics by chemical engineers in the industry.

As part of the study I intend to determine the current trend in South African academia with regard to Technical Engineering Drawing and Chemical Engineering.

The accompanying questionnaire will only require approximately 5-6min of your time to complete. There is no known risk associated with participating in the study and no personal information is required.

Please note that the information obtained from this questionnaire will be included in the report that will be submitted in fulfilment of the requirements for a Master's degree. However, no other information will be directly linked to your University except whether it is, or is not offering Engineering Drawing for first-year chemical engineering students.

Your contribution to this study is very important and the success depends on the number of participants who complete the questionnaire. Your contribution will help us to establish whether it is necessary for the University to reinstate engineering graphics for the chemical engineering students or not.

By completing this questionnaire, you give permission for the use of the results of this study for research purposes. If you have any queries or suggestions which we have not addressed and would like to discuss, please contact:

- Ms Suna Kotole – 018 299 1663; e-mail Suna.Kotole@nwu.ac.za
- Mr Pietman Jordaan – 018 299 1321; e-mail Pietman.Jordaan@nwu.ac.za

Yours faithfully

Mr Pietman Jordaan (Supervisor)

Ms Suna Kotole (Student)

APPENDIX B: QUESTIONNAIRE

Please note the following use of terms:

"Working with drawings" refers to doing the actual drawing or just having to read and interpret a technical drawing.

"Engineering graphics" refers to technical drawing including freehand sketching, 3-D modeling, and creating drawings.

The questionnaire should be answered based on your general experience over the years you have worked in the industry.

Section A: Biographical Information

1. Type of degree

B.Sc B.Eng Other

2. Year obtained:

3. Other qualifications:

4. Years in the industry

0-2 3-5 6-8 9-10 >10

5. Please indicate the number of years you have spent in the following divisions/ sections

Design Process control Management R&D Other

Other

6. Please indicate which division/section mostly works with drawings.

Design Process control Management R&D Other

7. Did you have Engineering Drawing in your undergraduate studies? Y N

8. Have you ever taken any extra class for engineering drawing? Y N

Section B: Experience

Based on your work experience, to what extent would you agree/disagree with the following statements. 1 being never and 5 being very much.

9. How often have had to read and interpret technical drawings?

1 2 3 4 5

On a scale of 1-5, 1 being totally disagree and 5 being totally agree, would you say:

10. In the companies I have worked for, the chemical engineer does the drawings.

1 2 3 4 5

11. In the companies I have worked for, the specialized draftsman does the drawings.

1 2 3 4 5

12. In the companies I have worked for the drawings services are not done by my company.

1 2 3 4 5

On a scale of 1-5, 1 being totally disagree and 5 being totally agree, would you say:

13. The background knowledge of engineering graphics helps when doing P&IDs.

1 2 3 4 5

14. The background knowledge of engineering graphics helps when doing engineering flow diagrams.

1 2 3 4 5

On a scale of 1-5, 1 being most unlikely and 5 being most likely, would you say:

15. Chemical engineers work with drawings at management level.

1 2 3 4 5

16. Chemical engineers work with drawings at non-management level.

1 2 3 4 5

17. Comments on experience:

Section C: Training

On a scale of 1-5, 1 being totally disagree and 5 being totally agree, would you say:

18. The drawing skills required for chemical engineers require formal training.

1 2 3 4 5

19. The drawing skills required for chemical engineers can be acquired by self-training.

1 2 3 4 5

20. Chemical engineers need to learn about geometric tolerances as required in detail design.

1 2 3 4 5

21. Chemical engineers need to learn about assemblies (how individual parts fit and operate together).

1 2 3 4 5

22. Orthogonal projections relevant for chemical engineers.

1 2 3 4 5

23. Computer generated 3-D models relevant for chemical engineers.

1 2 3 4 5

24. Comments on training:

Section D: Conclusion

On a scale of 1-5, 1 being totally disagree and 5 being totally agree, would you say:

25. I acquired some fundamental engineering thinking skills from doing engineering graphics 1 during my undergraduate studies.

1 2 3 4 5

26. Engineering graphics 1 helped me to develop a higher level visualization skill (spatial thought).

1 2 3 4 5

27. I would recommend that chemical engineers should have the engineering graphics skill to create drawings.

1 2 3 4 5

On a scale of 1-5, 1 being not at all important and 5 being extremely important, please answer the following questions

28. It is important to be able to work with computer generated 3-D models.

1 2 3 4 5

29. It is generally important to be able to read and understand technical drawings.

1 2 3 4 5

30. Please list computer programs have used / still using for chemical engineering design and maintenance.

Section E: Comments

31. Any further comments/suggestions/recommendations?

Thank you for taking the time to complete this questionnaire

SUBMIT FORM




Figure 7: Questionnaire

APPENDIX C: INTERVIEW SCHEDULE

1. Biographical information

- 1.1. What is your basic engineering degree?
- 1.2. Other qualifications?
- 1.3. Which year did you do your first year?
- 1.4. In your first year did you have engineering/technical drawings as one of your subjects?
- 1.5. Have you ever had an extra class for technical drawings?

2. Work experience

- 2.1. How long have you been working in the industry?
- 2.2. Which chemical industries and/or departments have you worked in?
- 2.3. In the companies you have worked for what would you say is the extent of the involvement of chemical engineers with technical drawings?
- 2.4. Have you ever had to create or modify any drawings of parts or assemblies? (Extent of detail?)
- 2.5. When presented with an engineering technical drawing how easy is it for you to understand/work with it?
- 2.6. In the chemical processing industries what level of technical drawing knowledge does one require?

3. Chemical Engineering and Engineering Drawings

- 3.1. What type of drawings or graphical information do chemical engineers generally work with?
- 3.2. Do chemical engineers work with machine drawings?
- 3.3. Which departments/divisions would you say work more with technical drawings (of parts and assemblies)?
- 3.4. In these departments, what is the responsibility of the chemical engineer with regards to the drawings?
- 3.5. Which programmes do you use for chemical engineering graphics?
- 3.6. What skill does one require for such application?
- 3.7. How can these skills be acquired? (formal or self-taught)

4. Module content

- 4.1. Do you think 3-D models and orthogonal views are relevant for chemical engineers?
(Why?)
- 4.2. What do you think is necessary to include in the technical drawing curriculum, particularly for chemical engineers?
- 4.3. Do you think chemical engineers need to learn about parts assemblies, tolerances, etc.? (Why?)
- 4.4. Would you say that the engineering drawing subject that you did in your first year at university (if the case) plays a significant role in the type of work you do/have done thus far?

5. General

- 5.1. Are there any specific benefits of engineering drawings that you can point out?
- 5.2. Given the work experience that you have, would you recommend that chemical engineers should learn how to create and work with technical drawings?
- 5.3. If yes, how would you recommend that this learning should take place? (Formal or self-training)

APPENDIX D: QUALITATIVE RESPONSES

Involvement with technical engineering drawings

“Apart from normal BFD's, PFD's, P&ID's, etc. also need to be able to interpret/understand GA's, sectional drawings of equipment, etc.”

“[Technical] drawings no, P&IDs definitely yes.”

“Once again, reading of PFDs is essential, but not drawing thereof”

“Chemical engineers will be part of fault finding and/or design verification. Interpretation of the drawings is critical.”

“The focus for chemical engineers is more on engineering drawing interpretation.”

Responsibility of working with technical engineering drawings

“Chemical engineers is required to do design verification or squad checks and must therefore know how to interpret the engineering drawings.”

“Yes Engineering Drawing is important for a chemical engineer. During rebuilds, it is essential to be able to read drawings.”

“Working for smaller firms the chemical engineer has to be much more hands-on.”

“We use Mechanical Flow Diagrams. The engineer updates the diagrams. Once approved, the draftsman updates it (CAD).”

“A chemical engineer must be able to draw a clear and logical PFD and isometric piping drawings on paper with a pen.”

“We expect from our engineers to be able to draw their own P&IDs and some aspects of equipment fabrication drawings in AutoCAD.”

Benefits of technical engineering drawings

“3-D models [are] used for model review and to see how everything fit together on site. Very good tool to have.”

“I think an understanding of building [chemical plant], in a sense, has to be understood by chemical engineers because they're the base of design. So now in terms of me designing something for a standing plant and I need to add something on, it's going to be difficult if I don't have any understanding in terms of dimensions to implement something like that [the addition to the design].”

“For the chemical engineer being able to manipulate and correct drawings done by the draughtsmen are crucial in an effective design ICE.”

“Reading and interpreting engineering drawings is very important to be successful in the industry”

Training

“Get people with industry experience to evaluate and support your staff in establishing super critical experience or training required to set your curriculum.”

“You don't need to spend hours teaching this as a separate course but rather as part of design, equipment reviews, HAZOP etc.”

“Education should cover a broad spectrum of fields even if some appear to be irrelevant later.”

“Rather concentrate more on a piping hydraulics course than rather on an engineering design [drawing] course”

Module content

“More emphasis should be given to how to read and work with the drawings.”

“The chemical engineer needs to know the language of drawings and models. [He/she] should also be able to put a drawing together for a typical plant layout and know typical piping specifications and design criteria, i.e. ASME, API standards.”

"It is of utmost importance that they [chemical engineers] are competent at interpreting detail drawings."

"I believe that more focus should be on interpreting drawings than drawing it yourself. This statement will also be industry and career path dependant. I am only referring this based on my own industry and experience."

"Only basic drawing skills to be included in the training program mainly for interpretation purposes"

"Skills are needed to be able to understand layouts, plots, ISOs, and 3D models - 2D is not enough on its own."