ENGINEERING CURRICULUM QUALITY MANAGEMENT USING ARTIFICIAL INTELLIGENCE

by

PIWAI NIGEL CHIKASHA

submitted in accordance with the requirements for the degree of

DOCTOR OF PHILOSOPHY

in the subject

ENGINEERING

at the

UNIVERSITY OF SOUTH AFRICA

SUPERVISOR: Professor Kemlall Ramsaroop Ramdass

CO-SUPERVISORS: Doctor Rendani Maladzhi

Doctor Ndivhuwo Ndou

June 28, 2021

Go down deep enough into anything and you will find mathematics.

- Dean Schlicter

Declaration

Name: Piwai Nigel Chikasha
Student number: 58523561
Degree: Doctor of Philosophy in Engineering

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I further declare that I submitted the thesis to originality checking software and that it falls within the accepted requirements for originality.
I further declare that I have not previously submitted this work, or part of it, for examination at Unisa for another qualification or at any other higher education institution.
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07/07/2021

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Publications

Publication list:

1. P. N. Chikasha, K. R. Ramdass and K. Mokgohloa. Aligning industrial engineering education with industry through atomic curriculum manipulation, The South African Journal of Industrial Engineering, Vol 31, No 4, pp. 92 103, 2020.
2. P. N. Chikasha, K. R. Ramdass, K. Mokgohloa, F. Nemavhola. Industrial engineers of the future a concept for a profession that is evolving, Advances in Science, Technology and Engineering Systems Journal (ASTESJ), 21M-03-337, 2021.
3. P. N. Chikasha, K. R. Ramdass, R. W. Maladzhi and N. Ndou. Balancing employment and entrepreneurship requirements in industrial engineering education, The South African Journal of Industrial Engineering, 2021.

This thesis is dedicated to my mother Jennifar Chikasha, and to my father Adolph Chikasha.

Acknowledgements

Special mention to my supervisor, Professor Kemlall Ramdass. Professor Ramdass was instrumental for the success of this study. I would like to acknowledge Professor Ramdass' inputs and also his facilitation and sponsorship for the publications made as part of this study. I am grateful for the support that I received from Professor Ramdass. I would also like to acknowledge Mr. K. Mokgohloa, Dr. R. W. Maladzhi and Dr. N. Ndou for the roles played in supervising this study and also the publications produced. The contributions made were invaluable and necessary for the completion of the study. I could not have had a better team.

I would like also to acknowledge my mother Jennifar Chikasha and my father Doctor Adolph Chikasha for their support and encouragement. From childhood, my mother and father inspired me to work hard and to value education. Finally, I would like to acknowledge my wife Sharon Chikasha for her support. Thank you Sharon for standing by me. This one is for you and me.

Abstract

This study investigated alignment of industrial engineering curriculum at the University of South Africa, to the skill and knowledge needs of industry. The study developed a curriculum management system that utilises artificial intelligence to interpret the skill/knowledge requirements of the industry from job advertisements, and then takes the approach of decomposed (atomic) curriculum management to align curriculum to industry. The concept of 'atomising' curriculum is characterised by decomposing program courses or modules into distinct micro-curriculum elements which although highly complex to manipulate, provide unmatched robustness in curriculum alignment to industry. The study contributed a blend of reforms and improvements to the industrial engineering curriculum in the UNISA context and developed an intelligent management system to manipulate curriculum to better align to the needs of industry.

The main objective of the study was to develop a system to support decision making in bridging the gap between higher education and industry needs, in view of the graduate engineer. The problem is misalignment of curriculum to industry needs. One reason for misalignment is that in some cases, teachers interpret and accept curriculum in different ways, according to the unique individual strengths, weaknesses, experience, personality and background of the teachers. Regardless, the result is curriculum misalignment, which was shown to ultimately contribute to problems such as graduate youth-unemployment, skill underutilisation and low innovation. In this study therefore, the intention is to develop an intelligent and automated system which can support the management of curriculum for improved alignment to industry needs.

The methodology begins with a survey carried out to map the needs of industry in terms of skill and knowledge requirement, from a graduate industrial engineer perspective. The curriculum management system is designed to align curriculum to industry, based on the needs presented by both the employment avenue and the entrepreneurship avenue. Control data is obtained from on-line job advertisement platforms, which after the necessary preprocessing, is fed into the management system. The curriculum management system maps industry needs to curriculum specifications by interpreting the qualitative job advertisement information into ranked quantitative curriculum elements by first converting job functions from the advertisements into some curriculum molecules then from the molecules into curriculum atoms (curriculum elements). These final curriculum elements become the means to curriculum adjustments, allowing curriculum manipulation across the entire program course. The complexity of the mapping process is proportional to the volume of control data. Results show that artificial intelligence (artificial neural network) sufficiently delivers satisfactory control. Results show that atomic curriculum manipulation, compared to the conventional molecular-type manipulation, presents a more meticulous and holistic approach to aligning engineering curriculum to industry.

It was concluded from the study, that atomic curriculum manipulation not only improves the effectiveness of curriculum alignment, but also promotes curriculum integrity. Atomic curriculum manipulation, as proposed in this study, decentralises curriculum management to the teacher level, rather than the institutional level. This encourages improved teacher-student and teacher-teacher interaction. Further studies will adapt the proposed solution to any particular program of study.

Key terms

Curriculum quality management, curriculum adaptation, curriculum improvement, AI curriculum management, curriculum manipulation, curriculum assessment, curriculum alignment, complex systems, curriculum decomposition.

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Chapter 1

Introduction

Quality of education has become a major priority across many countries, especially developed countries. Higher education, including engineering education, is affected by many internal and external factors, making quality control a complex task. Based on [1], [2], [3] and [4], the evolution of engineering education can be summarised as follows. Before year 1940, engineering education was mostly mathematically intense and theoretical, with strong emphasis on engineering science. From the 1940s going ahead, engineering education started to get more practical, with growing emphasis on engineering design. From about year 1945, emphasis on research grew. Around the same time, engineering education also saw a rise in defence related research and applications. With growing interest in research, from the late 1940s, there was high demand for academic engineering research at engineering schools and research centres. This resulted in a decline in the number of faculty members that actually had industrial experience, as most faculty members were retained within the education system, without working in industry.

From year 1980, there was a general shift from defence to commercial applications of engineering. The result was that graduates were technically competent, but lacking professional skills (communication, teamwork and so on) and innovation characteristics. The last half of this decade was characterised by massive campaigns for improved curriculum, especially towards developing social skills. The 1990s saw much work going towards accreditation frameworks for engineers. Towards the end of the decade, the accreditation frameworks significantly changed the evaluation of undergraduate engineering programs towards prioritising emphasis on student learning outcomes and accountability rather than curricular specifications. This introduced flexibility in study programs and curricular.

From year 2000 therefore, systems for continuous improvement for curricula started to gain popularity. Around this time, emphasis on professional development was also further prioritised. Going forward, engineering education saw continuous adjustments towards the use of modern engineering tools and technology. At the same time, teaching methods also evolved, becoming more focused on innovations such as group work, problem based learning, industrial work study, design projects, case studies and so on, shifting engineering education to rely less on textbook problems. The focus also turned to the educators, beginning to prioritise professional development for educators through such activities as workshops on teaching, conferences and symposia. Following this, were improvements in student experiences. This saw growing popularity of exchange-student programs, design competitions as well as diversification of learning material.

To the present day, there has been global emphasis on quality control for engineering education and inclusion of sustainability concepts as well as social issues such as racism, discrimination, gender issues and so on. The element of entrepreneurship and innovation has also gained much ground lately, in terms of engineering education curriculum. Figure 1.1 gives a graphical illustration of the summary of the evolution of engineering education.

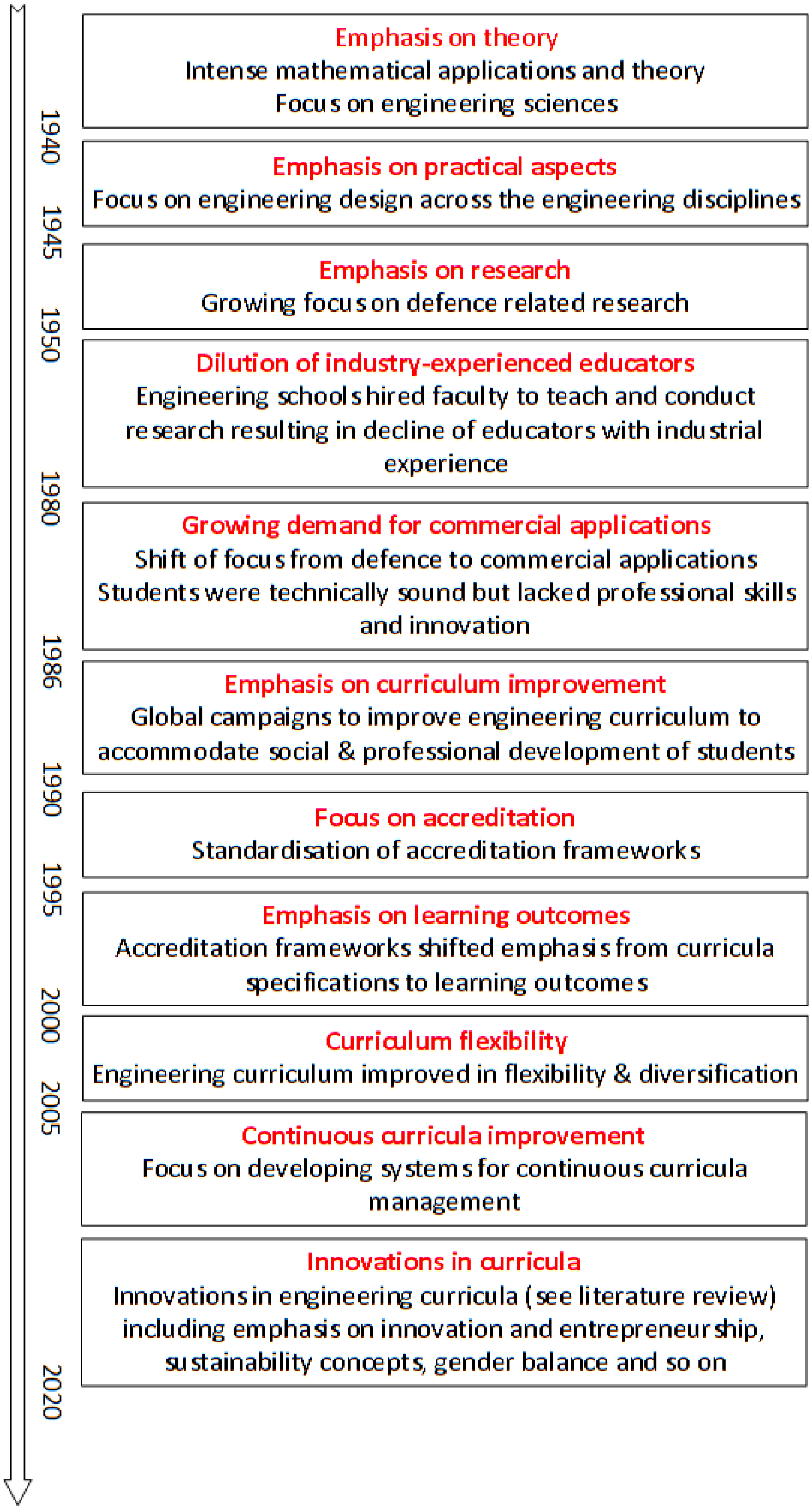


Figure 1.1: Evolution of engineering education, derived from [2] and [3]

Figure 1.1 shows that education is dynamic. This study, as with [1], [2], [3] and [4], ties these dynamics to a changing industry. It is very important to invest substantially in ensuring that education follows the dynamics of industry. This is how the global education system can ensure that, at the very least, education supports industry, or better yet, drives industry. Education is expected to follow industry trends. The current challenge is that sometimes education does not follow industry quick enough. Industry, for example, is able to quickly adopt new technologies (such as software), but the education system is slower in adopting. To explain this, reference is made to the diverse nature of industry. According to the 2017 - 2018 annual report [5], of the Engineering Council of South Africa, better known as ECSA, an estimated 29,074 engineers were registered and practising, employed across multiple industries comprising tens of thousands of enterprises specialising in a wide range of economic activity, yet these enterprises are supplied engineers by a dozen South African universities. This presents such a scenario whereby the learning process cannot adequately cater for all post-graduate employment possibilities.

Deeper analysis shows that, for example, there are hundreds of modelling software on the market, such that industry players, based on their unique requirements and circumstances, adopt which ever software package to best meet their requirements and circumstances. This means that hundreds of software packages are in use across tens of thousands of enterprises. It is not practical for curriculum to accommodate hundreds of software packages, for only one program course (system modelling for example). For this reason, education has been structured to utilise the software of technology that is seemingly most common in industry. Engineering education therefore includes the MATLAB software package at the majority of Universities across the world. This is a universal norm from engineering discipline to engineering discipline. On the national scale though, this general approach does not however guarantee alignment to local industry.

What if we surveyed the industry to determine the true practical needs of industry in terms of software for example? The idea would be to determine the precise software requirements of the local industry and then to directly adopt those identified software packages in curriculum. While this approach may improve curriculum alignment to industry, the challenge would be that the needs of industry (with thousands of diverse stakeholders) actually translate to multiple software packages which cannot be adequately covered by curriculum. In this way, this study therefore proposes that a better approach may be to focus on teaching students the ability to quickly and effectively learn new software/technology in order to improve curriculum alignment in terms of software.

This approach presents a potentially effective way to manage the complexity of curriculum alignment to industry. The needs of the industry can be interpreted in a more meticulous way. For example, as shown in Chapter 5 of this study, current trends show that the need (in terms of the industrial engineering profession) reflects high demand for optimisation competences. Consequently, the education system will typically shift to prioritise optimisation competences by adjusting curriculum to enhance such courses as Operations Research. A more meticulous approach would be to atomize (to breakdown/decompose) the ”optimisation” subject into micro-elements such as optimisation theory, data collection and processing, system design, concept development and so on. These micro-elements will in fact be common across several courses and with high inter-relativity. These micro-elements are then enhanced or prioritised across the full board of courses.

This potentially increases effectiveness and efficiency of curriculum alignment to industry. Even with this approach though, the complexity of the alignment however, still stands. This complexity however, can be well handled by intelligent systems such as artificial intelligence control systems. With artificial intelligence, a control system learns how to perform. This means that the system is taught how to interpret data or information. In the case of the curriculum management system, artificial intelligence means that the system is trained how to interpret some industry based information to produce accurate curriculum action, that is required to improve alignment of curriculum to industrial need. The curriculum management system proposed in this work is therefore based on artificial intelligence. The idea is to train the system in such a way that if industry has developed priority for a certain competence, then the respective micro-curriculum elements corresponding to the competence need to be enhanced and prioritised through curriculum.

The complexity is in the system having multiple inputs and outputs, which are actually interrelated in a sophisticated manner. While artificial intelligence can deal with this complexity effectively, the approach and methods may be challenging to implement. A situation may arise where by there is so much information for the system to learn such that the process of training the system may become highly involving and time consuming, typically resulting in poor performance. The

Figure 1.2 depicts this scenario, where the volume of training data is too high for the effective processing of the data into useful output.

Figure 1.2: Common artificial intelligence training challenge

It is therefore typical that ad-ons are implemented with the respective artificial intelligence algorithms to optimise performance.

1.1 Aim of the study

The aim of this study, is to align curriculum to the needs of the industry. This is done not only for the benefit of the graduates, but also the benefit of the industry and economy, if more skilled graduates are produced. Already, South Africa has seen progress in education, indicated by rising student enrolment at university level as depicted by Figure 1.3.

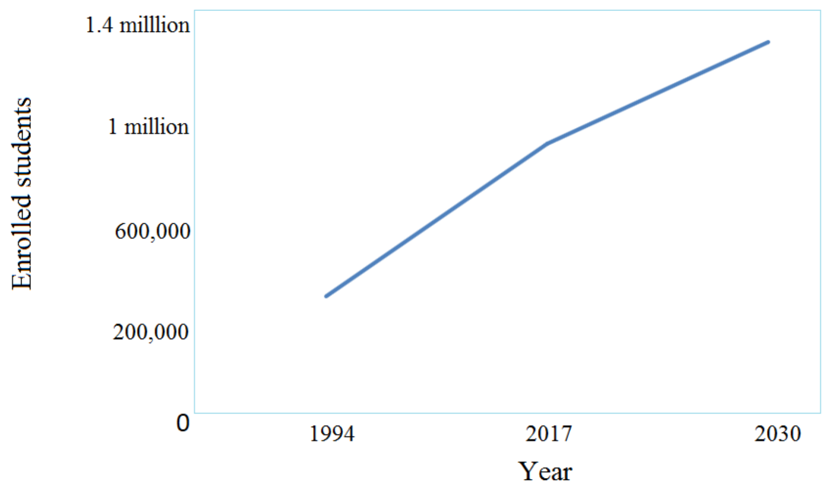


Figure 1.3: Trends in South African university enrolment

The trends indicate rising enrolment, just as intended by government. The trends are in fact similar for several African countries as well. Construction and establishment of new universities, as well as expansion of existing universities have both contributed to the attainment of the goal. Globally, the enrolment trends also reveal increasing enrolment, mostly attributed to by an increase in the number of international students and in student sponsorship [6].

While more work continues to be done to further increase student enrolment, a turn has also been made, over the past decades, to focus on the quality of education, from the view of student experience post-graduation. It is highlighted by Rahman et al. [7], that tertiary institutions meet challenges in producing graduates who are able to meet the needs of industry, while at the same time, the industry is having challenges finding skilled graduates who are adequately equipped to meet industry needs. This work develops an integrated Industrial Engineering (IE) curriculum management system, to align the curriculum to the needs of the industry. This means that the graduates produced actually graduate with the necessary knowledge and skill that is industry-sufficient and industry-applicable, regardless of the dynamics of the industry of the 21st century. This study is done at the University of South Africa (UNISA), focusing on the industrial engineering curriculum.

Engineering curricula, while meeting international standards and local industrial needs, must be as closely aligned as possible, to the dynamics of the national economic, environmental, social and political landscape. Such is the key to development and sustainability, especially for developing countries. Moreover, the goals and vision of an academic institute must actually be reflected in the curricula packages of the respective institute [8].

It is not enough, for example, to teach students how to design advanced robots with all sorts of functions, but without economic functions (academic-oriented learning). We argue that this is incomplete education. We argue that higher education must go a step further to teach students how to use the robot design capacity for economic impact (industry-oriented learning), as depicted by Figure 1.4.

Figure 1.4: Academic-oriented and industry-oriented learning

On one side, a student has developed a three-degree of freedom robotic arm but on the other side, another student has developed a three-degree of freedom robotic arm for grape picking functionality. If education promotes the former, rather than the latter, this suggests that the education system is starving the economy of potential innovation and development. From year 2000 to year 2018, the unemployment rate in South Africa was approximately 26 percent, with a graduate unemployment rate in 2018 of approximately 34 percent, while the adult rate was approximately 5 percent [9]. For those employed, it is estimated that small businesses actually employ approximately 53 percent of the workforce, yet our curriculum today generally prepares graduates more to be employees than entrepreneurs. By developing curriculum management systems, such factors can be addressed systematically.

1.2 Research background and context

This study focuses on higher education quality evaluation and management. The quality of a service is generally complex to model because a service is more of a utility rather than an object. A service has diverse components that make quality control more difficult to model [10]. Quality evaluation requires some decision making processes which contain qualitative components that cannot be easily integrated into mathematical equations. In higher education particularly, the intangibility of measurements and the existence of multiple stakeholders with different needs and requirements, both lead to a complex composition when considering system modelling.

Quality of higher education can be measured as the difference between graduate competence and the expected competence from the perspective of industry. Expectations vary from industry to industry and enterprise to enterprise just as the respective industry needs are dynamic. In this way, technology too is constantly improving. Engineering education has therefore significantly evolved over the past century. Engineering students graduate into a diverse work environment, that is affected by such factors as technology, as well as various social, environmental, political and economic factors, which in most cases are dynamic. This study argues that if the education system is not adaptive and dynamic, the quality of education is at risk of compromise, especially over long periods of time.

Some of the factors that affect the quality of engineering education include resources, facilities and laboratories, management and leadership, staff competence, teaching methods, funding, the taught curriculum and so on. Curriculum, in the context of education can be defined as the fullness of the learners' academic experience right through the process of learning [11]. The taught curriculum, specifically, is a critical pillar to economic development. In reality, curriculum is a key factor in defining programme outcomes [12]. Over the past three decades, numerous calls have been made for new improved engineering competencies and refined curriculum for engineering education [13]. In fact, currently, public universities in South Africa (and much of Africa), are prioritising curriculum redesign to achieve a more inclusive approach to education, and to decolonise knowledge [14]. The work of Fomunyam [15] looks into the decolonisation of South African engineering curriculum and revealed that theory, practice, language, academics and pedagogy in engineering all required decolonisation. The work emphasized the need to enhance curriculum change to liberate the South African engineering education. While higher education institutions are typically heavy structures, not easily movable or adjustable, it is critical to move towards a more flexible structure, adaptable to the various factors affecting education.

1.3 Research motivation

There is need, across Africa, and even world over, to produce graduates with the skill and knowledge that is required to solve the challenges faced in industry, while also successfully navigating the economic, social and political landscape. To do this, an understanding of the factors affecting education quality is required, as well as an understanding of how these factors actually affect the quality of education. These factors include [16]:

1. Resources and facilities,
2. Institute management,
3. Staff competence,
4. Teaching methods,
5. Funding,
6. Taught content (curriculum).

From this list, one significantly contributing factor, yet manageable at institutional level, is curriculum. Curriculum is the material delivered to students in or outside the classroom, during the entire period of learning. With engineering, the taught curriculum is what ultimately determines the competitiveness of a student in the industrial setting, and whether or not the student is able to survive and navigate the dynamics of industry. The engineering curriculum must adequately prepare graduates for the prevailing engineering work environment. This environment however, is dynamic and is affected by some critical elements such as [17]

1. Technology advancements.
2. National policies and interests.
3. Social, economic and environmental issues.

It is therefore necessary to develop advanced systems that manage engineering curricula, on the basis of current and futuristic (predicted) trends in the engineering environment. If small businesses account for more than half of today's work force, higher education must be structured to accommodate the implications. Seven small to medium businesses offering different drone related products and services in the Harare, Zimbabwe were studied in terms of background of the business owners. Out of the seven, only one was owned by people of engineering background as depicted by Figure 1.5.

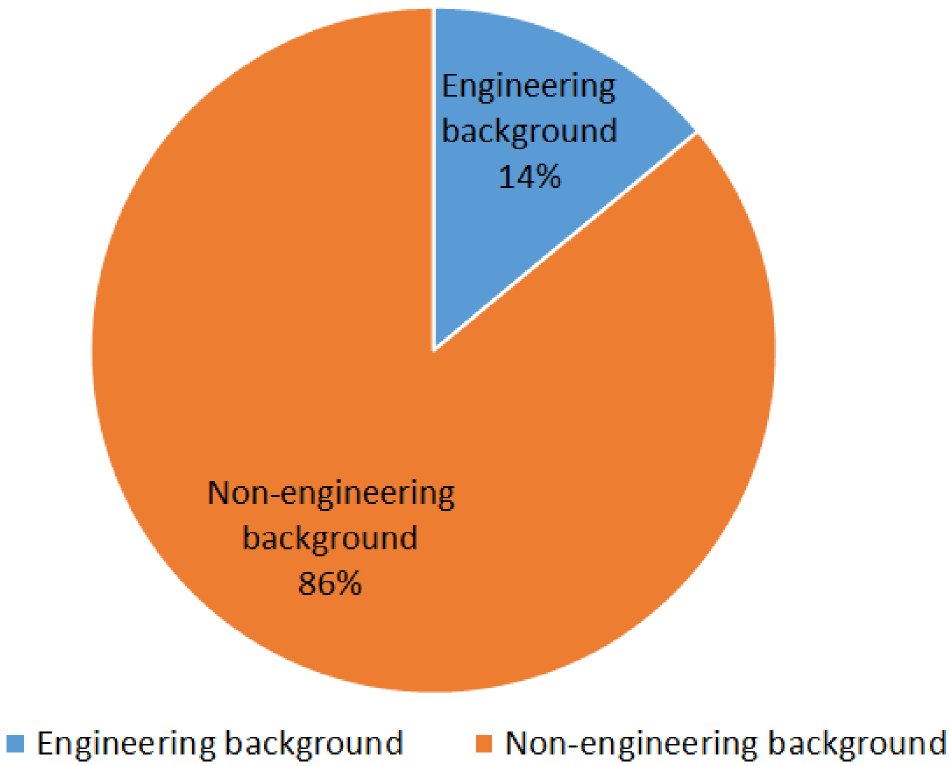


Figure 1.5: Drone business owner statistics

The rest were owned by entrepreneurs from different qualification and career paths. Further studies in fact revealed that 83 percent of those businesses not owned by people of engineering background had no effort in internal research or product value addition, or plans thereof, but solely relied on equipment imported from abroad, ready-to-operate. On the other hand, with engineering background, came some internal research and development (reverse engineering) which indicated reduced costs and product customisation to local needs. Curriculum must therefore motivate engineering students to consider entrepreneurship in engineering related fields, and to use the acquired knowledge and skill in engineering to enhance productivity.

1.4 Problem statement

According to a 2017 report by the Global Partnership for Education (a fund that mobilizes global investments for the improvement of education systems), the current trends in skills production in Africa do not match the developmental needs, especially in the fields of engineering and science. Many African higher educational graduates go unemployed, yet substantial shortages of skilled labour still persist. Unemployment rate in South Africa falls in the region of 25 percent [18], yet the economy is in need of labour to realise sufficient production. In some African countries, it can take up to five years before a graduate secures a job. Yet even after successful recruitment for employment, some graduates face the challenge of requiring additional technical training in order to satisfy the expectations of the job, despite the three or four years spent in university. Some of these trainings actually demand financial commitment. To address this challenge, this study will propose finding out what the missing element is in higher education curriculum, so as to ultimately ensure that graduates possess the skills required by the job market.

A continental trend is becoming common across Africa. One where if engineering graduates become unsuccessful in attaining employment for some years after graduation, the candidates do tend to venture into entrepreneurship. While entrepreneurship is welcome, especially in today's economy, a closer analysis shows that the type of entrepreneurship here ventured into is not entirely appropriate. More and more of these graduates actually venture into non-engineering related entrepreneurship, especially buying-and-selling, sadly, even to street vending level. While this scenario may mainly be attributed to by low industrialisation, quality of education is also a contributing element. Ideally, if the engineering graduate decides to venture into entrepreneurship due to lack of employment, or any other reason, then the type of business venture better be engineering related.

The problem is graduate unemployment (or difficulty in attaining employment or satisfying employment demands), as well as graduate underutilisation, in part, due to misalignment between curriculum and industry needs. While misalignment is well understood as a problem, methods have been implemented at higher learning institutions to align curriculum to industry. Such methods include periodic curriculum review and reform. While these methods, to some level, have produced positive results, the problem re-emerges in the form of incomplete alignment, resulting again in curriculum-focus diverging from industry focus areas, and the problem persists. Reasonably, this is expected, given the rapidness of the dynamics of industry, especially in terms of technology and society. More robust approaches are therefore needed to align curriculum, and to maintain the curriculum. This means that our engineering graduates are not adequately oriented and prepared for industry, even after four or three years of higher education. This problem has since resulted in or contributed to graduate unemployment, low innovation as well as industrial knowledge deficiency.

There is a strong stance that by optimising curriculum, these problems can actually be addressed, even at institutional level. The basis for this fact is that curriculum defines program outcomes, and these outcomes ultimately shape the competences of the graduate. If curriculum is therefore aligned to industry, the graduate output is better equipped to navigate the industry, and it then becomes a case of the Nation ensuring that industry is available and supported.

1.5 Research questions

The research question is as follows: can we adopt artificial intelligence to support curriculum manipulation decision making, based on a decomposed curriculum approach, in order to improve curriculum alignment to industry needs? The following research questions arise:

1. From literature review;
   How does the current higher education system reflect misalignment between curriculum and the skill demanded by industry?

   Then, with the understanding that conventionally, engineering curriculum prepares students more for employment and less for entrepreneurship, yet entrepreneurship is rapidly rising in terms of contribution to economic development, this brings the questions:

2. To what degree should graduate entrepreneurship prospects in industrial engineering be allowed affect the curriculum?

   Finally, this leads to the design question:

3. Can we provide improved curriculum management by adopting an approach where curriculum is decomposed into interrelated topics or micro-curriculum elements which are then manipulated? This is characterised by breaking down courses into topics (atoms) and then managing curriculum at this level.

These research questions presented thus define the research objectives, and the objectives point out to the expected contributions of this study. The hypothesis is that if an AI-based system can be taught how to interpret job adverts into industry skill needs, then the system can be used to manage curriculum, towards improving curriculum alignment to industry needs.

1.6 Research objectives

The objective is to develop an intelligent system that can manage, and so improve the quality of industrial engineering education at UNISA. The system regulates curriculum according to the needs of the industry and technological development. We therefore develop a service quality management system. Service quality is well defined in [10] as the difference between the expectations of the customer before service delivery, and the customer perceptions after service delivery. The customer in this case, is the industrial engineering student, whose desire for industry-oriented knowledge empowerment must be satisfied. The objectives are:

1. To propose some strategic adjustments to the Industrial Engineering curriculum at UNISA in order to improve curriculum outcome alignment to industry needs. This is intended not only to improve curriculum alignment, but also to modernise the curriculum.

2. To establish the scope and potential of industrial engineering graduate entrepreneurship in the current and future economy, as well as to develop a framework to enhance entrepreneurship competences in graduates.

3. To develop an artificial intelligence based system to manage the Industrial Engineering curriculum, one that interprets industry data to determine the required curriculum adjustments necessary to provide curriculum-industry alignment.

In this way, we develop a rigid-skeleton flexible-body approach, where higher education curriculum is staged on a rigid architecture, with flexible course elements which are manipulated according to the dynamics of the industry.

1.7 Expected contribution

This study is expected to introduce a more meticulous and holistic approach to systematically align engineering curriculum to the needs of the industry. We propose the concept of topical manipulation, that is to say ”atomising” program courses into micro-curriculum elements which although highly complex to manipulate, provide unmatched robustness in curriculum alignment to industry. We show that managing, or manipulating curriculum at this proposed atomic level, improves effectiveness and efficiency of the overall curriculum-to-industry alignment. The outcome of this study presents a valuable framework for quality management committees and administrators at higher learning institutions, for improved education quality and also contributes new knowledge to academia in terms of how education/curriculum can be managed.

There is need to adapt the curriculum to industrial dynamics so that graduates are fully geared and capacitated to navigate the post-graduation landscape. In this work, an integrated adaptive system for the management of industrial engineering (IE) curriculum at the University of South Africa (UNISA) is proposed. The system manipulates curriculum according to the state of industry, for the benefit of both the graduate and the industry as well. The study will:

1. Propose a cocktail of reforms and improvements to the industrial engineering curriculum at UNISA.
2. Develop an artificial-intelligence-inspired management system to manipulate curriculum to align to the needs of industry.
3. Develop a more integrated method to manipulate curriculum, one that decomposes curriculum into micro-elements that are highly interrelated.

The system proposed in this work is expected to address graduate unemployment; failure of engineering graduate entrepreneurship ventures and also industrial knowledge deficiency, by manipulating curriculum according to the needs of the industry. This work also contributes towards understanding the potential of industrial engineering graduate entrepreneurship and how curriculum can be adjusted to promote entrepreneurship competences among students. This study also contributes towards an analysis of the balance between employment and entrepreneurship tendencies in curriculum.

Chapter 2

Literature Review

The literature review for this work begins by studying the matter of curriculum misalignment, to point any existing gaps. We also take a look at some modern worldwide innovations across engineering education curriculum, innovations that have contributed to curriculum alignment. The literature review further explores curriculum reform strategies and some methods used to adjust or manipulate curriculum to meet some set requirement. The ultimate objective of this work is to develop a management system for industrial engineering curriculum, and so the literature review also looks into modelling complex systems as well as some of the tools available for complex system modelling.

2.1 Curriculum alignment

Curriculum defines the fullness of any study program, including the teaching methods, courses, modules, exercises, material and policies or regulations. Curriculum therefore spells out the learning outcomes, methods and knowledge content for students. To justify this study, an initial evaluation of the current state of curriculum alignment to industry is required. It is necessary to understand how serious a problem, curriculum misalignment is. Several studies have exposed the gap between curriculum and industry needs, both in the context of South Africa as well as globally. In the case of South Africa, [19] and [20] are some examples of studies that explicitly point to the need for emphasis on curriculum alignment.

Wu [21] argued that one of the causes of curriculum misalignment was the lack of effective and efficient curriculum management systems or tools. The author further argued that the development and implementation of curriculum management systems needed serious priority at institutional level, to the level of encouraging teachers to study the curriculum management theory and to even extend this requirement to the students. In [22], authors pointed to the fact that the need for explicit training for teachers on curriculum management is actually critical. The authors presented teacher training as a requirement, if higher education is to optimise the education system. Further, it was proposed that the training be guided by input from the full spectrum of stakeholders including the society, students, decision makers, industry and even parents. Cui and Lu [23] proposed formative assessment as a tool for optimising curriculum management. Formative assessment gives higher emphasis on the teaching process with respect to the teaching styles and methods, to ensure that curriculum deviation is controlled. The methods demonstrate improved effectiveness in maintaining curriculum alignment.

Santiago's investigation [24] showed that engineering education had a fairly wide gap in terms of problem solving competencies. Santiago showed that the gap between the problems solved in class during the learning process and those presented by the industry was wide, and was in fact widening further, year after year. This gap between class problem solving and industry problem solving was also discussed and exposed by Winberg et al. [25]. Mitchell et al. [26] identified that several engineering study programs struggled to balance the need for the provision of an innovative engineering education that met industry needs, and also satisfied graduate demands. Authors proposed a curriculum framework that combined the existing discipline-specific curricula and some elements of skill needs, followed by implementing the framework on a problem-based learning basis. The platform demonstrates improved regulation of education. Simpson et al. [27] viewed engineering curriculum misalignment from a unique point of view. The authors argued that in general, engineering innovation has been driven by learning from mistakes of the past, yet students were generally groomed to "succeed" on the first go. Consequently, and in practice, this shadows the concept of learning from failure. The authors therefore revisited curriculum to accommodate the incorporation of learning from failure and this was done within the context of the civil engineering course.

Garousi et al. [28] discussed the software engineering program in a general sense, to the conclusion that most programs still focused more on theoretical topics, causing a discrepancy between practical skill requirement and skills taught in class. It was highlighted that while quantities (volumes) of graduates were high, there was clear shortage of quality, in terms of competencies. Some improvements were proposed. The same issue is raised by Baker [29] with even more emphasis. Further analysis showed that curriculum misalignment is not only affecting engineering related programs. Misalignment is currently affecting even artisanal professions (electricians, carpenters, beauticians and so on), which are in fact expected to be as practical as the industry is [30].

Zimmer and Keiper [31], discussed misalignment as a common phenomenon in higher learning, and in fact as one of the main reasons why curriculum review is a necessity in order to maintain curriculum effectiveness. The authors pointed out that curriculum misalignment was becoming even more common due to the growing diversity of teaching staff which has in-turn resulted in different interpretation of the same course objectives, ultimately causing some changes to course material without adequate consideration for the overall program alignment. Akdur [32] illustrated how misalignment is clearly elaborated in the case of software practitioners, where typically, graduates do manage to satisfy computing disciplines but not so much, the related electrical and electronic engineering disciplines, which are yet equally required by the software industry.

After curriculum misalignment is confirmed to be a reality, and curriculum management to be the solution, Buyurgan and Kiassat [33] further highlighted that curriculum management needs continuity. The authors presented curriculum for a medium-sized United States private university and argued that curriculum assessment and management needed to be a continuous process, seeing on-going curriculum improvement according to the necessary set control indices. This introduces much needed flexibility in curriculum and allows the pursuit of innovative education.

Summary:

It is certain that curriculum misalignment (to industry demands) is a factor affecting the global education system negatively. Causes for this curriculum misalignment include diversity of teaching staff, as well as dynamics of industry, technology and society. This work argues that one of the main causes of misalignment is the dynamic nature of the industry, which cannot be stopped, but rather, curriculum needs to be adapted to these dynamics.

2.2 Modern innovations in curriculum

Over the past decades, emphasis has been placed on applying innovation to higher education curricula. These innovations have the potential to improve curriculum alignment to industry demands or needs. A common trend is that higher learning institutes are improving curricula to become more robust and integrated (multidisciplinary).

2.2.1 Problem solving concepts

The work of Chen et al. [34], proposed a problem-solving creativity enhancing program for industrial engineering curricula. In this way, three modules were developed and introduced (scientific research methodology, industrial communication and creative problem solving). Over a hundred students from Yuan-Ze University took part in a two-year exercise, followed by which a creative thinking examination was conducted, which revealed that, indeed, after completing the reformed curriculum program, students had substantially enhanced competences in innovation and thinking outside the box.

Hadim and Esche [35] presented the implementation of Problem-Based Learning (PBL) in two first-year-level courses (Mechanics of Solids and Mechanisms and Machine Dynamics). PBL, as an approach in higher education, is gaining much popularity across the engineering education community and is proved in [35] to enhance student communication skills, participation, learning diversity and enhancement of creative thinking. Chau [36] examines the results of the introduction of sustainability elements into civil engineering curriculum, towards addressing the social, environmental and economic dynamics in Hong Kong. A design project is executed by a student team, on the basis of a PBL approach and initial results, according to stakeholder evaluations, show significant potential contribution to knowledge on sustainability.

2.2.2 Automation

Elhoseny et al. [37] described higher education curriculum as difficult to automate. The work introduced a generic platform for an automated information technology system to manage the higher education quality. An automated system is also discussed in [38], where an automated information system is explored for the management of curriculum at Petrozavodsk State University. The automation of curriculum management systems has been proven to be efficient and accurate in realising the goal of tracking study programs and education quality. The majority of curriculum management systems available, are typically designed as administrative tools, for the purpose of managing education, in terms of performance and education tracking, as part of the universal goal of ensuring that student learning experience is complete. Such systems have in fact evolved even to the point of managing extra or co-curricula, covering such aspects as clubs, sports and so on [39]. Such curriculum management systems are capable of tracking student performance with unmatched accuracy and efficiency, providing vital information which is used to guide decision making in career path selection [40]. This means that students can be better guided as the students build their individual qualification profile.

2.2.3 Instruction methods

Alarifi et al. [41] proposed an improved instruction method for the Software Engineering program, defined by consolidating and mapping the needs of the local software market and also the objectives and constraints of the program curriculum. An analysis was then carried out to investigate the strengths and weaknesses of the program curriculum.

Schrlau et al. [42] investigate the use of the flipped classrooms approach to improve understanding, conceptualization and problem solving skills of Mechanical Engineering undergraduate students. The idea is to deliver content outside the 'lecture' room and promoting high student interaction inside the classroom. In this work, the 'Heat Transfer' course was restructured for flipped instruction, and the evaluation carried out demonstrated the effectiveness of flipped instruction over traditional lecturing.

Juan et al. [43] proposed the use of competitions to enhance the Mechanical Engineering program. It is concluded that the student competition approach enhances competence and knowledge among students, especially towards realising the theory taught, through practical problem solving.

2.2.4 Integrated curriculum

In [44], a proposal is given, to integrate the different disciplines of engineering towards improving and optimising the student experience. Maciejewski et al. [44], present an organisational model emphasising knowledge fusion across the engineering education value chain. Perez-Foguet et al. [45] further explore the idea of integrated engineering learning, particularly focusing on the implications of the fourth industrial revolution (Industry 4.0) which views industry more like an intelligent and dynamic process or system, affected by information technology, interoperability, decentralisation, virtualisation, modularity and so on. Authors argued that engineering education required transformation towards treating curriculum in a more integrated manner, especially to align to the characteristics of Industry 4.0. The integration of all the engineering disciplines is in fact becoming common, rather than the conventional approach where curriculum is highly discipline-dependent.

2.2.5 Social considerations

Two common social challenges faced by education institutes relate to producing highly employable graduates and also addressing the sustainable development competences as part of engineering education [13]. Work presented in [46] describes a platform developed towards promoting diversity, creativity, and interdisciplinary talent into engineering. Authors proposed a learning system designed to address student, instructor, employer and stakeholder needs, combining industry partnership, student-centred pedagogy and continuous social development while addressing gender gap.

Swart et al. [47] present an usual approach to addressing social considerations as part of engineering education. The authors take on a serious social challenge as viewed by the South African community, and introduce elements of this challenge into engineering studies. The challenge addressed is that of the HIV and AIDS epidemic. This direct approach is proven to improve awareness and understanding among graduates, as applied to whatever respective social challenge.

Another social element to consider is that of leadership. Several reports in fact, do call for undergraduate programs to aim towards developing engineers with leadership ability. Knight et al. [48] discuss effective approaches for engineering leadership development among students. The Scrum approach, a concept that promotes teamwork is experimented with, for the purpose of exposing engineering students to project management skills, and is proven effective [49]. Project management is a critical tool in engineering and becomes even more relevant with experience and further management study.

2.2.6 Sustainability concepts

The past few decades have seen a number of engineering and technical universities dedicating serious effort to integrating sustainable development into the engineering curricula. Sharma et al. [50], conducted a study on the inclusion of sustainability concepts in curriculum. Knowledge of sustainability elements in engineering graduates is vital in today's industry, where maximum output is required from minimum input. Researchers explore the merits of the introduction of such concepts to make up part of engineering studies [36], to the effect that graduates having such exposure were better equipped for the construction industry, especially towards roles of project management.

The work of Lim et al. [51] addresses the need for sustainable development elements in engineering education. This work combines sustainable development components and construction studies, adopting the approach of direct (horizontal) combination, that is, inserting the components into existing modules, instead of inserting the components independently, more like stand-alone modules. Sustainable development elements covered include policy and regulations, economic issues, environment concerns, communal issues and so on. Integration of sustainable development concepts in engineering curricula is also explored in [45] and in [52], on a case study basis.

2.2.7 Risk management

Guntzburger et al. [53] describe risk management as a key responsibility for engineering practitioners. Risk management ties down to safety, which in today's work environment claims substantial investment from enterprise to enterprise. In [53], authors explore the link between risk management and ethics and demonstrates that there is need to further develop engineering curriculum towards promoting more environmentally and socially responsible engineering practices.

2.2.8 Innovation and entrepreneurship

It has become a global trend for tertiary institutes to integrate entrepreneurship components to higher learning. Entrepreneurs have been proven to be agents capable of bringing change, innovation and solutions to problems at various levels. Devadiga [54] presents a study where the dynamics of software engineering start-ups are analysed and compared against curriculum. It was argued that elements of entrepreneurship require more prioritisation in curriculum. Measures to promote innovation and entrepreneurship were proposed.

Azemi [55] studied how innovation, entrepreneurial mind-set and systems technology were related. It is shown that introducing entrepreneurship components to curriculum is becoming a global norm, especially as small businesses and start-ups continue to contribute more and more significantly to the labour market. It is found that there is need to explicitly develop entrepreneurship competencies in students not only for the purpose of widening the opportunity horizon, but more so for the purpose of aligning to the growing demand for innovation and entrepreneurship across the global economy.

In general, entrepreneurship, as a career path, is typically associated with instability, due to uncertainty in job security. Holler et al. [56] however, present entrepreneurship as an avenue of potentially high stability, highlighting the need to prioritise entrepreneurship concepts in university policies, particularly for engineering education. The authors, present entrepreneurship as a driving force for innovation and economic development. Ayalew and Zeleke [57] study how entrepreneurship desire may affect independent job-creation potential among students in engineering schools across three higher learning institutes in Ethiopia. The study shows that 57.4 percent of students had an entrepreneurship mind-set for the post graduate career. The study also reveals that while it is key for higher learning institutes and Government to develop systems that support entrepreneurship, the attitude of students towards a career in entrepreneurship needs to tally. Curriculum is therefore required to project entrepreneurship accordingly. Herman and Stefanescu [58] investigate the potential for higher education to stimulate entrepreneurship among graduate engineers as well as business students. The aim is to increase the entrepreneurship mind-set among students. Joao et al. [59] also explore entrepreneurship potential among students, with similarly guided aim. Cheng et al. [60] analysed the typical problems of engineering education with respect to entrepreneurship. The study proposed a training program for engineering students, one that integrated entrepreneurial education with core studies in the form of a training package. It was evident that entrepreneurship was indeed becoming a key element of higher learning, including engineering education. It therefore makes sense to consider the entrepreneurship opportunities, when managing engineering curriculum.

2.2.9 Software

As with any engineering program, software is a critical component. Nehra and Tyagi [61] discuss the comparison of proprietary and free open source software products. Typical proprietary products include Multisim, LabView, Solidworks, MATLAB to list a few. These are globally accepted and form part of engineering programs across most tertiary education institutes of the world, however, most of these software are expensive, hence the need to consider free open source software. In [61], it is highlighted that selection of appropriate software tools is actually one of the key challenges in engineering education. Special consideration needs to be made for the local industry as to the type of software packages currently in use, and then curriculum needs to be adjusted to accommodate the relevant software. As for the proprietary software products, over and above the expense, these products usually limit features according to the license type. This has actually been seen to be a contributing factor in encouraging illegal software copying [61].

With free open source software, costs become manageable, and software access restriction is eased. Even in industry, open source software are becoming more common, especially because companies in industry too are working towards lowering costs, especially start-ups and small companies. Medrano et al. [62] provide a review of some engineering design software tools that are free and open source, while in [63] a framework is discussed and presented, for effectively integrating free open source platforms to engineering, with the aim to actually improve the learning experience and outcomes for students. An example is [64], where the XCOS open source graphical programming tool is proposed, as another option to replace the Simulink product.

2.2.10 Summary

The way curriculum is viewed is becoming increasingly flexible. Institutions across the world have embraced the liberty to manage curricula according to circumstance. Worth reiterating, is the fact that studies are showing that curriculum is best treated as a highly integrated package, rather than a collection of unique courses or modules. In order to satisfy the competence demand of the labour market, it is necessary for higher learning institutions to maintain innovation across all facets of education. It is important to carry out continuous studies to identify any gaps in curriculum and then to provide innovative solutions.

2.3 Curriculum manipulation methods

According to [13], three possibilities exist, for curriculum manipulation. These are; the add-on approach, integration approach (horizontal integration) and the re-building approach. Re-build typically demands high investment compared to the rest, and for this reason, the re-build approach is less common.

Dolog et al. [65] presented a method of curriculum reform for the Software Engineering qualification at Aalborg University, Denmark. First, the initial (traditional) program curriculum was described and analysed respective of skill and knowledge levels, guided by the Blooms taxonomy method. Student competence levels were then compared against the expectation of the qualified engineer with four years of experience according to the Software Engineering Body of Knowledge (SWEBOK), as presented in [41]. It is on the basis of the comparison, that amendments to curriculum were proposed, implemented on an add-on and integration basis, and run for a two-year period, before being evaluated.

Most commonly, curriculum is manipulated by introducing particular courses or topics (add-on approach), as necessitated by the given circumstances. A case-study strategy is used in [50], where a sustainability course is introduced and students were evaluated prior and post the course. A duo method is implemented, consisting of qualitative and quantitative (survey, tests and examinations) techniques. Quantitative data is analysed, in [50], using multinomial logistic regression, descriptive statistics and explanatory analysis. Qualitative data on the other hand is evaluated by thematic analysis. Von et al. [66] also proposed the introduction of sustainability content to the undergraduate Chemical Eng program at University of Cape Town. The approach applied moves to slightly reduce the theoretical aspect, and promoted project-based learning, by a student project running the four year duration of the program.

A feasibility study is carried out in [8], for the New York State Bureau to School Libraries to assess the real-world performance of Curriculum Mapping. An APL-programming-language based system (CMAP), is developed and successfully applied to curriculum mapping. The result was a reliable tool for analysing and managing curriculum on both add-on and integration level. In [67], a dynamic and scientific curriculum system was developed, for China's higher education. The work analysed the present-day curriculum of electrical engineering and automation, before discussing general principles of electrical engineering and automation curriculum design, then proposed a construction path for refined curriculum through the add-on strategy. To address the demands of the national manufacturing and development strategy, serious effort has been dedicated to adjusting mechanical engineering education in China [68]. The scale of adjustments has taken the rebuild approach in some cases.

Summary

The general and conventional method to manage curriculum is one characterized by a mapping process, executed at institutional level. There are two dimensions to curriculum management. First, curriculum management can be executed in a generic dimension, that is to say the process of selecting program courses; for example, selecting elective courses. The other dimension of curriculum management is one where some specific program curriculum is reviewed and adjusted in order to improve the program outcomes. The latter is the curriculum management discussed in this paper, with the aim to improve curriculum alignment to industry needs.

2.4 Modelling complex systems

A complex system is one characterised by several components capable of interacting with each other. The behaviour of such systems is intrinsically difficult to model, because of the relationships and dependencies between the several parts of the systems, internally or even externally. This work requires that the curriculum system, in its complexity, be modelled as accurately as possible. Based on the developed model, the system is then capable of making intelligent decisions to manage the curriculum. Decision making in such qualitative systems usually introduces a complex scenario, beyond the reach of the usual empirical statistical techniques. Such systems typically require methods that are more heuristic rather than algorithmic.

2.4.1 Modelling educational systems

Mehta et al. [69] discuss and present several Delphi-based implementation techniques of Total Quality Management (TQM) in engineering studies. Authors deduce relationships among TQM strategies using the Interpretive Structural Modelling (ISM) approach, which is proved to assist in identifying the measures required and even the sequence in which the measures are to be taken, so that education quality is improved.

Trevelyan [70] presents a model based on quantitative and qualitative empirical data consolidated across various engineering disciplines. The developed model considers the importance of social aspects as key to obtain predictable future outcomes of engineering, from a large number of individual human activity and interactions. In the work of Cowling [71], a model to describe various possible curricula for degree courses of the software engineering program was presented. The model, at low level, allowed for distinction of the different branches of the field of the program. The model further organised the focus areas of the curriculum and also the relationships between the areas. Ultimately, the model gave aiding tools that are used to enhance decision making, for such aspects as, time allocation for different topics.

Chen et al. [72] gave an evaluation of how university employee dissatisfaction with the set institutional investments determines the quality of education. A model was developed, to measure staff satisfaction. The model had six elements, such as the institutional vision, management structure, results, staff remuneration and so on. A questionnaire was developed and 248 staff engaged to determine the level of satisfaction. The developed model was useful in managing service quality.

Srikanthan and Dalrymple [73] developed a model (reference to existing literature) to manage quality in higher education. This work concluded that it was highly possible to not only develop a model for education management, but also to use the model to adequately address higher education quality issues.

Cullen et al. [16], explored the Balanced Scorecard technique, to manage and improve education performance. Other methods include such quality management modelling tools as Total Quality Management (TQM). Proprietary instruments such as SERVQUAL (and other related platforms) have also been used in such work as [74] and in [75]. SERVQUAL is a multi-element survey tool which integrates qualitative analysis and quantitative information for the assessment of quality of service. SERVQUAL has actually been a key tool for measuring quality of service, primarily because this product is easy to implement and simple to utilise, although, it generalises concepts and ideas more. More robust systems based on modern control principles can be implemented.

Conclusion

In order to systematically manage curriculum, a model to represent the curriculum system is required. Being quality systems, education management systems are complex. A heuristic approach to model curriculum is proposed. From literature review, such systems are diverse, and designed according to the intended purpose. This provides significant flexibility as to how to design the curriculum management system.

2.5 Modelling methods

Several methods exist, to model complex systems, including such as those discussed under Section 2.4. The methods have evolved substantially over the last two decades. In [7], advanced models are discussed, which include Support Vector Machines, Logistic Regression, Neural Network, Decision Tree, K-Nearest Neighbor; applied to developing a functional classification model for predicting and assessing the attributes of the students in meeting industry-based selection criteria.

2.5.1 Cluster analysis

Cluster analysis is a technique characterised by grouping data into distinct classes according to certain properties [76]. A common clustering approach is the Expectation Maximization (EM) method. This approach is very useful when data needs to be classified or grouped, on the basis that the source is not clearly known.

The work of Nelwamondo et al, [77] studied and evaluated the performance of the expectation maximisation algorithm and that of a neural network based algorithm in modelling some targeted processes. The study revealed that the expectation maximisation algorithm provides better precision and is more suitable for cases when there is low or no inter-dependency between the input variables. The neural network, which in this study was combined with a genetic algorithm, was shown to be most suitable when there are inherent non-linear relationships between variables.

2.5.2 Neural network models

Over the past years, the science of artificial neural networks (ANNs) has seen growth in popularity in solving the problem of prediction, classification, pattern recognition, clustering etc. One aspect of ANNs that stands out is that of high-speed processing emanating from the parallel implementation design. Other pluses of ANN are the properties of non-linearity, learning and prediction, fault tolerance, adaptivity and advanced input-output mapping [78]. Neural networks provide high accuracy even when the problem to be solved has incomplete data or is poorly defined and characterised by multiple possibilities [79].

In the case of education management systems, the behaviour of people can actually be presented mathematically through neural nets, giving networks not only the ability to predict outputs, but even to classify some input data and recognise any possible patterns [80]. If neural networks are capable of mathematically presenting non-linear relationships between service provider and customer satisfaction, then the network can also model the decision-making process [81].

Mahapatra and Khan [10] develop a neural network based education management system with forty-three survey items, including class hours, quality of learning laboratories, communication skills of teachers and so on. Data was collected from several stakeholders including current students, alumni, recruiters and parents across India, through a questionnaire consisting of forty-three items, over a six month period. Expectations and also perceptions, relating to the quality of the educational service delivered to students were captured, as well as the responses.

Hajek and Henriques [82] model the European innovation performance through neural nets. The multi-output neural network model is employed, one which is proven to be useful in enhancing and optimising human thinking and deciding, especially at strategic planning. The proposed neural net runs on a deep pool of data which includes such aspects as employment rate, educated population, Government expenditure on research and development and so on. In this same work, [82], authors successfully implement a Multiple Layer Perceptron (MLP), which is feed-forward neural net, comprises several layers and capable of propagating backwards during training. The MLP is shown to indeed be able to predict innovation performance.

Mahapatra and Khan [10] present Technical Education as a diverse field, difficult to break down as to what 'quality of education' truly means. Robust systems are required to accurately manage education. According to this work, it is critical to identify some minimum quality indicators, applicable to all concerned stakeholders, before designing and developing education management systems. Authors developed a measuring platform (EduQUAL), and designed a neural net system to estimate the effectiveness of the teaching systems, from various stakeholder perspectives. The stakeholders, included current students, alumni, staff, parents, government, recruiters, industrial and social players. Consequently, it is therefore difficult to set standards or norms that suit all the stakeholders. Mahapatra and Khan thus explored the development of an elementary regime, based on some critical minimum requirements, integrated into a functional decision making system.

Gee and Abbass [83] take a unique approach to curriculum management, where a set up resembling the shepherding problem (dogs guiding sheep towards a destination) is designed. The system is based on a neural network backed agent to control and monitor curriculum. Results show high accuracy and practicality of the approach.

Pavlin-Bernardic et al. [84] investigate the accuracy of artificial neural network in predicting the general level of giftedness. A total of 221 students were surveyed and input variables collected for artificial neural networks, such as teacher nominations, peer nominations, student school grades, pre-enrolment assessment and parents education. The output variable was the classifier which stated whether a student was gifted or not. Two neural networks algorithms were implemented, the multilayer perceptron and the radial basis function, with the multilayer perceptron outperforming the latter in accuracy.

Chien et al in [85], proposed a fuzzy-type neural network approach to estimate a prediction for national innovation performance. This work implemented an adaptive neural-fuzzy inference system to determine performance of innovation. In comparison to statistical modelling techniques as well as neural network modelling, it was shown that the ANFIS method was superior to both the neural network and statistical methods, in modelling the innovation performance. The model was shown to hold ability to genuinely guide decision makers in planning and in allocating resources in order to meet certain innovation objectives.

Hedayah et al [86], also explored the application of the neuro-fuzzy concept for the development of a student classification model, to estimate future student performance. Fuzzy IF-THEN laws are fused with that learning capacity of neural nets, thus producing a solution that is able to be taught through some set laws or guidelines, and then provide a high accuracy mathematical system to classify data.

2.5.3 Decision trees

Decision trees are a useful model for decision making under various conditions, more so in solving complex conditional problems [87], even capable of better addressing the challenge of missing information, rather than just simply ignoring data with missing values. Decision trees can be used in the selection of the 'most relevant' input variables that should be considered in a particular situation [88], in this case, perhaps the particular study courses that need to be adjusted to address the shortfall of a certain skill in graduates. Decision trees are also very useful in making predictions.

Othman et al. [17] study some key factors affecting the employability of graduates. It is shown that, while student grade point average (GPA) is traditionally the most relevant element determining graduate employability, it is not adequate to ignore other factors, which collectively, significantly affect the overall quality of a graduate. In this work, the decision tree is shown to produce highest accuracy in modelling graduate employability, compared to mathematical vector machines and neural nets. The study is based on data collected between year 2011 and year 2017, as provided by the Department of Education in Malaysia.

In [89], authors developed an employability model for graduates using data classification. Bayes algorithms were explored, as well as some tree-based techniques, to establish if graduates were employed or not. Results obtained revealed the J48-type tree outperformed, in terms of accuracy, the Bayes algorithms. In particular, the J48 obtained as much as 92.3 percent accuracy, compared to the 91.3 percent obtained by Bayes algorithms.

2.5.4 Naïve Bayes Classifier

Naive Bayes is a widely used algorithm in solving the classification problem. This approach is probabilistic, based on assumptions that variables/features are independent of each other and weighed [90]. Most higher learning institutions today rely on databases for collecting and storing various information about the institute and relevant stakeholders. Data mining then becomes necessary in determining some useful indicators from the numerous data available. Aziz et al. [91] proposed a framework to predict student performance, using the Naïve Bayes Classifier to effectively extract patterns from a database, using a proprietary data mining platform, WEKA. A prediction model is developed, from the parameters of student gender, race, entry mode to the university, income of family and also (GPA) grade point average. The model developed was shown to be useful to university staff and management towards ensuring high quality education standards for the students.

2.5.5 Lazy classifier

Vijayarani et al. [92] present an analysis of the performance of Bayesian and Lazy classifiers for the purpose of classifying some files stored in the computer. Through applying various systematic conditions, experimental results show that the lazy classifier is in fact more accurate than the Bayesian classifier, in classifying the availed files.

One the most common lazy classifier is the K-Nearest Neighbor. This classifier manages data according to similarity with fellow neighbors [93]. It is a simple and intuitive approach, although requiring a large number of samples for high accuracy. For problems that require classification of certain input information, lazy classifiers are typically most suitable.

2.5.6 Method selection

Past decades, research has significantly been aimed towards the application of neural networks as well as agent based modelling to model complex systems. Neural network technology takes the approach of the human brain in solving problems. In this way, the technology presents efficient processing of large data quantities, from a wide range different sources, and then making decisions on the basis of the data [79]. The key take away is the element of the ability to apply knowledge acquired from past experiences to solve new problems, which is the basis of neural network technology where a neural network recalls previous problem solutions to construct a 'neuron' system that can make rapid decisions, classifications, and predictions accurately [79].

Looking at higher education, we are presented with an imperceptible situation characterised by multiple stakeholders with different inputs, influence and control. It is fairly difficult to measure the performance of higher education schools and departments hence some platforms for measuring performance fail to accommodate all the relevant information. Neural nets were proven to address this challenge best [94], and so this approach is selected and explored in this work.

The main reasons for selecting the neural network to solve the problem are summarised as follows [95]:

1. Neural networks offer better accuracy when input variables have some sort of relationship, as is the case with this work.
2. Neural networks require no a priori information underlying process. The network can learn complex relationships including both qualitative and quantitative data and is trained to analyse new conditions and provide suggested solutions from there.
3. Neural networks provide higher precision than statistic-type methods, especially if the case to be solved has incomplete data or is poorly defined and characterised by multiple possibilities.
4. Neural networks have been proven to be faster than other techniques in solving complex problems. The network can develop relevant weighting independently, based on relationships between the variables.

In light of these positives surrounding neural networks, it is also important to take note of some of challenges associated with neural networks:

1. The major downside is that substantial training time is typically required to sufficiently train and also to test neural networks. A lot of training samples are also typically required [96].
2. On a lighter scale, optimum network geometry is also difficult to establish, for example data-set size, type, volume, relevance and accuracy, pre-processing, validation and so on [97]. The network could solve the same problem differently for different sets of data, typical due to over-fit data. Too many hidden nodes usually result in over-fitting while if the number of hidden nodes is too small, the back-propagation algorithm fails to converge to a minimum during training [98].

3. In terms of data extrapolation, ANNs typically perform less accurately if they have to extrapolate out of the range of data used for training [99].

2.6 Optimising ANN performance

The training of ANNs can be a very involving process, especially for complex and huge networks. Several approaches can be taken when it comes to improving the performance of ANNs. The structure of the ANN can affect the performance of the network, especially in terms of training time. Zagoruyko and Komodakis [100] proposed a novel architecture where residual network depth is decreased while width is increased. It was demonstrated that a sixteen-layer-deep wide residual network actually outperforms thousand-layer-deep networks in accuracy and efficiency.

Yahia et al. [101] discussed the Extreme Learning Machine algorithm. This algorithm is constituted by an ANN with one secret layer, and demonstrates rapid learning, while maintaining satisfactory accuracy. While ANNs are useful tools for classification of data, the traditional ANN typically trains slowly, thus compromising capacity for large scale applications. Mei et al. [102] proposed a Brain-oriented Emotional Learning (BoEL) technique to improve the speed of traditional ANN. This BoEL algorithm essentially resembles the high speed of the emotion-influenced learning realised by the brain of mammals. In this work, authors further implemented the Genetic Algorithm (GA) to optimally tune the weights and biases of the BoEL neural network. This combination was evaluated several datasets and is seen to provide better precision than the original BoEL technique, as well as the traditional ANN algorithm.

Florensa et al. [103] discuss deep reinforcement learning without failing to point out the challenges associated with long training time for wide data sets. A general framework was proposed, one that at first learnt some useful skills at some prior-to-training phase, and then applied learnt skills to then learn faster downstream, i.e. during training. The catch is that this design required minimal domain knowledge of the downstream tasks. Overall, the approach significantly boosted the learning performance, in fact, uniformly across a wide range of the downstream tasks.

Bengio et al. [104] proposed the conditional computation technique to address the problem of training deep models where the process becomes time-consuming and computationally expensive. The proposed technique was characterised by selectively activating only certain parts of the network at a particular time, yet maintaining prediction accuracy. This work presented results to the effect that this conditional computation technique improved computation speed without compromising quality.

2.6.1 Optimisers

Several optimisers can be used to optimise neural network performance. These include such optimisers as gradient descent, Adagrad, Adadelta, Adam, Adamax and so on [105]. These optimisers realise different methods, some related to some extent. Adagrad, for example, scales learning rate for each parameter up or down, according to the history of the prior gradients while Adadelta is more of an extension of Adagrad, with the addition that only a certain number of past gradients is stored. RMSProp divides the learning rate by some decaying factor, which is exponential. Adam stores sum of past squared gradients and also realises exponential decay and so on. Gradient descent is commonly used, with the stochastic gradient descent version typically ranking high especially for cases when convergence quality is of high priority and convergence time not highly essentially.

2.6.2 Adaptive learning rate

The rate at which a neural network learns, is a key setting (parameter) to tune, during the network training process [106]. Conventionally, for training, a fixed learning rate is used, set by initially selecting a high value and gradually decreasing the value over time. The typical problems resulting from poor learning rate tuning are:

1. Reduced accuracy when learning-rate is not high enough and causes the optimiser to converge at local minimum and not global minimum.

2. Slow convergence when learning-rate is not high enough.

3. Divergence from minimum when learning-rate excessive.

Takase et al. [107] present a discussion on conventional adaptive learning rate algorithms. While the algorithms typically gradually decrease the learning rate over training time, the authors proposed to adjust learning-rate adaptively upwards or downwards so that the total training loss (for all training samples) is decreased as much as possible. Experiments showed better performance compared to conventional methods.

A novel algorithm with fast-convergence is proposed and applied to multi-layer ANNs with feedforward and backpropagation in [108]. The algorithm implements a learning rate that is based on eigenvalues of the respective Hessian matrix of the input data in such a way that the learning rate varies dynamically according to training input data used. It is shown that the best choice of learning rate is in fact quickly derived and accurate convergence can be achieved much more quickly (a reduction in iterations by a factor of hundred) compared to the traditional ANN.

The standard multilayer perceptron (MLP) is investigated in [109] where the learning rate is adjusted according to some sliding mode control algorithm. Satisfactory speed increase is achieved. Adaptive learning rate is also explored in [110], where back propagation artificial neural network algorithms were used to classify breast cancer tumours through ultrasound image processing. This work also shows that implementing adaptivity of learning-rate outperforms the constant counterpart.

Apart from adaptive learning rate, momentum-optimisation is another method to improve convergence of ANNs, and the two are in fact compared in [111]. Experimental results show that momentum-optimisation improves convergence speed, based on a diabetes detection experiment. Adaptive learning rate was also explored in [112], where training is semi-supervised and the learning rate coefficient is determined by some performance indices. In this way, the system is able to optimise the learning rate according to the performance of the system, particularly with respect to convergence acceleration.

As stated, the back propagation algorithm tends to be slow and is prone to overshooting especially if the learning rate is relatively on the high side. This problem typically results from the fact that a constant learning rate means fixed step size regardless of gradient, compromising efficiency at steep gradient [96]. Nawi et al. [96] proposed that the learning rate be proportionally adjusted locally, a strategy shown to improve accuracy. Almost similarly, in [113], the idea was to use Taylor's formula to adjust the learning rate according to root mean square error. Experiment reveal that the proposed system lowers iteration time, compared to constant learning rate systems.

Smith [114] explored the concept of cyclical learning rate. This approach does away with the need to adjust the learning rate by trial and error, as this approach varies the learning rate in a manner that is cyclic. The accuracy in classification by this cyclic method is shown to increase, while convergence is quickened, compared to the constant learning rate alternative.

Conclusion

The learning-rate of a neural network is a key hyper-parameter, that affects performance of the network. Several techniques exist in literature, for the manipulation of the learning rate to optimise network performance with respect to accuracy and time efficiency. A wide gap exists, to explore learning rate manipulation strategies for network optimisation. This study explores manipulation of the learning rate according to a 'window shopping' inspired technique.

2.7 Research gap

Autonomous curriculum (in terms of quality of outcomes) management systems are becoming more and more common across most higher learning institutions. Such systems are capable of managing education in a manner that is robust and are capable of guiding career determining decisions [115]. The importance of such systems cannot therefore be underestimated. The majority of curriculum management systems available though, are typically designed for the purpose of managing education from an administrative perspective, involving tracking student academic and non-academic performance and developing prediction models to guide future decisions [116]. These systems are therefore typically used for guiding course selection and arrangement as part of constructing the student study program while optimally balancing all related aspects such as credit count, learning/class hours, marks, course costs and so on. Several universities and colleges have in fact developed and implemented advanced standalone systems for curriculum management. A gap however exists in exploring the automation of curriculum management for the purpose of aligning curriculum to the needs of industry, by interpreting industry dynamics to directly recommend appropriate curriculum adjustments to autonomously address the competence requirements of industry in real-time.

From literature, a gap is also identified in terms of the approach to implement curriculum manipulation. Conventionally, curriculum manipulation is realised by adjusting curriculum on a more course-by-course basis, or discipline-by-discipline, in order to address industry or even non-industry needs. The gap is in investigating curriculum manipulation approaches that can manage curriculum holistically, treating curriculum not as courses and modules, but rather as micro-elements that make up the respective courses and modules; micro-elements that are highly interrelated and common even across multiple courses. This is especially viable for engineering curriculum considering the highly integrated nature of engineering education. For a better understanding of engineering education, it is important to look back in time in order to explore how the education has evolved. This ultimately provides guide as to how to better handle engineering education management or manipulation.

2.8 Engineering trends

The industrial engineering profession traces back to the late nineteenth century and for most of the twentieth century, the growth of this profession was expedited by the manufacturing sector, as well as government and service organisations [117]. The industrial engineering profession is widely understood to be dynamic, with a future dependent not only on the ability of the engineering practitioners to meet the respective economic and industrial operational demands, but also dependent on the ability of the practitioners to innovate and actually drive the economic and industrial operational trends.

2.8.1 General engineering

Technology is one certain part of engineering, that continues to change with time. This has been the case even over the past century. Curriculum therefore needs to prepare future engineers for a work environment that is characterised by constant updates to the technologies used in engineering. Meade et al. [118] studied how changes in the field of software affect the futuristic role of the software engineer. The element of open-source technology is one of the discussion point, and it is highlighted that the future engineer is one to appreciate open-source technologies in order to better fit into the engineering work environment. Artificial intelligence for example, has reshaped technology significantly over the past decades, and the evolution of such technologies continues to pace faster and faster [119].

Bourn [120] explored the effect of globalisation to the future of engineering. It was shown that globalisation had some effect on skill needs as well as interdisciplinary skills. It was argued that engineers of tomorrow possess 'globally orientated' skills, and substantial inter-cultural competencies. This is especially supported by the fact that engineering is global, with relevant stakeholders distributed across the entire planet. The idea of 'engineers without borders' has since been adopted by some non-governmental organisations to describe their international projects. The work of Vellmar et al. [121] also presented globalisation as a key part of tomorrow's engineering.

Lobanova [122] demonstrated how the future of engineering was one closely aligned to environmental sustainability as well as the well-being of humans. With growing demand for technologies, products and systems that are environmentally friendly and health friendly are also seeing growth in demand. It is argued that environmental and health sustainability concepts need incorporation into engineering education. In this way, engineering designs for example, need not only to be optimised for the intended functions/purpose, but also for the environment and health of consumers and general population.

2.8.2 Industrial engineering

The industrial engineering profession, as hinted by the title, is industry driven. According to Kumar [123], the future of industrial engineering is heavily being influenced by customer demands and expectations. The demands and expectations of the customer are on a trajectory of rapid growth, giving rise to the need for constant improvement in production processes as well as operational systems, in order to minimise cost yet maximising quality. Industrial engineering is key in realising this goal.

In developing the concept of 'the industrial engineer of the future', it is important at first, to reflect on the fact that industrial engineering is a profession where scientific knowledge must be applied with professional judgement, in order to optimise processes, operations, products and so on [123]. The future of industry therefore has a part to play in the future of the industrial engineering profession. The work of Wollschlaeger et al. [124] shows that Internet of Things (IoT) is a key part of tomorrow's industry. Industrial engineers of the future are therefore expected to embrace the concept of IoT. At curriculum level, it is presented that it is necessary to adjust curriculum to take more consideration of IoT in order to produce graduates who are more oriented for the work environment of today and also tomorrow.

Veraldo et al. [125] explore the value of interdisciplinary competences to the future of industrial engineering. It is shown that, due to the diversity of industrial engineering work, which continues to evolve, interdisciplinary skills are a critical aspect. A teaching method which emphasizes interdisciplinary scope and teamwork is proposed. The work of Butts and Valentine [126] explicitly demonstrates how approaching engineering from an interdisciplinary perspective promotes technological development. Butts and Valentine outline how some advanced technologies have been developed for the agricultural sector, through research projects that involved multidisciplinary teams, bringing together experts in fields such as food science, agronomy, entomology, pathology, and so on.

González-Domínguez et al. [127] take a look at how the circular characteristics of the economy affect the future of industrial engineers. It is demonstrated that the industrial engineer of the future is one to master concepts of circular economy strategies. It is proposed that circular economy concepts can be realised in curriculum through collaborative design project works. This allowance for circular economy concepts through collaborative exercises promotes the idea of students taking responsibility for their learning process, thus better preparing the students for an industry which is fast-paced and demands strong sense of responsibility and decisiveness.

To set the foundation for the concept of 'the industrial engineers of the future', the general trends of the past half century are presented. The 2004 industrial engineering handbook provides details of the general trends of the industrial engineering functions in the twentieth century as depicted by Table 2.1. The trends show the general view of the proportion of the main industrial engineering functions, decade after decade.

Table 2.1: Twentieth century industrial engineering function trends - adopted from [117]

<table>
<tr><th>1960</th><th>1965</th><th>1970</th><th>1975</th><th>1980 1999</th></tr>
<tr><td rowspan="6">Work simplification and methods of improvement</td><td rowspan="3">Work simplification and methods of improvement</td><td rowspan="2">Inventory management</td><td>Information system design</td><td>System development</td></tr>
<tr><td rowspan="2">Inventory management</td><td rowspan="2">Inventory management</td></tr>
<tr><td rowspan="3">Project engineering</td></tr>
<tr><td rowspan="3">Project engineering</td><td rowspan="2">Financial management</td><td>Financial management</td></tr>
<tr><td rowspan="2">Manufacturing and manufacturing technologies</td></tr>
<tr><td>Plant layout and facility design</td><td>System design</td></tr>
<tr><td rowspan="2">Plant layout</td><td>Plant layout</td><td rowspan="6">Labor standards</td><td rowspan="4">Project engineering</td><td>Project engineering and operations management</td></tr>
<tr><td rowspan="5">Labor standards</td><td rowspan="2">Quality</td></tr>
<tr><td rowspan="4">Labor standards</td></tr>
<tr><td rowspan="2">Engineering design</td></tr>
<tr><td rowspan="2">Labor standards</td></tr>
<tr><td>Labor standards</td></tr>
</table>

2.9 Attributes

Graduate attributes can be defined as the qualities that a university or college community agrees to develop in the students during their study period at the respective institution [128]. These attributes exceed academic competences and technical skills reaching over to qualities that prepare graduates for social good, in a global economy that is dynamic and with an unknown future. It is inadequate today, to conduct curriculum management related studies, without accommodating graduate attributes. Some common and typical graduate attributes include [129]:

1. Effective communication
2. Strong citizenship
3. Leadership skills
4. Problem solving skills
5. Team work
6. Strong ethics
7. Presentation skills
8. Peer influence
9. Ability to work under pressure
10. Strong reporting skills
11. Interpersonal skills
12. Time management
13. Office skills
14. Social responsibility
15. Critical thinking

Today, graduate attributes have become a core element of tertiary learning outcomes and integration of generic attributes into university or college curriculum is on a world-wide rise, especially towards promoting development of skills that better equip students for the work environment and also for self-employment [130]. Higher learning institutions have therefore over the past few decades, placed increasing value on developing graduate attributes and ensuring that the attributes are reflected within graduates.

Yorke [129] presents an argument that there is in fact some correlation between quality of education and graduate attributes, presenting the case that graduate attributes need also to be utilised as a measurement of program outcome effectiveness. Many universities across the world have, or are in the process of reforming curricula to fairly integrate and incorporate graduate attributes [131]. Hill et al. [132] provide a neat presentation of some of the benefits of graduate attributes, summarised as follows:

1. For most jobs, a significant portion of work time is spent in interacting and interfacing with other personnel within the work environment. If graduates do not possess strong social skills, they are likely to struggle with attaining professionally sound communication. Graduate attributes are able to enable social professional functionality at the work place especially considering how dynamic the work environment of today is.

2. To acquire employment, or even to succeed in self-employment, discipline-specific competence (technical competence) alone is not adequate. For example, if a graduate industrial engineer does not elaborate the interpersonal skills that are typical during a job interview, this jeopardises the chance of success, even though the graduate was top of the class. Graduate attributes have the potential to promote the social and interpersonal skills that are required for graduate navigation of the employment or self-employment space.

3. Today's global economy is one where knowledge quickly becomes obsolete. There is need to therefore prepare students for a work environment that is constantly changing in order for the graduates to remain employable. There is need to promote flexibility and adaptability in students to enable the students to better prepare for the work environment. This again, can be facilitated by graduate attributes.

One challenge though, is that some lecturers or educators may not see or perceive the value and essence of developing graduate attributes, and may thus consequently be reluctant to realise graduate attribute obligations throughout their teaching experience [132]. For graduate attributes to be effectively implemented, curriculum is one place to look at. Oliver and Jorre [133] study the effectiveness of graduate attributes at university level, and based on survey findings, proposed a regime of recommendations for the management of graduate attributes into the future beyond year 2020, towards enhanced employability and citizenship. These recommendations are summarised as:

1. graduate attributes to be made more visible to students and also to the relevant stakeholders such as parents and guardians.
2. graduate attributes to be embedded in curricula
3. graduate attributes to be constantly explained throughout program courses
4. evaluate graduate attribute effectiveness through industry surveys
5. regular revision of the attributes
6. increase emphasis on the following top attributes (based on findings):
    (a) communication
    (b) teamwork
    (c) citizenship
    (d) critical thinking
    (e) problem-solving
7. develop robust mechanisms to measure effectiveness of graduate attributes.

This research also makes an analysis of graduate attributes to determine the necessity of strongly emphasizing attributes in curriculum.

Chapter 3

Industrial engineering profession

The Industrial Engineering (IE) education is a fine mix of technical subjects and business studies [33]. Industrial engineers develop systems and processes that improve quality and overall productivity in whatever discipline, applying skill and knowledge in engineering, mathematics, management and business administration. Industrial engineers therefore work across several industries, inclusive of health and pharmaceuticals, transport and communication, construction, banking, manufacturing, mining, agriculture, e-commerce, government, entertainment, finance, sports, packaging, insurance and so on. In all this work, the core idea is to develop systems and process that save money, producing optimal results and maintaining a conducive workplace.

Some examples of some of the work that industrial engineer typically do are:

1. Reducing queue waiting times at the circus.
2. Designing the layout of an assembly plant.
3. Determining sustainable strategies to minimise environmental spills at a mine.
4. Determining optimal location for shopping mall construction.
5. Assessing the impact of automating a manufacturing line.
6. Developing systems for package preparation and dispatch at a shipping warehouse.
7. Determining shop allocation in a large shopping mall.
8. Developing an inventory management system for a warehouse.
9. Designing a bar-coding system for assets of a company.

The diversity of possibilities for industrial engineers ensures that job opportunities are available across various industries of the economy.

3.1 Statutory guide

It is not practical to discuss quality of education for any engineering field without reference to the Engineering Council of South Africa, better known as ECSA. ECSA is a South African statutory organ supporting the profession of engineering, with the aim to promote high level training and education of practitioners, to promote professionalism in engineering and also to promote the interests of the profession in the nation.

The graduate industrial engineer is guided, according to ECSA, by the Training Guide for Candidate Engineering Technologist in Industrial Engineering [134] and the Training Guide for Engineering Technicians in Industrial Engineering [135]. These documents provide discipline-specific training guideline for the industrial engineers and this is why it is important to refer to this documentation when discussing curriculum management. According to [135], an industrial technician carries out the duties of investigating and reviewing the utilisation of human capital, facilities, materials, equipment, operational processes and established practices, in order to recommend improvements in operational efficiency across a variety of commercial, industrial and production environments. As listed in [135], these environments include [117]:

1. Primary industries as well as the respective downstream beneficiary industries such as agriculture, mining, fisheries and forestry
2. Construction industries
3. Manufacturing industries
4. Processing industries including chemical, cosmetics, petrochemical, agriculture, food and so on
5. Services industries including banking and insurance
6. Medical and health industries
7. Transport industries
8. Logistics industries

9. Engineering consulting industries
10. Information and Communication Technology industries including virtual reality, simulation, business management systems, artificial intelligence (AI) and other decision support mechanisms.

Within these industries, are various specialisations, demanding a wide range of skill, knowledge and expertise. The following specialisations are listed for the technician in industrial engineering [135]:

1. Agri-processing Engineering Technician
2. Control and Automation Engineering Technician
3. Plant Engineering Technician
4. Process Engineering Technician
5. Clinical Engineering Technician
6. Resource Management Engineering Technician
7. Fabrication Engineering Technician
8. Operations Engineering Technician
9. Manufacturing Engineering Technician
10. Manufacturing Technology Engineering Technician
11. Logistics Engineering Technician
12. Industrial Efficiency Engineering Technician
13. Industrial Machinery Engineering Technician

The list given above already begins to elaborate the diversity of industrial engineering and consequently, the vastness of the expertise and skill that is required. In the introduction of this chapter, some of the fields in which industrial engineers work were listed. In reality, there are dozens of fields in which industrial engineers work, including complex fields such as medicine. It is not practical therefore to aim to expose students to all the possible fields, during the education process, within three or four years. What is practical is to ensure that the critical concepts used in all these fields are mastered by the student, and then to ensure that the student has the ability to research, learn and adapt. With the proposed curriculum management strategy of atomic manipulation, this becomes more attainable. In fact, the ECSA guidelines for industrial engineering [134] and [135] highlight that with the dynamic nature of the industrial engineering profession, the diverse range of industries that graduates could find themselves in and the wide range of specialised skill/expertise characterising the profession, it is virtually impossible to define some set of predetermined educational/training paths for the industrial engineer. Instead guiding principles are implemented.

Consequently, for candidacy phase for example, one of the top guiding principles is that a candidate is to be actively involved with developing a solution to at least one problem that is broadly defined, doing so, right across the entire life cycle of the solution. This translates to starting from problem definition, on to evaluation and then the selection of proposed solutions, over to solution design as well as solution implementation and then finally, post implementation support. This principle illustrates the value of gauging profession based on industry rather than theory. This principle also tallies with the idea behind the curriculum management system proposed in this study.

That said, in [134], [135] and other IE guides, emphasis is put on highlighting that IE is continuously evolving according to industry. The methods taught also need to evolve especially towards the realisation of problem solving skills and strategies that can address the dynamic problems presented by industry. The Southern African Institute for Industrial and Systems Engineering (SAIIE) actually hosts an annual conference and also specialist-type group meetings, designed to encourage and provide continuous professional development (CPD). This goes to reinforce the need for continuous adaptation of not only industrial engineering practice, but industrial engineering education as well.

3.2 Work opportunities

This work aims to align the UNISA industrial engineering curriculum to the industry and economy. To do this, it is necessary to understand and appreciate the opportunities available within the scope of industrial engineering in South Africa. Immediately, two questions arise; where are the industrial engineers, and what are they doing? If these questions are answered, the answers given would be key in assessing the IE curriculum and in guiding any adjustments to the curriculum.

Opportunities for industrial engineers are vast, especially in industrialised countries. Industrialisation has huge impact on the volumes of opportunities for industrial engineers, where more industrialised countries have more opportunities. Africa is generally on a trajectory of industrialisation, with manufacturing spending expected to exceed 600 billion US dollars by 2030, with South Africa among the top players, as well as Nigeria and Egypt, and some new players including Rwanda, Morocco and Ethiopia [136]. The African Union has in fact placed industrialisation at the centre of the Agenda 2063.

The question of where industrial engineers are, has two general answers, that is in entrepreneurship and in employment, as with most qualifications. If curriculum can sufficiently prepare students for employment and entrepreneurship, then logically, the purpose of education in this context is fulfilled. At this point therefore, the discussion studies industrial engineering work with respect to employment and entrepreneurship.

3.2.1 Employment

It is necessary to analyse the state of IE employment (or utilisation) across various industries. This analysis should reveal where the IEs are employed and where they are not, in terms of the sectors of the economy. Logically, larger industries are expected to employ more industrial engineers than the smaller industries. If an analysis can be made, of the relative size of a particular economic sector against the proportion of IEs employed by that sector, a reflection of the utilisation of IEs can be derived. Assumption: It is assumed that the size of a sector (such as mining) can be measured in terms of gross domestic product contribution.

3.2.1.1 IEs per sector

An analysis of the distribution of industrial engineers across the main economic sectors (industries) gives some indication as to how industrial engineers are spread. In full, these sectors are as given by Figure 3.1.

(1) Agriculture, forestry and fishing

(2) Mining and quarrying

(3) Manufacturing

(4) Electricity, gas and water

(5) Construction

(6) Wholesale and retail trade, hotels and restaurants

(7) Transport, storage and communication

(8) Finance, real estate and business services

(9) General government services (including education) and

(10) Personal services

Figure 3.1: List of GDP sectors

Figure 3.2 shows the general distribution of IEs across various sectors, according to 2015 data.

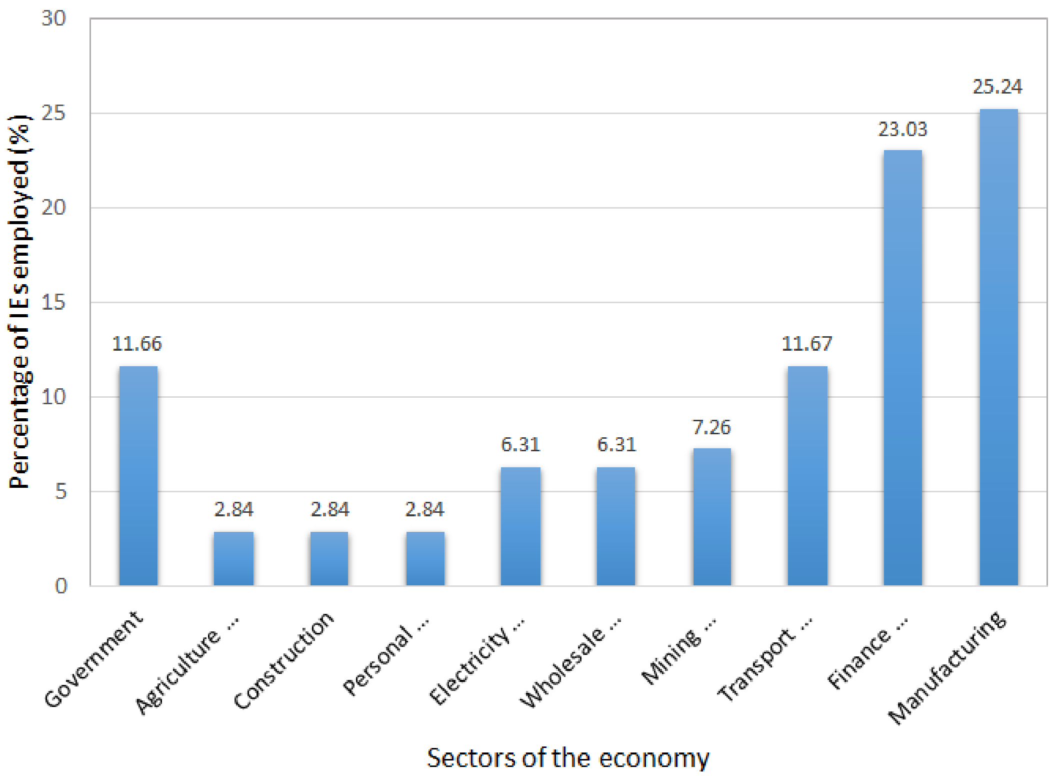


Figure 3.2: Distribution of IEs across various sectors - Adapted from [137]

Figure 3.2 shows that the finance and manufacturing sectors currently employ approximately 48 percent of industrial engineers in South Africa. Moving on, it is necessary to appreciate the contribution of the various sectors to the GDP.

3.2.1.2 GDP contribution of economic sectors

The contribution of various sectors to the South African GDP is illustrated in Figure 3.3.

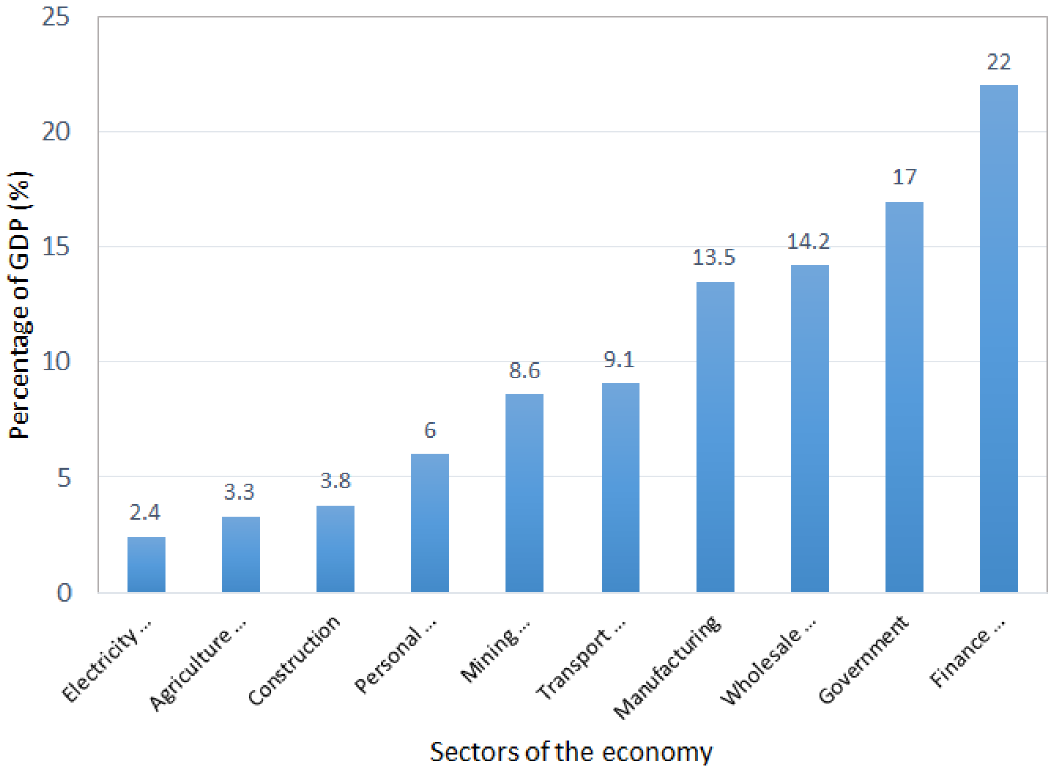


Figure 3.3: GDP contribution of various sectors - Adapted from [137]

Figure 3.3 shows that the top three contributors are (1) Finance, (2) Government and (3) Wholesale. Industrial engineering is multidisciplinary and curriculum must enable industrial engineers to contribute across all industries. This is possible if the taught curriculum is robust enough to cover the related material and also if the necessary industry structures are in place to accommodate the industrial engineers. A comparative analysis of IE employment can be made, to determine how the percentage of IEs per sector relates to the size of the sector in terms of percentage GDP contribution of the sector, with the aim to point out sectors where industrial engineering might be underutilised. Effectively, this analysis is based on a scaled difference index, between the percentage contribution of a sector and the percentage if IEs employed within that sector.

3.2.1.3 Analysis of IE employment

Effectively, the analysis is based on a scaled difference of the percentage contribution of a sector and the percentage of IEs employed within that sector. The differences are presented graphically on Figure 3.4.

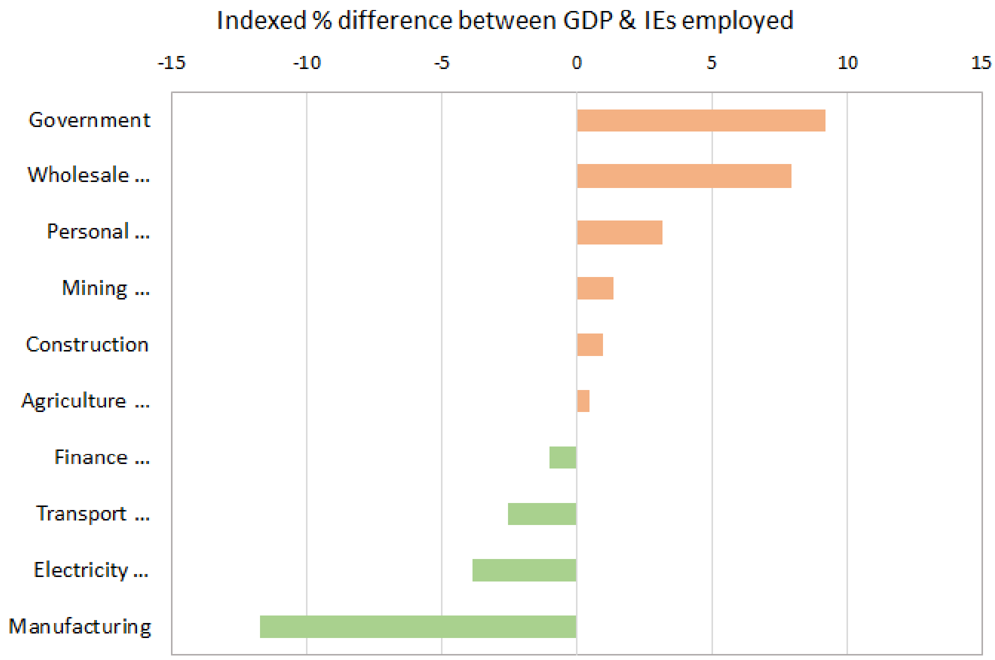


Figure 3.4: Analysis of IE employment against sector

Problem

Figure 3.4 shows a problem of mismatch between size of industry and relative proportion of industrial engineers employed within the respective industry, based on the logic that a large industry requires more industrial engineers compared to a smaller industry. Figure 3.4 shows underutilisation of industrial engineers in some industries, where ideally, all deviations must fall close to zero, if distribution of industrial engineers is consistent.

It can be concluded from Figure 3.4 that

1. Government and

2. Wholesale, retail trade, hotels and restaurants,

have the highest indicated underutilisation of industrial engineers, given the respective size of these two industries, with government showing the highest underutilisation. The personal services industry shows medium underutilisation, while mining and construction show low underutilisation of IEs. If action can be taken to improve utilisation of IEs in the three following industries (1) Government, (2) Wholesale and (3) Personal service industry, the resultant impact on employment opportunities for IEs can be ground-breaking. How can the curriculum be manipulated to facilitate this improvement in utilisation?

3.2.1.4 Conclusion

By analysing the distribution of opportunities for industrial engineers, it is possible, to some extent, to determine areas where IEs could be put more into use. Consequently, this produces a curriculum enhanced avenue worth exploring.

Government

Government is a relatively large industry (by GDP) yet represented by low percentage uptake of IEs. How can the uptake of IEs by government be increased? Until now, generally, there was almost continental concern for efficiency in government organs like municipalities, yet universities produce several IEs with the skills required to develop and optimise systems and processes, towards sustainability and efficiency [138]. Some examples of the type of work that government can leverage on IEs are:

1. Development of health emergency management systems.
2. Designing the layout of government complexes or buildings.
3. Development of crime management systems.
4. Development and management of medication distribution systems.
5. Development of management systems for civil servants' deployment.

Curriculum adjustments to consider

Increasing uptake of IEs by government will ultimately be a decision influenced by government more than any other player. However, the IE curriculum can be adjusted to make IEs better qualified to suit the requirements of the relevant governmental functions. The proposed curriculum is adjusted and populated by course work and course projects that practically and technically relate to governmental functions such as those listed above. Further, at university level, a facility can be run to secure different governmental projects, which can then be streamlined to the students, especially those students approaching the end of the study program.

Wholesale, retail trade, hotels and restaurants

Within this industry, scope for industrial engineers is mostly on a personal basis rather than corporate. A hotel for example, may not need a full-time industrial engineer but rather on a consulting basis, periodically, as and when there is need for example to optimise the on-line booking system.

Curriculum adjustments to consider

To enhance utilisation of IEs within this field, from a curriculum stand-point, the idea is to promote independent entrepreneurial (freelancing) competencies within the curriculum, as discussed in Section 3.2.2.1.

Personal services

As with the industry of wholesale, retail trade, hotels and restaurants industry, scope for industrial engineers is almost entirely on a personal basis.

Curriculum adjustments to consider

Likewise, to enhance utilisation of IEs for the personal services industry, from a curriculum stand-point, the idea is to also promote entrepreneurial competencies in the curriculum. The topic of entrepreneurship is discussed in Section 3.2.2.1.

3.2.2 Entrepreneurship

According to [139], an entrepreneur is in simple terms, one who is self-employed. Industrial engineering entrepreneurs would therefore typically start businesses that provide industrial engineering services. We discuss entrepreneurship in terms of freelancing, in this work, without necessarily considering the creation of a formal business or enterprise. A freelancer is an independent worker who works alone (or with some partners), creating work for oneself. According to [140], freelancing is fast becoming the predominant form of business enterprise across the European Union. This is also true for South Africa and other African Nations. However, different professional fields have different potential for entrepreneurship. The field of Computer Science is highly recognised for graduate entrepreneurship opportunity. Typical entrepreneurial projects in this field include mobile application development, web-development, graphic design, software and database development, and so on. Artisanship also, is recognised for entrepreneurship opportunities, especially for such trades as those related to the construction work, such as for interior designers, electricians, painters and carpenters; and also other trades such as boiler making, catering, beauty care and so on. Odds are generally high for sustainable entrepreneurship ventures in these fields. This study argues that the same can be said for the industrial engineering trade.

3.2.2.1 State of entrepreneurship

This section discusses the prevailing state of entrepreneurship in IE. One characteristic worth taking note of is that of education. According to a 2017 survey conducted by Seed Academy [141], at least 3 in every 5 entrepreneurs had some university or college qualification. The education characteristic is represented by Figure 3.5.

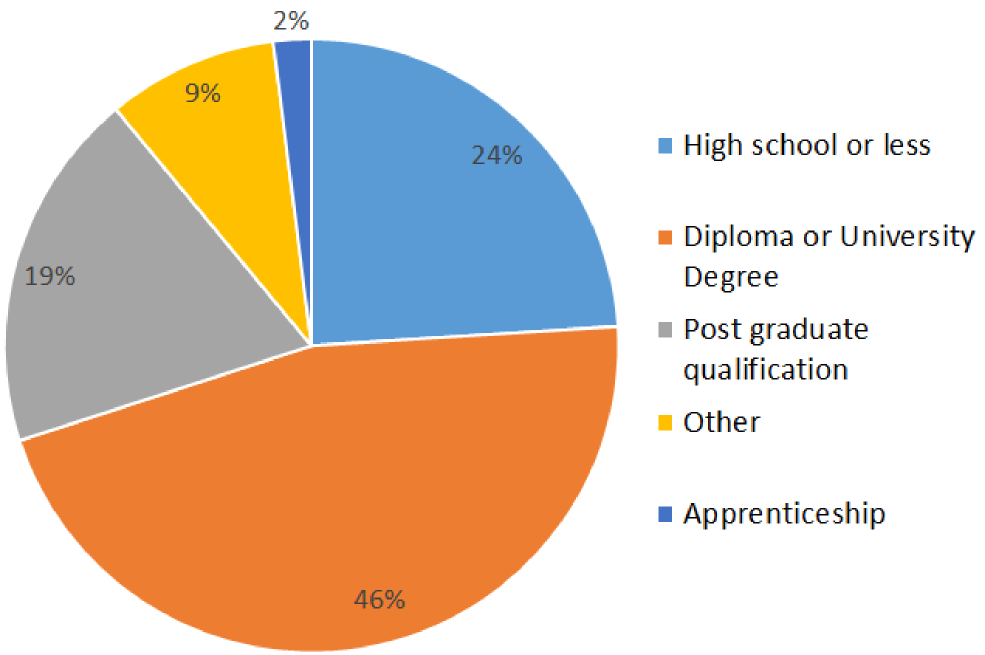


Figure 3.5: Qualification characteristic [141]

The study of the relationship between entrepreneurship and level of education has been a focus area over the past few decades [142], [143] and [144]. Education has been shown to improve entrepreneurship success. South Africa, and many African countries have actually started setting up business centres and entrepreneur incubation hubs at universities, so that formal education and entrepreneurship education become more centralised.

Further analysis also reveals that youth make up the better population of entrepreneurs. According to the Seed Academy survey, 57 percent of South African entrepreneurs were youth, as depicted by Figure 3.6.

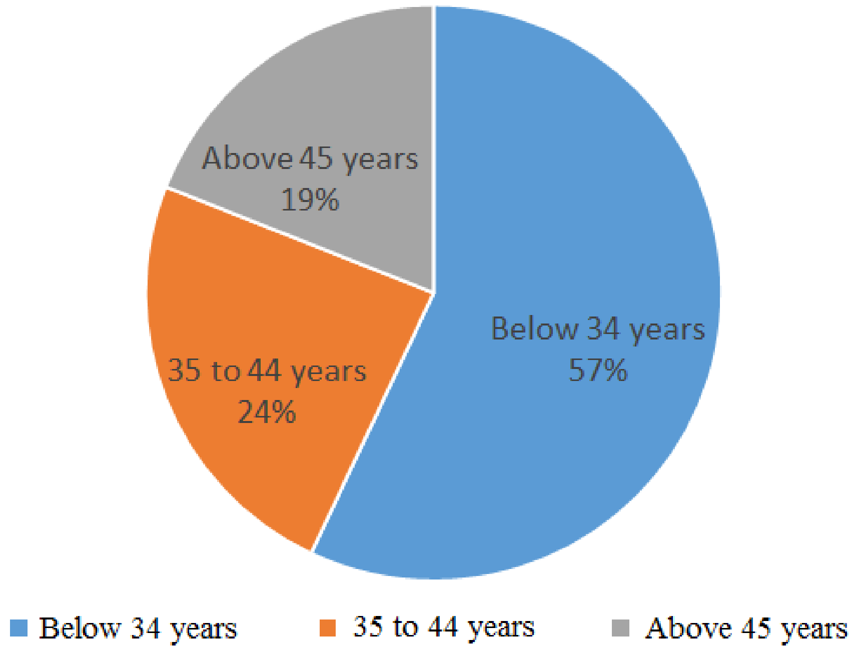


Figure 3.6: Age characteristic [141]

Current efforts by the South African government are expected to further increase youth participation in entrepreneurship. Another characteristic to consider is that of age. Traditionally, women have been less represented in entrepreneurship, and this trend continuous, as depicted by Figure 3.7.

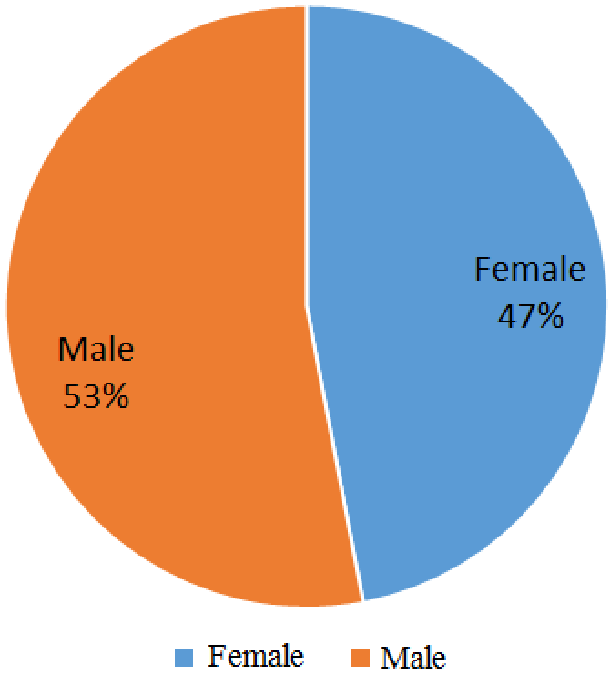


Figure 3.7: Gender characteristic [141]

At 47 percent, woman entrepreneurship has however actually increased, being 35 percent in year 2015. One contributing factor is that in parallel, education too has become more and more equally accessible across both genders. In this study, the state of entrepreneurship in industrial engineering is determined by analysing on-line data from freelance project advertisements. It is assumed that the state of entrepreneurship in industrial engineering can be assessed at greater detail, on the basis of freelance data available on-line.

A survey is conducted on the Jobvine on-line platform, as well as the Upwork platform, which host a 'freelance' section where various freelancers bid for work, including IEs. Bidders earn from an equivalent of ZAR 75 to as much as ZAR 750 per hour of industrial engineering consulting work, depending on the number of years of work experience, among other factors. The survey conducted aims at establishing whether certain freelance IE skills are more prevalent or on more demand than others. In particular, interest is in capturing the following:

1. Skill-sets listed by freelancers

2. Skill-set demand from jobs posted

By analysing the above stated data, it is possible to give an evaluation of the state of curriculum in addressing skill-set demand.

3.2.2.2 Skill-sets listed by freelancers

Eighty-eight freelance IEs are considered, each having completed several jobs successfully, across different industrial engineering freelance jobs. At this point, the intention is to find out what skills IEs list on-line so that ultimately, an evaluation is made as to how closely the skills listing matches the skills demand. Figure 3.8 illustrates the top skill-sets listed on-line by IE freelancers.

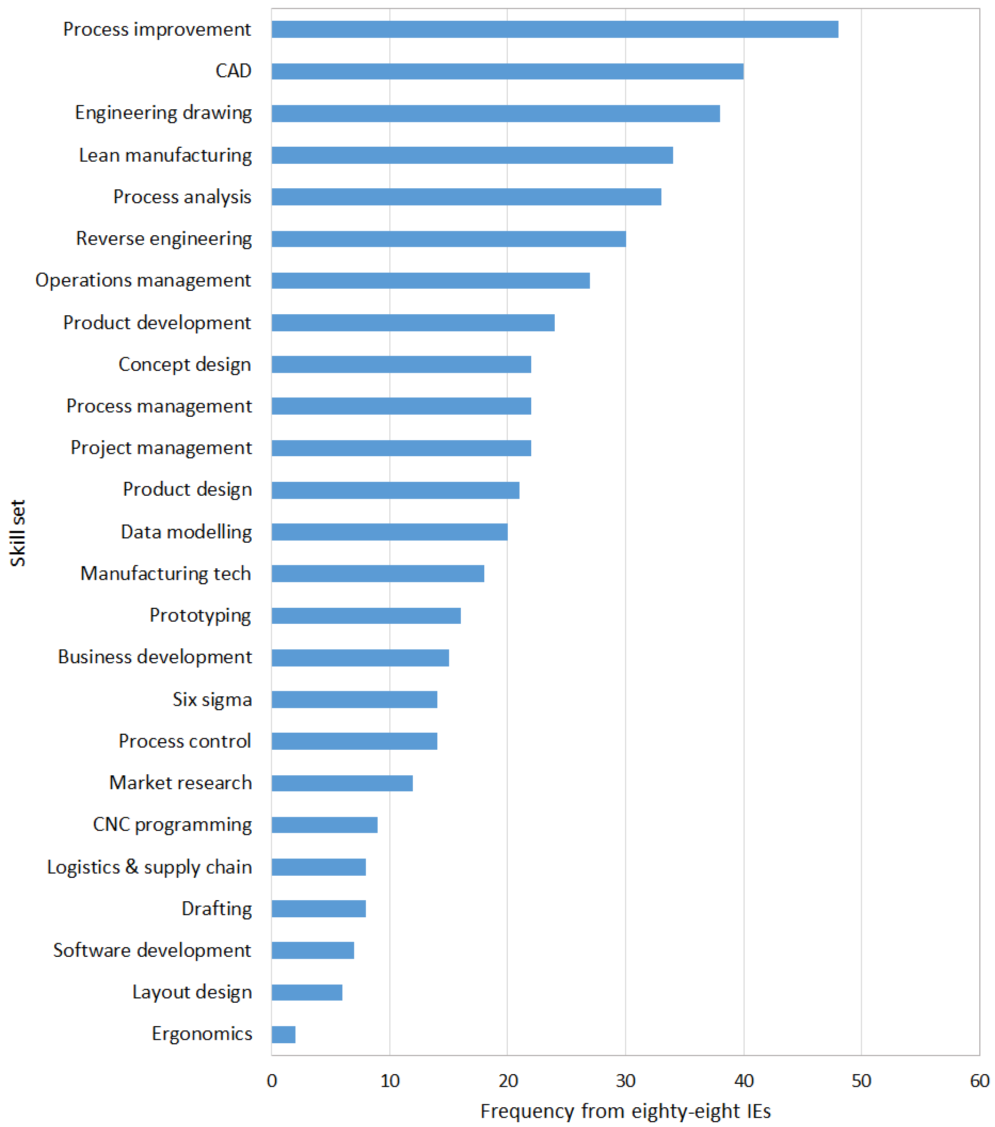


Figure 3.8: Top skill-sets listed by freelancers (from survey)

Figure 3.8 shows the hierarchy of skills listed by job seekers. The hierarchy can be compared to that of skills demanded by the different jobs that are posted.

3.2.2.3 Skill-set requirements

Now that the general trend of the skills that are listed by job seeking freelancers is laid down, it is important to analyse and determine if this trend matches the skills that are actually sought from IEs. Figure 3.9 illustrates the top skill-sets demanded by jobs.

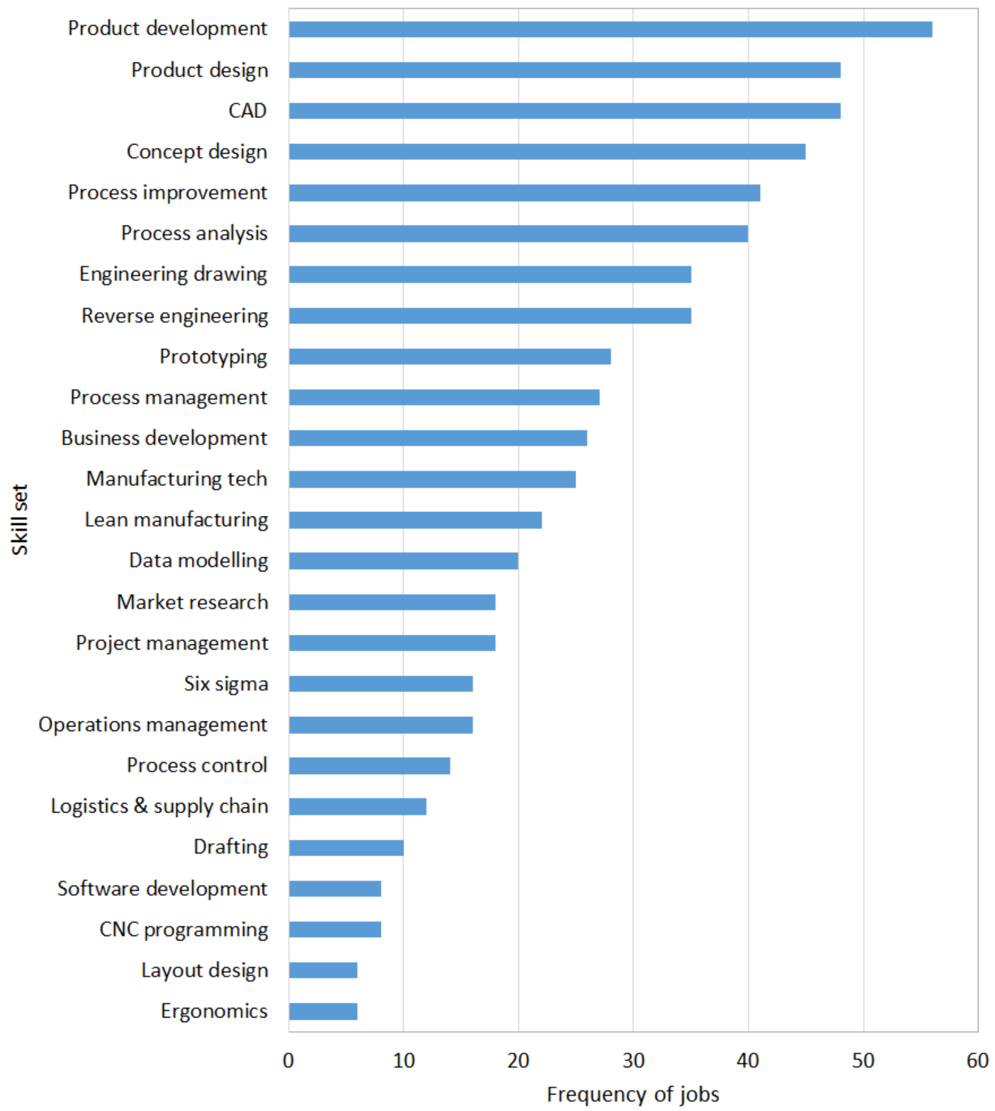


Figure 3.9: Top skill-sets demanded by jobs (from survey)

For the eighty-eight IEs considered, the total number of completed jobs is 628 and 56 of these jobs involved product development, which is just under 9 percent, thus fairly high.

3.2.2.4 Analysis of skill listing versus demand

The information available is sufficient to run an analysis of how related the skills offered by IEs are to the needs of the different posted jobs. Of interest, is the difference between the concentration of a particular skill set on the job post listings and concentration of that skill on job seeker listings. This difference is indexed and normalised and presented in Figure 3.10.

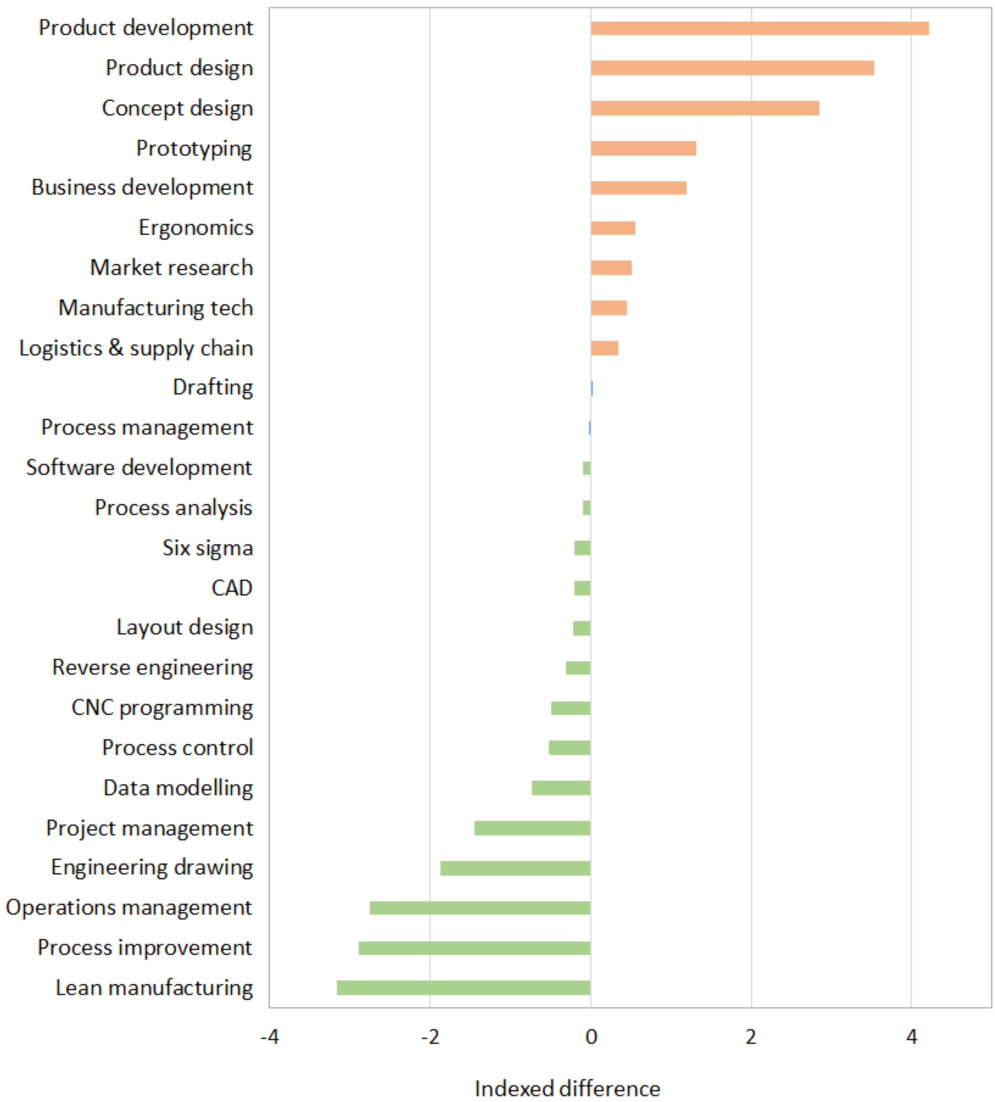


Figure 3.10: Skill demand versus listing (from survey)

Problem

Figure 3.10 shows a problem of misalignment between skills needed by industry and skills offered by job seeking industrial engineers. Ideally, the graph should fall close to 'zero' for all elements to show balance (alignment) between industrial skill need and skill offering. The skills at the positive side of the graph are more important as they indicate the skills that are actually more demanded by industry than they are offered by job seekers. These skills are product development, product design, concept design, prototyping and business development, with product development scoring highest. Analysis shows that the top skills in fact, are closely related, are practical and are design oriented. Typical jobs for example include:

1. Design a self-sanitizing door handle.
2. Design a gear system for a mobile robot.
3. Optimise a fleet management system.
4. Analysis of machinery/ equipment performance data.
5. Develop a concept for a folding gate.
6. Develop a smart medical thermometer from concept.
7. Sales data analysis.
8. Cost analysis and optimisation.
9. Risk analysis.

Note

It must be noted that the bulk of the jobs actually require CAD software, which can be very expensive and out of reach of the freelancer, especially the recently graduated freelancer. It is worth incorporating open source free software into the curriculum for CAD purposes.

3.2.2.5 Conclusion

It is important for curriculum to prepare industrial engineering students for entrepreneurship or self-employment. By aligning curriculum to address entrepreneurship, the expected outcome is that competences in work opportunity creation across the Personal services and the Wholesale, retail trade, hotels and restaurants industries (which account for approximately 20 percent of the South

African GDP) are increased.

Curriculum adjustments to consider

Strong emphasis is required within the curriculum, on entrepreneurship or freelance skill development. A course already exists within the curriculum, one that explicitly addresses key aspects of entrepreneurship, however, a proposal for enhancement is given in Section 3.5.5.

3.3 Graduate attributes

In this study, an investigation into the trends of distribution of demand for graduate attributes is made for the industrial engineering profession. The study outline is to collect data from industry through a survey to determine the attributes that employers seek when recruiting industrial engineers. Input data for this survey is collected from an on-line job advertisement platform. For each industrial engineering job post, recruiters typically highlight the following:

1. job description
2. minimum qualification
3. desired personal attributes

Such on-line platforms therefore provide diverse information for survey. The collection as well as processing of data from job advertisement platforms for the purpose of education management has been investigated in such work as that of Pitukhin et al. [145]. One hundred job post samples are processed to produce the distribution depicted by Figure 3.11.

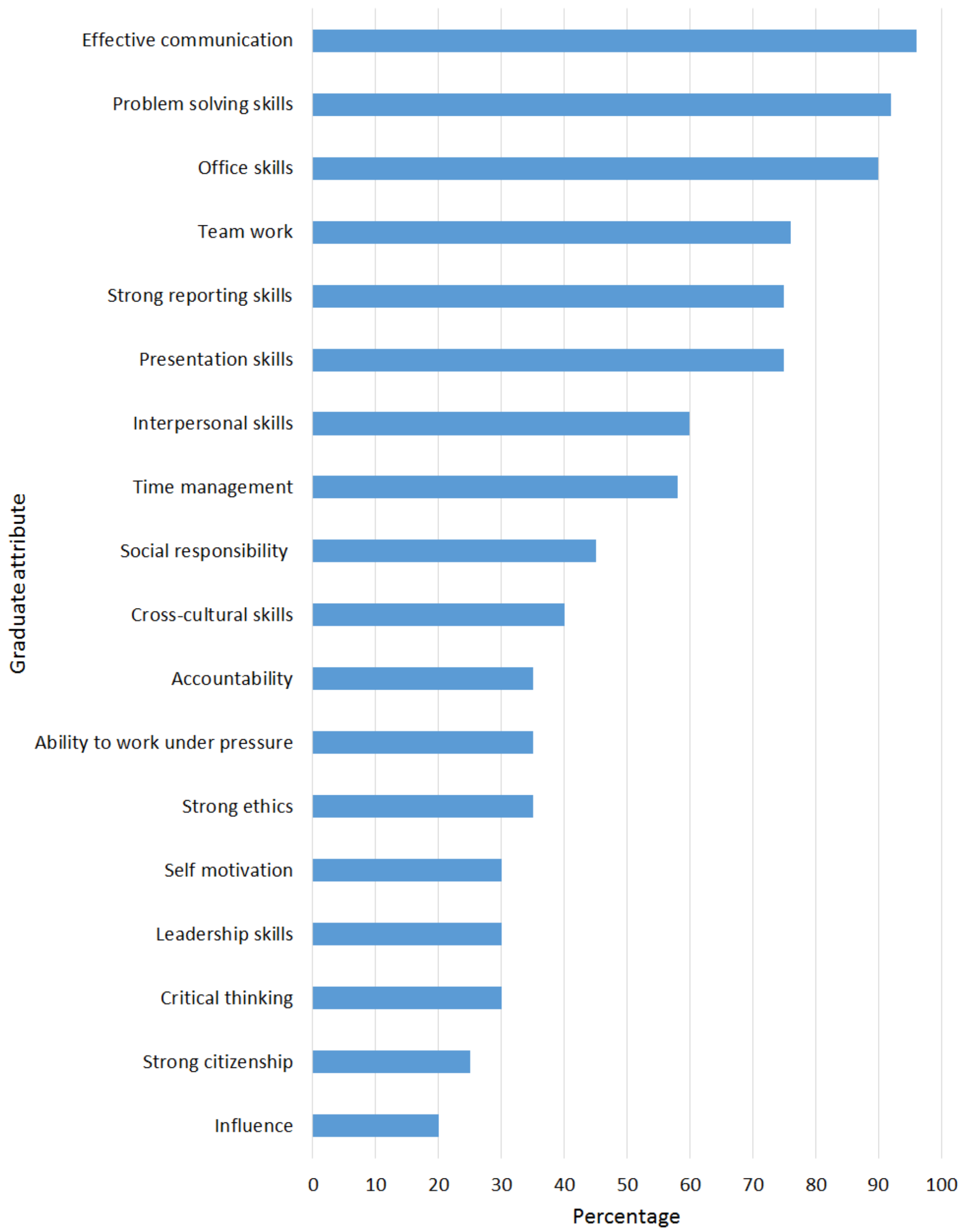


Figure 3.11: Graduate attribute distribution (from survey)

By cross-referencing the survey results above (industrial engineering profession) with those presented by Oliver and Jorre [133] (general multi-profession study), it is possible to determine any reciprocity as well as any data disagreement too. The strategy is to therefore compare the top attributes sought by industry, as presented by the work of Oliver and Jorre, against findings from Figure 3.11 and Table 3.1 outlines this comparison.

Table 3.1: Comparison of findings from graduate attribute study

Literature [133]	**Figure 3.11 [from survey]**
1. communication 2. teamwork 3. citizenship 4. critical thinking 5. problem-solving	1. communication 2. problem-solving 3. office skills 4. teamwork 5. reporting skills

It can be observed from this combined analysis, that the communication attribute is of highest priority, not only from the industrial engineering perspective, but also in a general sense. The problem solving and teamwork attributes are also of high priority. Analysing the attributes presented in Table 3.1 deeper, reveals that of the top attributes, the aspect of communication is in fact represented in 50 percent of the given top attributes.

These findings reveal that there is indeed need to prioritise realisation of graduate attributes in curricula. This study argues that this realisation requires an approach that is more effortless, especially with regards to the educators or teachers. This is possible if the graduate attributes become even more embedded into curriculum less explicitly, but rather more inherently. This concept is detailed in Section 3.6 which presents the proposed framework of this study.

3.4 IEs of the future

This section introduces the concept of 'Industrial Engineers of the future' with respect to the role played by curriculum. This concept is developed according to:

1. relevant literature
2. ECSA guidelines
3. current characteristics of work opportunities

4. graduate attribute demand

By consolidating and analysing this information, it is possible to project some of the competences that will be critical in defining the future industrial engineer.

3.4.1 Trends

From Section 2.8, the general trend is that industrial engineering saw a shift from industry/factory functions to more commercial functions. This tallies, to a reasonable extent, with the findings presented in Section 1.2, where the evolution of industrial engineering is discussed. The trend depicted by Table 2.1 can be extended up to year 2020. To archive this, details illustrating the trends of industrial engineering between year 2000 and year 2020 are required. From [5], it is shown that this period between year 2000 and 2020 was generally characterised by growing diversity and flexibility within the industrial engineering profession. This period saw a rise in demand, particularly, for such competences as those aligned to:

1. environmental sustainability
2. human safety and health
3. risk and loss control
4. product and system development

This trend can actually be cross-referenced to the general global developmental priorities and goals. Risk management and loss control in particular, are two areas that both the private sector and government have prioritised over the past two decades [53]. The idea of loss control has been globally received as a means to increase profits, without necessarily increasing product pricing, especially given the competitiveness of today's market [53]. Impacts of the Sustainable Development Goals (SDGs), set by the United Nations, have significantly affected industry across the planet, especially in terms of business management and operations. The decade from year 2020 has been set as the 'Decade of Action', with respect to the SDGs and this global campaign is expected, and is already affecting industry. Consequently, this goes to affect several professions, with industrial engineers included. This makes it vital for the education system to incorporate and prioritise sustainability concepts. It is common at present, for example, for recruiters to actually consider knowledge on sustainable development goals in setting selection criteria for recruitment. Beyond recruitment, it is also common for job functions to involve duties to do with operational sustainability, for example an industrial engineer at a mining company will typically be tasked to develop systems to manage power usage. With growing popularity of the UN SDGs, the majority of project support initiatives today, as well as project funding schemes, both locally and internationally, are typically set to prioritise projects with elements of sustainability.

Table 3.2 is an extension to Table 2.1 illustrating a forecast beyond year 2025 in terms of industrial engineering job functions. This begins to shape out the industrial engineer of the future.

Table 3.2: Extended industrial engineering function trends - derived from [5]

1960	1965	1970	1975	1980	2000	2025+
Work simplification and methods of improvement	Work simplification and methods of improvement	Inventory management	Information system design	System development	Safety health and environment	Human safety and health
Plant layout	Project engineering	Project engineering	Inventory management	Inventory management	General management	Environment
Labor standards	Plant layout	Plant layout and facility design	Financial management	Financial management	Project and operations management	Finance engineering
	Labor standards	Labor standards	System design	Manufacturing and manufacturing technologies	Inventory management	Manufacturing and production
			Project engineering	Project engineering and operations management	Logistics	Engineering design
			Labor standards	Quality	Finance engineering	Business development and sustainability
				Engineering design	Engineering design	Process, system and operation optimisation
				Labor standards	Manufacturing	
					Product and system development	
					Technical sales	
					Business development	
					Engineering standards	
					Systems and ICT	
					Process	
					Risk and quality	
					Human resource management	
					Labor standards & ergonomics	
					Production (plants)	

Table 3.2 depicts the functions that are predicted to top demand charts as far as the industrial engineering profession is concerned. It is seen that the function areas of business development and of sustainable development top the list. This is justified by the global movement towards improved support for entrepreneurship and sustainability. The function of optimisation is shown to remain high on the list just as the case in the present day. From the prediction, the areas of human safety and environmental science are also key. As African industrialisation continues to expand and evolve in technology and processes, systems to ensure human safety across all industries are key, especially such industries as mining and heavy manufacturing.

3.4.2 Projection

This section presents some guidelines based on which some unique, high priority areas of the industrial engineering profession of the future are derived. The following are identified:

1. Innovation and entrepreneurship
2. Sustainable development
3. Digital technologies

These economic aspects are projected to dominate the future economy as well. Academic prioritisation of these aspects is expected to better orient the industrial engineer for the future.

3.4.2.1 Innovation and entrepreneurship

The national and even global call for an improved entrepreneurship environment means that the economy can anticipate growth in small to medium enterprise establishments as well as innovation and development, especially from the youth population. In engineering education, this call has largely been answered, with entrepreneurship education being integrated into engineering degrees [146]. Barba-Sanchez and Atienza-Sahuquillo [146] analyse the impact of entrepreneurial competence in the engineer of the future, to identify and appreciate the role of entrepreneurship education in economic development. The work predicts that engineering professions of tomorrow strongly demand entrepreneurial competences, especially at graduate level. Martínez and Crusat [147] point out that over the past few decades, the engineering job market has generally become more competitive. The authors further show that trends indicate that the job market will in fact become even more competitive in the near and long-term future. It is therefore critical to invest in entrepreneurship competences for the future engineers.

Entika et al. [148] argue that entrepreneurial competences are so vital for the future engineer that there is need to globally standardise how entrepreneurial concepts are incorporated into engineering curriculum. The authors highlight that not enough has been done yet, to create and pass the appropriate material of entrepreneurship education for incorporation into engineering education. The work features a discussion on the definition of entrepreneurship education for the future graduate in engineering, and addresses the question of what entrepreneurship education means to engineering graduates of the future. Hixson and Paretti [149] actually argue that entrepreneurship education cannot be separated from engineering education. A successful career in engineering, as the world races Industry 4.0, would be heavily centred on entrepreneurship competences. In safeguarding the career, Lugo et al. [150] propose the synchronisation on of the engineering and business courses.

3.4.2.2 Sustainable development

The Sustainable Development Goal (SDG) initiative is a global movement and one that has massive influence on the economic future of South Africa, as with every other country. The SDG initiative calls for intensive transformation for every country, affecting the operations of the entire national value chain including government, private sector, industry, civil society and science [151]. Since the turn of the century, massive strides have already been made towards the SDG initiatives and it has never been more certain that sustainable development is the heart of the future global economy, as enterprises start to reflect sustainability concepts through internal objectives and visions. The concepts of environmental and social sustainability, are the most commonly discussed [152].

While the market is becoming more competitive, operational costs are generally increasing. This makes it important to be able to optimise business operations, systems or products. This includes improved loss control systems, price management, product development/improvement, resource management and so on. Sustainable development concepts are expected to be a significant part of the work of the industrial engineer of the future. De Oliveira et al. [153] reiterate that cleaner/greener industry has huge economic implications and highlight that the growing advocacy for sustainable production will continue to grow into the future. It is shown how the concept of green industry affects the global economy, outlining that environmental sustainability particularly, has direct influence on the long-run financial performance of an enterprise, especially in the future, more than present day. Paramati et al. [154] show that renewable energy projects have national-scale economic impact, and such projects deserve policy support. The authors also highlight that the demand for renewable energy solutions will continue to rise into the future.

A survey by Vivoda and Kemp [155] on public statements of mining associations and the extent to which statements relating to sustainability are incorporated into policy, reveals that while the mining industry has allowed a sustainability shift, more needs to be done. The study shows that, out of 61 associations, 33 percent had no public statement on sustainability at all and of the 67 percent with statements, 32 percent had no active sustainable development policy. With improved education, education that is optimised to enhance sustainable development competences, the trends are expected to continue to shift towards the sustainability goals. Caron et al. [156] also highlight that sustainability concepts have been pivotal in the mining industry since year 2010, and that it has become necessary for professionals in the mining industry to appreciate and accommodate sustainable mining practices.

According to Alawin and Oqaily [157], sustainable development is so key for the future that the concept of sustainable development should not be localised to the private sector only, or to engineering and science only. The authors show how, at national level economics, implementing strategic sustainable development objectives may contribute to improved trade deficit management. Sustainability in industry has significant potential to lower importation budgets while in fact increasing exports. Yüksel [158], discusses the steel-making process by-products, revealing how use of the by-products contributes sustainable development. Literature suggests that slag from the iron and steel industries, when used to complement cement, improves the micro-structure of built concrete. Yüksel reviews the use of steel slag in construction and highlights how this concept is key for future construction-related specialists and engineers. Commonly, when industry is discussed, it is the manufacturing and production industries that are typically considered, with the rural industry typically neglected. This is the case, yet the African (and in fact global) rural industry holds a substantial share of the agricultural ecosystem. Voronkova et al. [159] call for a future that is characterised by improved resource management to promote rural sustainable development in agriculture and tourism in Russia, in order to realise shared national prosperity.

From a global perspective, while industry has started to see some progress in the implementation of sustainability concepts, more still needs to be done. According to a Dutch study [160], the current state of the hotel industry shows that more innovation is required to meet the sustainability demands of the industry, especially given the sophistication of customer requirements. Innovative controls are required to improve waste and power management, to make operations more sustainable.

3.4.2.3 Digital technologies

The twenty-first century is characterised by growing popularity of digital technologies, defined by electronic tools, machines, systems, and software that generate, process and utilise data. Digital technologies today are used across all industries and these technologies make processes or operations more efficient or more accurate. The manufacturing sector is particularly going through a fourth revolution and this calls for improved strategies for IE education. Industry 4.0 calls for digital technologies, especially in the area of Internet of Things (IoT). Another area is that of big data, as well as data analysis/processing [161]. Sutopo [162] highlights that in this digital era, there is more need to implement systems that can commercialise higher education research, that is to say, systems that can transfer academic work to industry. Marttonen and Baglee [163] study the trends in industrial maintenance services and point out that the fourth industrial revolution will see the concept of 'big data' becoming key to efficient industrial maintenance management, in the near future.

In the medical field, digitisation has transformed the practice of medicine, and trends show that this digitisation will continue into the future. Nano-based technologies have reshaped cancer diagnosis, making the detection of cancer bio-markers possible at earlier stages [164]. Surgical processes have seen automation, patient profiles have been digitised for improved access to information (such as medical history), prosthetics have become more advanced. Digitisation in the medical industry is fast-paced and graduate industrial engineers need to be prepared for an economy that is highly digital. Javaid et al. [165], amidst the COVID-19 pandemic, discuss digital technologies to ensure better patient isolation, by creating automated virtual centres to minimise physical crowding at hospitals and clinics. Other studies that outline the importance of digital technologies in the medical field, and the future impact of such technologies are [166], [167] and [168]. It is highlighted that the medical industry is fast shifting towards a future of advancements in science, engineering and technology, and that it is critical for the future practitioner to master digital technology concepts.

Finance and economics have both been substantially transformed by digital technologies. Kirillov et al. [169] propose the use of advanced mathematical models and algorithms to assess the feasibility of engineering projects in order to support capital investment decision making. The proposed digital system demonstrates robustness and the ability to process huge amounts of diverse data.

Digital technology has transformed the face of marketing. Classen and Friedli [170] trace the age of digital marketing technologies in the sales of industrial services. The authors illustrate that smart systems have gained massive ground in industry over the past decade and such technologies are still on the rise. Hristoforova et al. [171] discuss the impact of digital marketing in the tourism industry. Studies illustrate that digitisation of tourism marketing is on a trajectory of exponential growth and will in the nearest future define how tourism is spread across the world. Virtual reality marketing is one of the latest digital technologies used for marketing. The study demonstrates how digitisation brings efficiency as well as comprehensiveness to market penetration. For a successful career in industrial engineering in the decade(s) to come, one is required to demonstrate sound appreciation of digital technologies across all industries. In [172], internet marketing is compared to traditional marketing and it is shown that internet marketing is a superior marketing tool in today's economy, and more so, tomorrow's.

In agriculture, the present and future have never been more digital. Agriculture across the entire planet has been redefined by automation and robotics, information communication technologies, drones and sensors as well as digital surveys and advanced climate and environment modelling technologies. Deichmann et al. [173] show how digital technologies have brought about solutions to the challenge of access to the market in farming, especially for the small-holder farmer. In the same work, it is also shown that digital technologies have been instrumental in knowledge-sharing and extension servicing especially for rural farmers. The concept of smart agriculture is in fact a global topic today, and trends point towards a future in which agriculture is highly digital. Agriculture is known to accommodate a fair proportion of industrial engineering service providers such that it becomes key for future industrial engineers to have a strong digital technology orientation in order to meet the market demand for product or service delivery. Klerkx and Rose [174] introduce the concept of 'Agriculture 4.0' with alignment to that of 'Industry 4.0', highlighting that the era of Agriculture 4.0 has begun and is characterised by advanced digital and biotechnological innovations in agriculture. In [175], the idea of precision agriculture is discussed and it is further highlighted that digital technologies in agriculture are so key that they require attention even at policy level.

As the world becomes more and more digital, the threat to information security however, worsens. Cyber-security is therefore a key area of technology today, and even more, in future, as new cyber-security threats continue to evolve [176]. The future is one that is characterised by rapid advancing digital technologies. The concept of digital technologies requires adequate attention for the industrial engineering student.

3.4.3 Characteristics of the future IE

From the study conducted, it is concluded that the future industrial engineer is one to have mastered the following:

1. innovation and entrepreneurship
2. sustainable development competences
3. digital technologies

To add on to these competences, findings from Section 3.3 prompt that the attribute of effective communication be prioritised explicitly, for a more successful career in industrial engineering. The overall characteristics of the industrial engineer of the future are depicted by Figure 3.12.

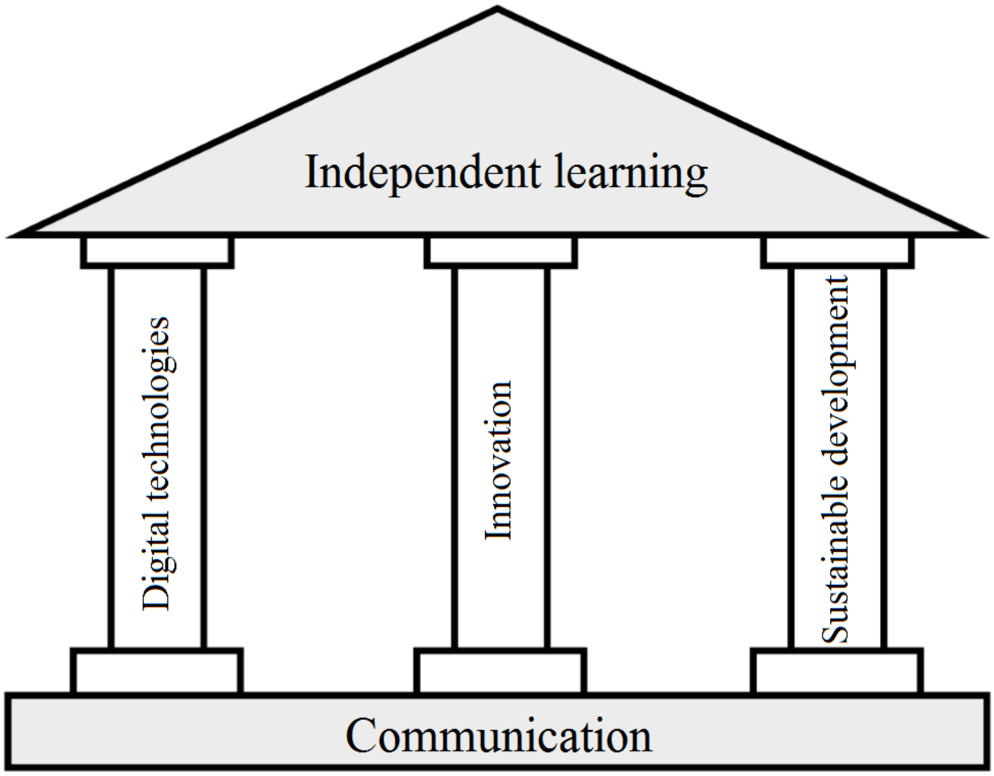


Figure 3.12: Characteristics of the industrial engineer of the future - developed from findings in Section 3.4.2

In Section 3.6 the concept of the future industrial engineer is incorporated into a proposed curriculum framework.

3.5 Proposed curriculum

The industrial engineering qualification is defined by the taught curriculum. The curriculum at the centre of this work is that for the Advanced Diploma in Industrial Engineering program. The overall system and the approach implemented however, are suitable for implementation on diverse program curricula. The Advanced Diploma in Industrial Engineering program is set to provide learners with advanced knowledge in fundamental engineering. The program emphasises industrial engineering principles and provides learners with in-depth knowledge in the field and equips the learners for further and more specialised study. The general outline of the curriculum is given in Appendix A. The idea of this work is not to restructure the curriculum but to enhance the existing curriculum without removing any key courses. The proposal is guided by findings from Section 2.2 of the literature review.

3.5.1 Automation

This work proposes automation of the process of curriculum management. This automation is based on artificial intelligence and is designed to align the curriculum to the prevailing professional needs of the industry. This work therefore argues that it is not sufficient to only review curriculum on a periodic basis, guided by an internal staff committee, rather, an adaptive system is required to continuously manage curriculum, as illustrated by Figure 3.13.

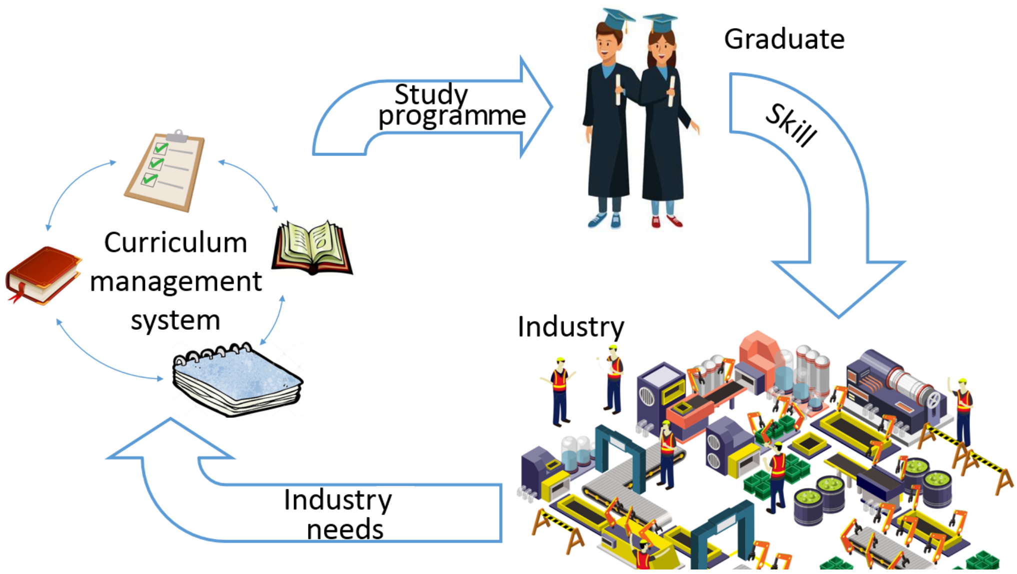


Figure 3.13: Proposed automated curriculum management (drawn)

In this way, a systematic and holistic curriculum management is proposed, and is detailed in Chapter 4.

3.5.2 Instruction methods

In terms of methods of instruction, the proposed curriculum is characterised by the approach of students learning on a problem/project basis, where class work is derived directly from the industry. In this way, the course assignments, examinations/tests, projects and even practical exercises are drawn directly from real project/job advertising platforms, rather than books. With the study done in Section 3.2.2.1, it was revealed that at least 80 percent of all freelance adverts are in fact comprehensive enough to define expected time-lines for the completion of a given project, specific terms-of-reference as well as the financial reward of the project. The use of such material as study aids is therefore expected to enhance practicality by promoting reference to real problems of the current day, that require real solutions which can be interpreted and understood.

3.5.3 Integrated curriculum

It has been highlighted that industrial engineering is multidisciplinary, with a diverse span of job duties, spreading across various application fields, from manufacturing to medicine and beyond. It is therefore evident that the classroom cannot prepare the student for all possible industry-related work quandaries. Consequently, this means that the industrial engineering should have the ability to learn quickly and to adapt knowledge. In reality, and as highlighted in the case study presented in Section 4.3.1, industrial engineers work with multiple stakeholders, assuming more of a central role. A project to develop a concept for a 'self-sanitising door handle' for example would require the industrial engineer to coordinate the health specialist of the project, as well as marketing, finance and perhaps even legal officers of the project. An analysis of data from a set of given recruitment information (Section 4.3), presented the findings illustrated by Figure 3.14, regarding the typical work environment of employed IEs.

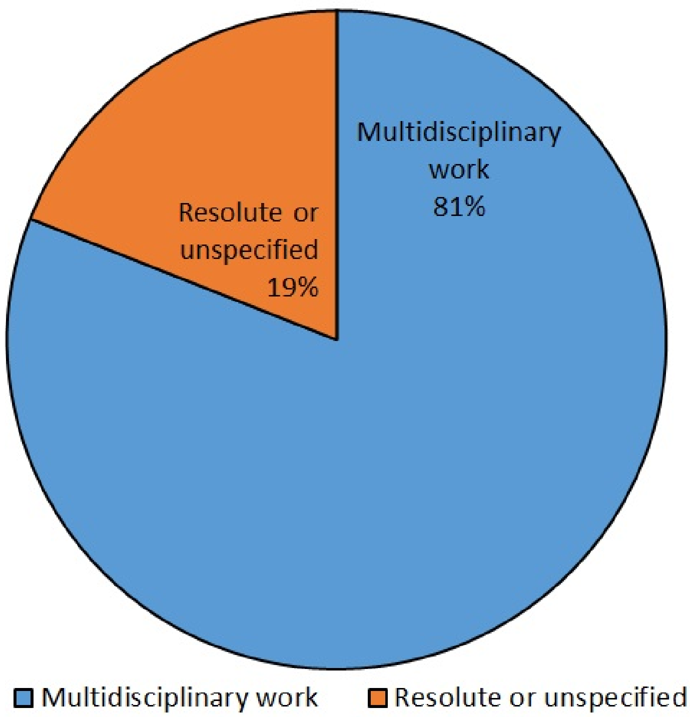


Figure 3.14: Industrial engineering work environment (from survey)

It is shown that at least 81 percent of employed industrial engineers will take centre position, in multidisciplinary environments. The study program too should therefore allow adequate simulation of this multidisciplinary characteristic. It is proposed that curriculum promotes explicit inter-faculty and even inter-disciplinary learning. The program class assignments and projects are required to contain components that require students to cooperate with other students from different departments and even faculties/schools. A systematic approach is required for proper facilitation, documentation and evaluation.

3.5.4 Sustainability concepts

The sustainability topic is one key topic that requires clear outlining on the curriculum plan [13]. As stated in Section 1.1, curriculum must meet international standards and local industrial needs, whilst also remaining aligned to the dynamics of the national economic, environmental, social and political landscape. This narrows down to business sustainability. The proposed curriculum should take such concepts into account to ensure that business products and/or processes are sustainable.

Today, there is worldwide concern for sustainability, with emphasis on the ”three Ps” that is, the People, Planet and Profit, where businesses ensure not only the well-being of shareholders through profits, but also the well-being of the people and the planet, [177]. The proposed curriculum too, therefore plays a role in reflecting these three Ps. Based on media trends, in the context of South Africa, the main economic, environmental, social and political factors that need to be considered are:

1. Women empowerment
2. Youth empowerment
3. Graduate unemployment
4. Electricity shortage
5. Environmental pollution
6. Increasing fuel price
7. Climate change
8. Import substitution (indigenisation)

It is proposed that these topics become mark points for student work especially projects. Design solutions for example, could be evaluated from an environmental perspective, towards determining potential impact on the planet.

3.5.5 Innovation and entrepreneurship

Over and above the inclusion of an entrepreneurship course within the curriculum, it is noted through the study outlined in Section 4.4 that there is need to improve the entrepreneurial experience of the student during the study process. To achieve this goal of promoting entrepreneurship through curriculum, it is proposed that a unique case-study approach be taken, where learners are tasked with a target number of practical industry-based freelance work projects, as part of the study experience. These projects are such as those listed under Section 3.2.2.4, sourced from online freelance work advertising platforms, reflecting the true nature of the needs of the industry. Each student is required, after completing a project, to present the project for evaluation in class, by both lecturers and students. Strategic and robust evaluation criteria for the evaluation are proposed. The proposed evaluation points, with reference to ECSA guidelines [134] and [135], are:

1. **Objective**
   As diverse as the IE profession is, there are some certain skill sets that gain more popularity than others, as shown in Chapter 4. The curriculum management system developed in this work, is designed to read and understand the state of industry to determine distribution of skill demand in terms of course curriculum elements. Accordingly, the entrepreneurship projects undertaken by students are best guided by the management system output. Typical objectives include:

   (a) Design
   (b) Optimisation
   (c) Data analysis and management
   (d) Economics
   (e) Business development
   (f) Financial management
   (g) System development and so on.

   The objectives of the different projects need to reflect the practical diverseness of the industry, from student to student, course to course and year to year.

2. **Competence**
   It is also important to evaluate the student competence, given the project taken and the problem(s) solved. ECSA guidelines address the concept of engineering activities, to the effect that the engineering activities carried out for any given problem need to be well defined, Well-Defined Engineering Activities (WDEAs). Student competence can therefore be evaluated according to the activities carried out, in terms of such characteristics as:

   (a) Practice area. Practice areas include aviation, medicine, sport, education, manufacturing, insurance and so on.

   (b) Complexity. Complexity typically has to do with the level of discipline-discipline interactivity. Some projects are fairly more complex and demanding that different performance indices from different stakeholders, be satisfied. A project to optimise human resource utilisation for example involves satisfying indices set by representatives of the following departments:

      i. human resources
      ii. finance
      iii. logistics
      iv. executive/management
      v. legal.

   On the other hand, a project to design the gear system of a mobile robot involves satisfying indices set by the engineer or project owner. The former therefore carries more complexity in terms of working relations and index balancing.

3. **Approach**
   The approach taken in solving the given problem needs to be evaluated to determine the level of skill comprehension of the student. This goes to highlight creativeness, planning and research skills. Practical problems are required for the industrial engineering student, such problems that cannot be solved by artisans due to the theoretical calculations and engineering decisions that accompany the proposed solution.

4. **Technology**
   Technology is dynamic especially in the twenty-first century. Projects need to demonstrate optimal selection of equipment or software. Engineering education needs to see flexibility in terms of the tools that students use

during the learning process. The projects taken by students need to be evaluated to determine technological appreciation of the student. Industrial engineering commonly addresses problems that require visualisation. That said, it is to the advantage of students and the industry that students explore such software packages as Adobe Photoshop or Illustrator, for example. The equipment and software used in project delivery need to reflect trends in technological advancements.

5. **Sustainability perspective**
   At some level, engineering affects the environment, or deals with projects in fields that affect the environment negatively. Project also need to be evaluated in the context of sustainability of the proposed solution. Not just environmental sustainability in fact, but also social, economic and operational sustainability.

6. Other evaluation criteria are to do with how the project or job was secured, the financial perspective of the project or job as well as literature review.

In completing these projects, not only is a student developing skill, but the student is also building a personal professional portfolio in the field of industrial engineering. Inclusion of this proposed entrepreneurship component in curriculum, enables students to experience industry in class. This means that on completing studies, the graduate has in fact worked on some real industry problems and has potentially earned some income during the process.

3.5.6 Software

While, over the past few decades, essential software packages have become more available and affordable and free tools are in fact rapidly gaining popularity [178]. The proposed curriculum is set to promote entrepreneurship in graduates. The fact that most of the industrial engineering work (especially design) requires specialised software cannot however be ignored because some of the software is in fact expensive and typically out of reach of the graduate. Figure 3.15 gives an indication of the proportion of projects that require specialised software, based on the surveyed carried out in Section 3.2.2.2.

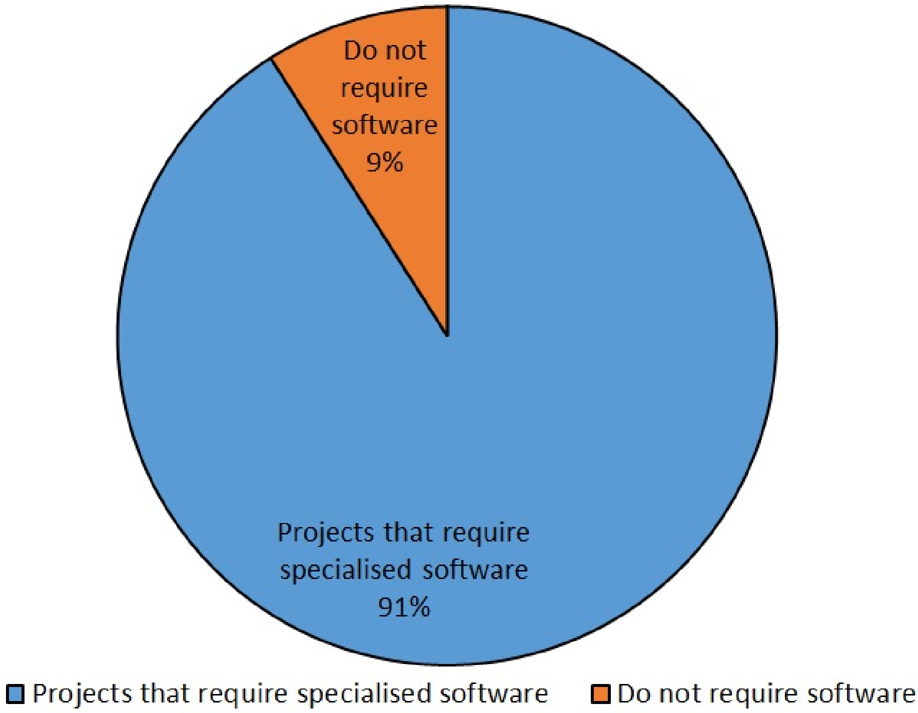


Figure 3.15: Software requirement analysis (from survey data in Section 3.2.2.2)

From a sample of 200 projects, 91 percent required specialised software, typically AutoCAD, MATLAB, SolidWorks and so on. MATLAB requires an annual subscription of approximately ZAR 13,500 while AutoCAD requires approximately ZAR 22,500. For this reason, it is critical that more attention be paid to open source software, such as FreCAD, GNU Octave and so on.

3.5.7 Summary

The proposed curriculum, is one that does not add or subtract any courses or material. The proposed curriculum is an improvement to the conventional curriculum, one that is autonomously managed and adjusted on a continuous basis according to the state of industry. The proposed curriculum takes education integration into account, through discipline interrelation, with the view that the industrial engineering field is diverse. The proposed curriculum also pivots on industrial data, to promote entrepreneurship and innovation among the students, as well as the concepts of sustainable development.

3.6 Proposed framework

Traditionally, engineering education was more biased to focus on the educator and what the educator teaches, rather than focusing on the learner and what the learner learns [179]. Today, higher learning institutions are turning this tradition around. This work develops and proposes a framework for the management of industrial engineering curriculum for the purpose of optimising curriculum alignment to industry needs. The key elements of the framework include:

1. analysis of the style of learning
2. type of profession
3. graduate attributes
4. statutory guide
5. concepts of the industrial engineer of the future
6. modern curriculum innovations
7. automated curriculum management

These elements shape the framework that is proposed in this work, taking literature findings into consideration, as well as study findings presented in this work.

3.6.1 Style of learning

The nature of today's industry demands practitioners who are able to adapt to rapid dynamics in technology, economics and so on. Studies and surveys in Chapter 4 show that the rate at which technology is developing in industry is increasing and that strategies are required to ensure that students learn how to adapt their competences. The ability to learn independently is therefore key, for the industrial engineer. In fact, recent studies have shown that students absorb and apply knowledge better if active-learning approaches are utilised [180]. Figure 3.16 illustrates the style of learning under the proposed framework.

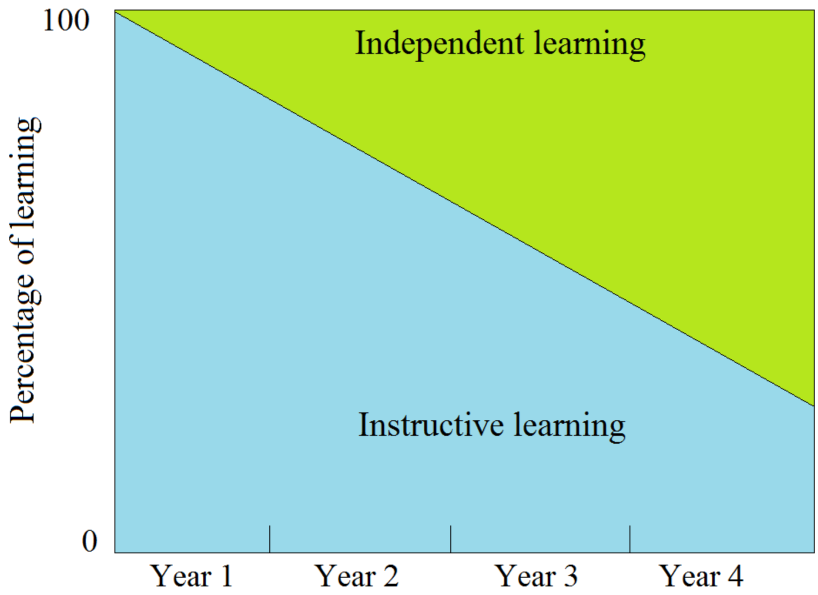


Figure 3.16: Style of learning (author)

It is shown that as the student progresses through the study process, the student is required to continually learn how to learn independently. In the final year of study, the student is required to independently learn 60 percent of the learning material. This is considered an effective way of ensuring that graduates have what it takes to navigate different work environments related to industrial engineering, to adapt to unfamiliar fields, and still make the required professional contribution to industry. To implement this, a learner-teach-learner strategy is drawn-up, where the teacher assumes a supervisory role in the classroom, where students are assigned different topics or subtopics to research and then teach ahead of the entire student class, while the teacher monitors the process. A gradual increase in the implementation of this approach is instituted, beginning at approximately 8 percent independent learning rate in the first academic year, up to 60 percent in the final year. This approach allows the following aspects:

1. teacher to assess the true knowledge reception/retention of the students,
2. teacher to assess the true depth of learning content,
3. teacher to assess the interactiveness of the learning environment,
4. teacher to assess the effectiveness of independent learning,
5. teacher to identify students strengths' more effectively.

Figure 3.17 illustrates these five aspects graphically, respective of the teacher, classroom, teaching-student and the pool of educational knowledge available in the library of study resources.

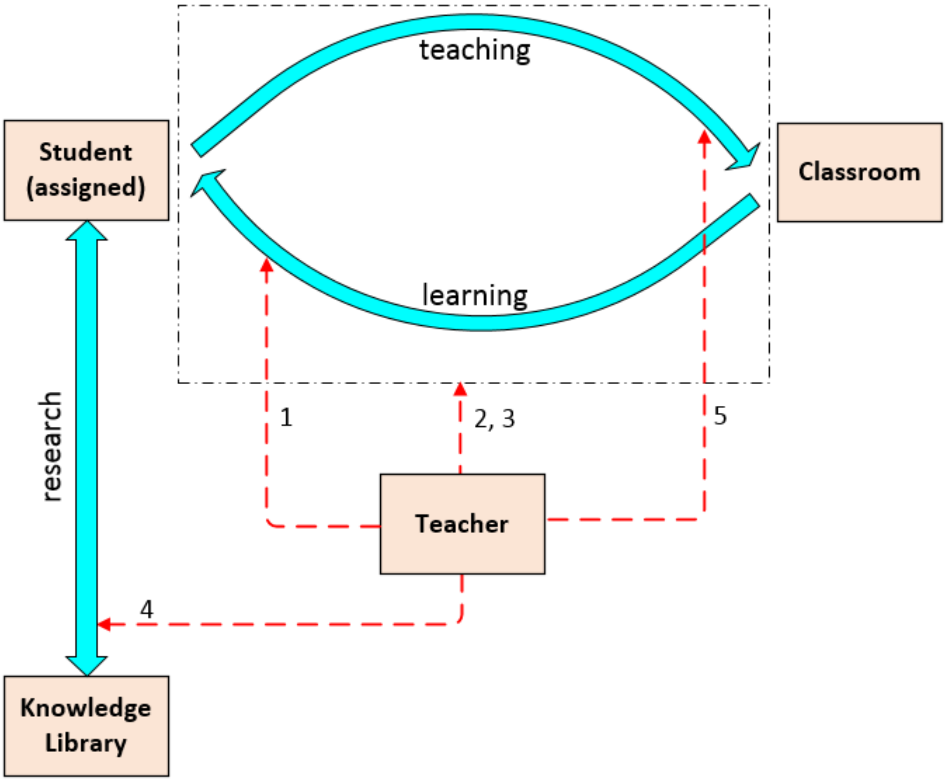


Figure 3.17: Graphical presentation of the proposed learner-teach-learner approach (author)

The numbers marked along the red dashed lines on Figure 3.17 indicate the five aspects given above, positioning each aspect according to how the teacher comes into play. The idea presented by the framework can be supported by recent studies which have shown that approaches where students teach other students have potential to improve knowledge retention, as illustrated by Figure 3.18 which presents a learning pyramid.

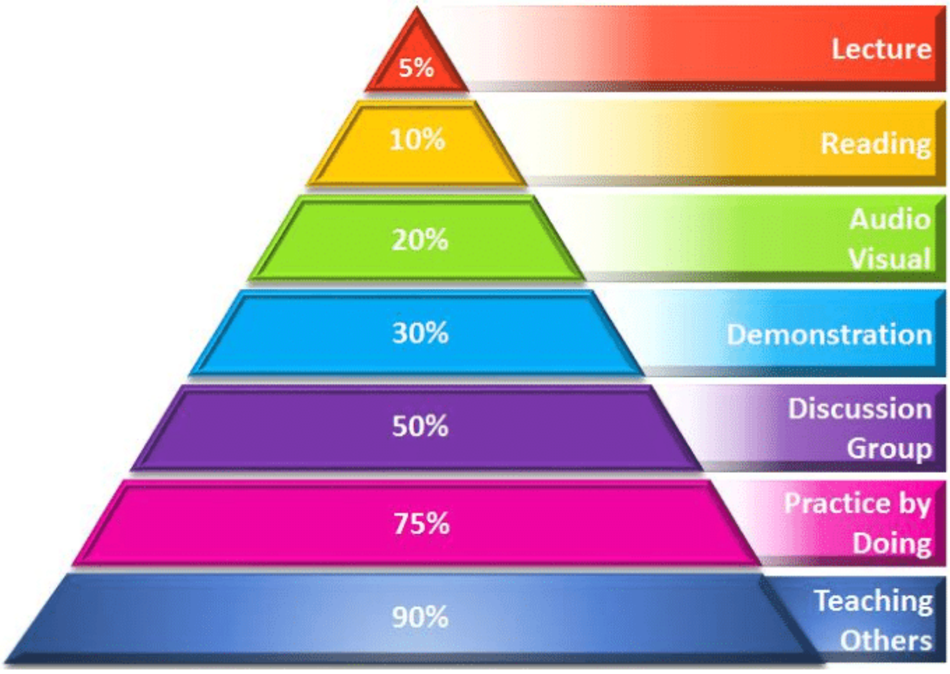


Figure 3.18: Illustration of knowledge retention [180]

Figure 3.18 shows that knowledge retention rate twenty-four hours after a lecture can be as low as 5 percent while that after the participatory teaching approach where the learner teaches other students is approximated to 90 percent.

3.6.2 Onion diagram

The overall framework proposed in this work is presented by Figure 3.19, as an onion diagram. The idea is to illustrate that the framework is set up according to a ring network, which starts at the outside by regulating the general style of learning, and converging at the center, with automation of curriculum management in accordance with the state of the industry.

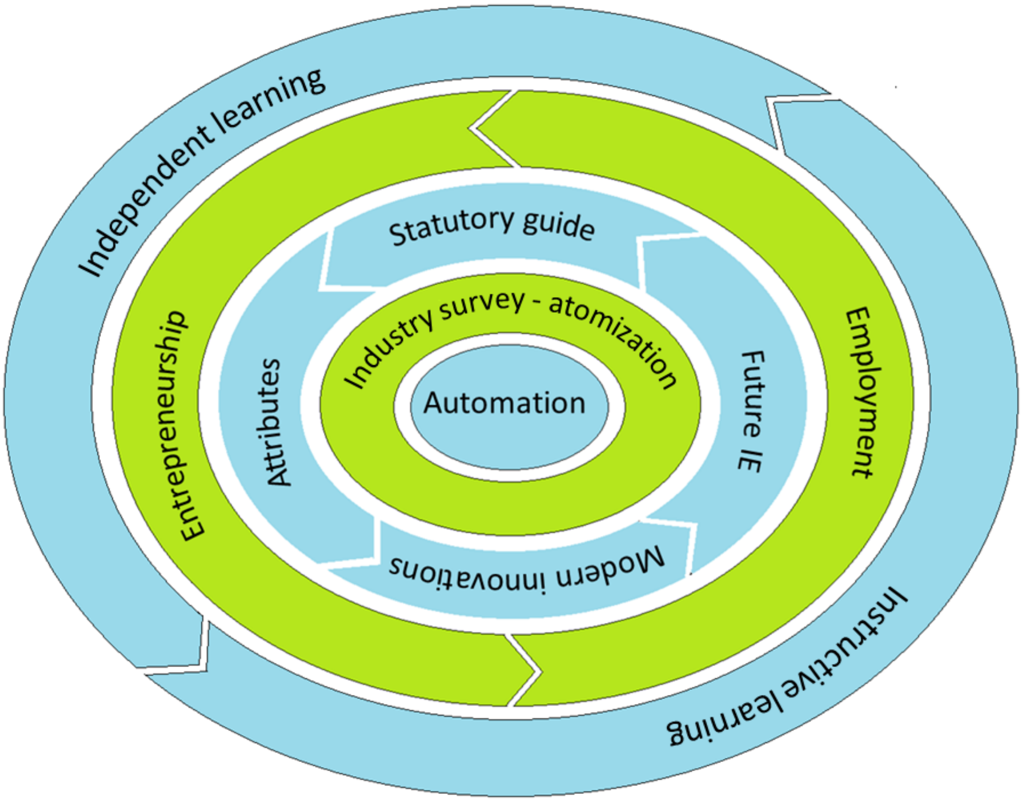


Figure 3.19: Onion diagram for the proposed framework (author)

The proposed framework is operational at the educator level, rather than faculty or school level. This ensures uniformity and effectiveness at implementation. It can be derived from Figure 3.19 that the framework is ”pealed” from the outside going inside. The interpretation of the framework is as follows:

1. On the outside, the framework addresses balance between independent learning and instructive learning. The idea is to shift focus more to independent learning, with gradual increase as the student advances towards the end of the engineering program. For each semester and for each course/module, the framework guides teachers to collaboratively and uniformly distribute topics and subtopics for teacher instruction and student-self-instruction.

2. On the next level, the framework guides the teachers to balance the employment and entrepreneurial competence requirement of the industry. It is common for education to focus on preparing students more (if not entirely) for employment rather than entrepreneurship. This proposed framework explicitly promotes balance in student competences. Details regarding the realisation of the proposed competence balance are given in Section 3.5.5.

3. On the next level, the framework goes to address the architecture of the curriculum, that is the elements of graduate attributes, modern curriculum innovations, statutory guidelines for engineering and also concepts of the 'industrial engineer of the future' as detailed in Sections 3.3, 2.2, 3.1 and 3.4. A deeper analysis of the four elements reveals that all four elements have a key attribute in common. All four elements indicate that effective communication in the engineering profession (better yet, the industrial engineering profession), is pivotal to a successful career. This finding is presented graphically in Figure 3.20.

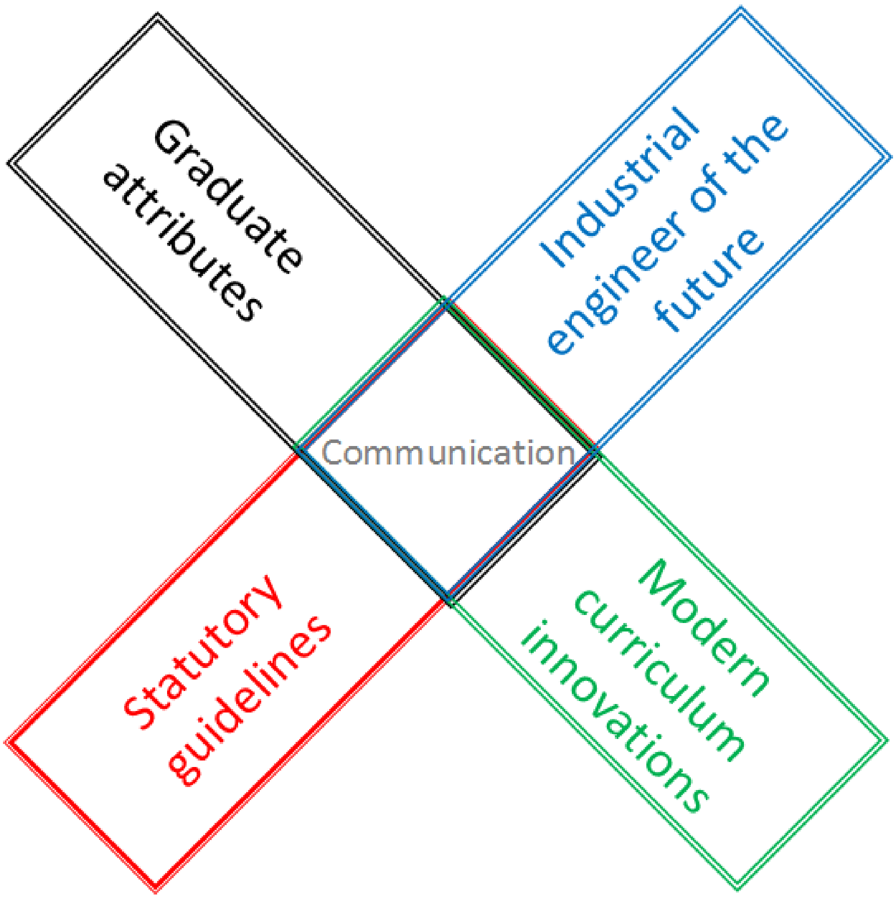


Figure 3.20: Analysis of the elements of the framework (author)

This finding justifies the implementation of a strategy to transform curriculum to ensure that students master advanced communication skills. Conventionally, the following strategies have been implemented to enhance communication competences in engineering students:

(a) Group discussions (group assignments)

(b) Presentations

(c) Physical demonstrations

(d) Interactive sessions (seminar, symposia, conferencing and so on)

(e) Oral examinations

Of the listed strategies, the least explored in engineering education of today, despite being historically most common, is that of oral examination [181]. The work of Goodman [181] shows that oral examinations for engineering students creates substantial potential for improved communication competences. When examined in groups, oral examination is shown to in fact more than double the attribute of teamwork among students. Rouser [182] draws the same assessment, that oral examination is an effective way of fostering stronger communication skills, based on a study with aerospace engineering students. Other studies that present the effectiveness of oral examination for engineering students include [180], [183] and [184].

The proposed framework accommodates the element of oral examination, in accordance with literature findings. This tool is proposed for the final year of study stage, across all courses. The reason for this is to ensure optimum process management given that engineering classes are typically smaller at the end of the program than at the beginning. This therefore allows better supervision by the relevant teachers.

4. On the next level, an industrial survey is carried out to establish the requirements of industry, according to IE graduate professionals. On this level, the concept of decomposing curriculum into micro-curriculum elements is presented, as outlined in Chapter 4.

5. Finally, on the inner-most level, the framework implements a strategy to automate the process of aligning curriculum to industry needs by means of manipulating the respective micro-curriculum elements as detailed in Section 5.4.

One key aspect of the proposed framework is that of practicality. The framework takes consideration of the implementation of final product in a practical sense, that is to say, on the basis of the individual teacher, through the course/module that the respective teacher is responsible for.

3.6.3 Final framework

The final framework is crafted to ensure that industry and education tally as closely as possible. The framework creates a systematic flow from industry to education and back to industry, with a computer algorithm at the centre of the cycle. The final framework is given in Figure 3.21.

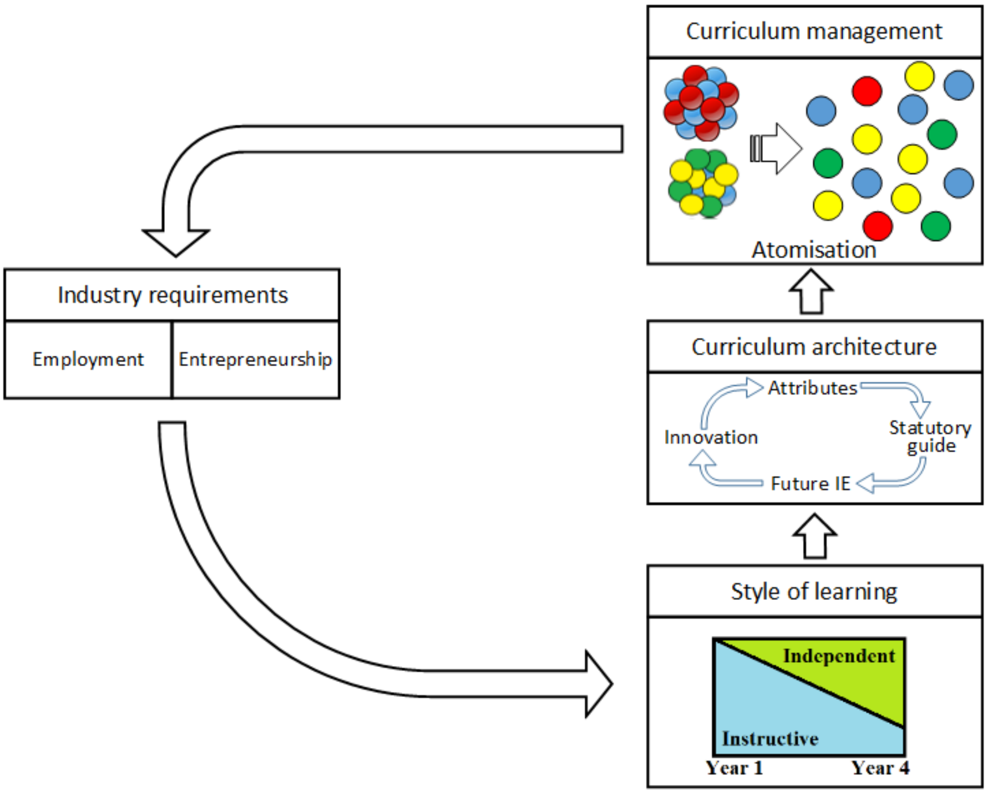


Figure 3.21: The developed framework

The framework outlines the aim to implement an intelligent system to utilise industrial data to drive industrial engineering education. In summary a framework is proposed in this work, that marries industry and education in a manner that is more intimate. The framework optimises the style of learning by gradually shifting towards independent learning from instructive learning, as the student progresses from start to end. The framework presents an architecture that is centred on effective communication as critical tool for graduate industrial engineers. The framework therefore presents strategies to ensure that students develop adequacy in communication. The practicality of the framework is supported by the fact that implementation of the framework is at low-level, that is to say at the level of the teacher, rather than faculty or school level.

Chapter 4

Research methodology

This study focuses on system development for improved alignment of curriculum to industrial need. This research is an explorative case study that involves the collection of both qualitative information and quantitative data. A mixed methods approach to research is therefore taken, with statistical analysis. Qualitative research is based on non-numerical and unstructured data, typically collected through observations, questionnaires and interviews [185] and [186]. Qualitative research typically studies aspects of human life [187], in a more social dimension, investigating such issues as those to do with individual interests or feelings. From a philosophical point of view, the typical branches of reference are positivism and postpositivism, as well as constructivism.

Quantitative research is based on mathematical or statistical techniques [188] and [189]. With qualitative research, mathematical models, hypotheses or theories are developed or utilised in the study [190]. Quantitative research is typically used across multiple environments including economics, population studies, science, marketing, health services, education, political science and so on. Application typically derives from the positivism philosophical branch. It is becoming common throughout the research community to use approaches which combine both quantitative and qualitative methods. Qualitative methods may for example be used to study and interpret conclusions produced by quantitative methods. In another sense, quantitative methods may actually be used to evaluate qualitative study outcomes. In any case, put together, the duo is referred to as the mixed methods research.

The concept of 'mixed methods' refers to a research methodology that integrates both quantitative and qualitative data within one investigation or study [191]. This mixed methods approach allows a more comprehensive and a deeper overall utilisation of data, than the quantitative and qualitative methods [192]. The mixed methods approach is utilised for this study because the design of the research is one that collects industry data and then analyses the data quantitatively and qualitatively in order to determine parameters to improve alignment of curriculum to industry need. On the data analysis side, the industry needs are quantised and translated to numerical distributions of need across multiple curriculum elements. On the data collection side, a database of job advertisements posted on-line is analysed and interpreted to deduce industry skill dynamics.

In this study, the pragmatism paradigm is adopted. The pragmatic paradigm as a world-view, focuses on that which works, rather than that which may be considered as definitely true [193]. With the pragmatic world-view, there is a general sense of rejecting the idea that facts or truths about the real world can be resolved by utilising a single scientific method [194]. Pragmatism argues that the truth can in fact be judged by consequence. In terms of research design therefore, the pragmatic paradigm is considered useful in establishing research design guidelines especially in cases where studies combine different approaches [195]. With the birth of the mixed methods research approach, need also arose to establish philosophical legitimacy of the approach. While pragmatism, as a philosophical support for the mixed methods approach, has seen some criticism from researchers, with recent and improved understanding, justifications have been presented across literature, for the reference of pragmatism in mixed method studies [196]. The general view of criticism is the vagueness in addressing some of the inconsistencies between assumptions of the quantitative and qualitative paradigms. Most recently and more commonly, researchers have considered the pragmatism paradigm to be a fitting philosophical justification for the approach of mixed methods [197] and [198].

In this study, the baseline is that practicality of the research outcome is of great significance. A strong case for the proposed curriculum management approach (curriculum decomposition) can be made if the approach provides better curriculum outcome alignment to industry demands. To complete this study, a deductive approach is taken, with interpretive analysis to examine job advertisement posts available on-line. From this job advertisement examination, curriculum details are deduced, with reference to some standing engineering guidelines. Data collection is carried out by the means of a survey. The survey is supplemented by an observation-type method of consolidating and classifying some primary characteristic information which reflects the skill needs of the industry. This information is collected directly from job posts available on relevant on-line job advertisement platforms.

This chapter revisits Section 3.2 to answer the question of what industrial engineers do, now that the question of where the industrial engineers work has been answered. In this chapter, the design algorithm for the curriculum management system is also discussed, as well as the utilisation and evaluation of the system. In Chapter 3.5, curriculum was proposed, from some literature survey outcomes and also from the IE work opportunities in South Africa. This chapter presents the management system that maintains this proposed curriculum autonomously.

4.1 Curriculum management

In Section 1.5, it has been discussed that this work examines the possibility of implementing a rigid-skeleton flexible-body approach, where the industrial engineering curriculum assumes a rigid architecture but with some degree of flexibility in the curriculum components, to allow manipulation according to the needs of the industry. This leads to the question, how should curriculum be manipulated, what aspect of curriculum must be manipulated?

4.1.1 Conventional

Conventionally, curriculum is managed through an Assessment System, where a committee of some select staff members convenes, gathers feedback from multiple stakeholders, critically analyses the feedback, and then develops and implements strategies to effect findings.

4.1.2 Curriculum management system

This work proposes an autonomous approach to curriculum management. This means that an intelligent system processes feedback from stakeholders and gives some recommendations.

4.1.3 Curriculum manipulation

It was highlighted in Section 1 that globally, curriculum redesign and optimisation is rapidly taking centre stage. Rendong [199] highlights that curriculum management should view curriculum as being interdisciplinary and systematic. Curriculum manipulation can therefore be considered as having two possible approaches:

1. Primary curriculum manipulation (molecular).

2. Secondary curriculum manipulation (atomic).

Primary manipulation, which is most common, is characterized by adjusting curriculum on a course-by-course basis (molecular level), for example by adding or removing topics or elements that constitute a particular course. Primary curriculum manipulation systems over the past two decades have in fact gained massive popularity, with recent focus on curriculum liberalisation, characterised by more freedom of choice for learners in composing programmes for oneself [200], and today, several such curriculum management systems are available, most customised to each university. In this context, curriculum management therefore sets out to create, arrange and organize study content with the aim to academically equip students to achieve some set targets. Given the integral nature of curriculum though, this paper proposes secondary curriculum manipulation, a more meticulous and holistic approach which is characterized by atomizing the entire program curriculum into certain key elements (curriculum elements). These elements are then manipulated at element level. The motivation is that curriculum courses are interrelated, with common elements across different courses thus atomic curriculum manipulation is expected to improve curriculum management. Secondary manipulation is selected for this work because secondary manipulation gives more control over the overall curriculum, taking into account the fact that curriculum is interdisciplinary and interconnected.

4.2 System input and output

As with any system, the curriculum management system discussed in this work has some input and some output. It therefore makes sense to outline the input and output of the system, before discussing the design. The Figure 4.1 depicts the structural diagram of the curriculum management system.

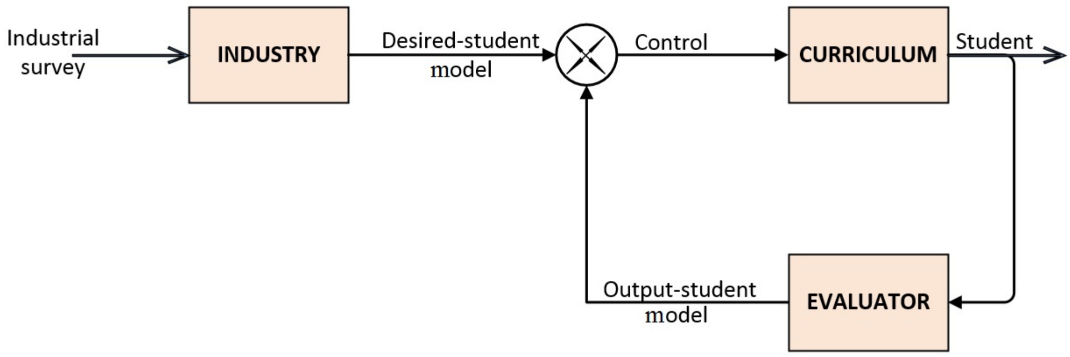


Figure 4.1: Conceptual structural model of the curriculum management system

Figure 4.1, it is shown that some input data is required from industry to create some 'desired-student model'. This model is then compared against some 'output-student model' which represents the graduate. In this way, it is possible to determine the relationship between the two models in terms of alignment or misalignment.

4.2.1 Input

Data is collected to model the requirements of industry. The survey method is used, through an observation approach, to consolidate some primary information of the needs/requirements of the industrial engineering profession from job advertisement platforms. Industry requirements are the primary goal to be satisfied, if logic should be used in the sense that, if IEs can meet the industry requirements, the engineers will be able to take on jobs and projects in the field and excel their careers.

Primary data of the needs/requirements of the industry is collected from job postings listed on job advertisement platforms, on-line. The analysis of job advertisement to influence curricula has been investigated in such work as that of Pitukhin et al [145] which processes requirements of employers into curriculum guide. In particular, [145] presents findings to the effect that the ICT industry actually demanded 75 percent of competencies in the form of practical knowledge and only 25 percent in theory. In [201], job advertisement analysis is also used for skill extraction.

In this work, the neural network is trained with input data captured from on-line adverts, in terms of each industry need. As an example, the 'business management' industry need, is mapped to the curriculum elements such as supply chain, economics, communication, human resources, resource management and sustainability. The input is therefore the industry need, which is 'business management' in this case.

While this approach allows collection and manipulation of real data from industry, as it is, this approach would not be sufficient in comprehensively modelling the requirements of industry. In Section 3.2, it was noted that the destination for graduating IEs is employment and entrepreneurship. The industry needs should therefore not be modelled solely on the basis of employment data while ignoring the element of entrepreneurship. In this work, the curriculum management system to be developed is set to account not only for employment industry-requirement input data, but entrepreneurship data as well. This leads to a new question, to say, to what extent does industrial engineering entrepreneurship contribute to the overall industrial engineering space? How far should the curriculum go in preparing students for entrepreneurship? This is discussed in Section 4.4

4.2.2 Output

The input data is processed to produce some output. The output is an indication of which elements of the industry engineering curriculum require more or less attention so that graduates obtain adequate skill to navigate the engineering environment. The output of the system shows how the various elements of the curriculum relate to the state of the industry. The output is characterised by a list of the key curriculum elements, according to each industry need. As with the example stated earlier, of the 'business management' industry need, the output is therefore such curriculum elements as supply chain, economics, communication, human resources, resource management and sustainability.

In modelling the curriculum management system, input and output data is collected from both employment and entrepreneurship requirements. This is discussed in Section 4.3 and Section 4.4, which make use of practical cases to elaborate the data manipulation.

4.3 Employment data

Data to model the IE skill/expertise requirements, according to the state of the industry, is collected from on-line job advertisement and recruitment platforms.

Several examples (cases) are considered, for example the first case discussed in Section 4.3.1.

4.3.1 Case 1

The first case is a posting seeking to recruit an industrial engineer at a logistics company. The position summary states that the incumbent is responsible for the planning of the utilisation of assets (personnel included), to improve efficiency of operations, and to establish work measurement programs. The job functions are listed as:

1. Evaluate overall staff and individual performances.
2. Train senior staff on operational procedures.
3. Analyse and improve the workforce and asset utilization.
4. Develop and recommend systems to improve workforce and asset utilization, and reduce waste.
5. Execute cost analysis, with the aid of engineering templates.

From the information presented above, it is possible to extract meaningful curricula information, that is useful in modelling systems, especially those that relate to human thinking. This is the point where the concept of atomisation of curriculum is detailed. When hundreds of such job advertisements are analysed, it becomes possible to draw up trends. The next section details the conversion of advertisement information into curriculum information.

4.3.2 Curriculum decomposition

The decomposition (atomisation) of curriculum aspect is pivotal to realising the objectives of this study. The question is as follows; how can job functions be interpreted into micro-curriculum elements (atoms)?

The idea is to first convert each job function into some curriculum activity/activities (that is to say some curriculum molecule/molecules), then convert each activity into topics, that is to say atoms. As an example, the job function given as ”evaluate overall staff and individual performances” is converted into the curriculum molecule ”staff evaluation” which is in-turn converted to some curriculum atoms such as ”performance evaluation, data management, research skills, human resource management", which represent diverse curriculum elements, some of which will be common across multiple course. The delicacy of these conversions call for a systematic atomisation approach, in order to achieve acceptable conversion accuracy. In this study, the conversion is guided by:

1. reference to engineering handbooks:
   (a) industrial engineering handbook, [117]
   (b) general engineering handbook, [202]
2. industrial engineering training guides:
   (a) Discipline-Specific Training Guide for Engineering Technicians in Industrial Engineering, [134]
   (b) Discipline-Specific Training Guide for Engineering Technologists in Industrial Engineering, [135]
3. intuition

A criterion is developed, justified and implemented as a way to guide and standardise the process of atomisation of curriculum. The approach taken is to give precedence to the guidelines provided by the industrial engineering manual in the atomisation process, then using the training guide to refine the atomisation, and then finally intuitively aggregating the output. This criterion is depicted by Figure 4.2.

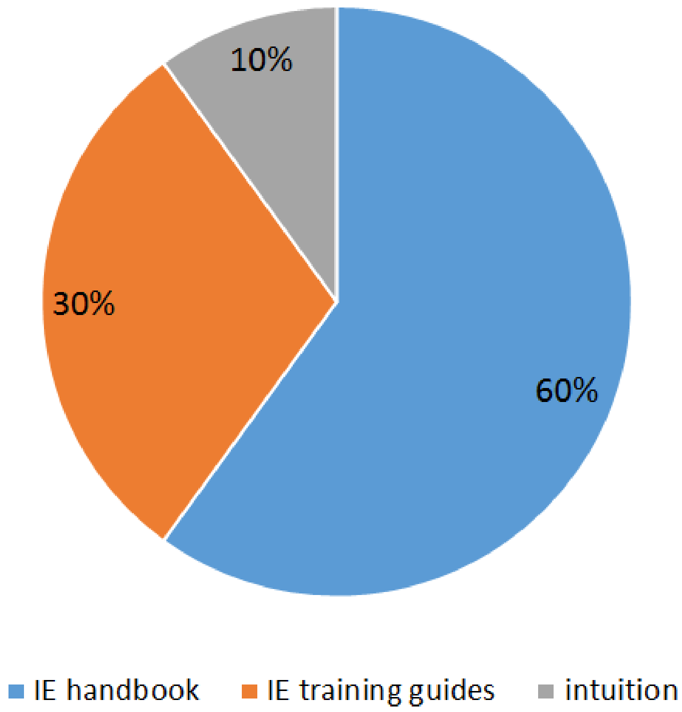


Figure 4.2: Proposed decomposition criterion

The reason supporting this criterion is that the handbooks, particularly the industrial engineering handbook, comprehensively provides a detailed outline of various aspects surrounding industrial engineering, from both the professional and qualification perspectives. An element of intuition is however required, for the purpose of contextualisation. With the information available and the guidelines set, it is possible to establish the industry needs presented by each job advertisement, at molecular and decomposed levels.

4.3.2.1 Illustration of decomposition

From the first case study, Section 4.3.1, the corresponding key micro-curriculum elements and respective molecules are given as:

Staff evaluation: Performance evaluation, data management, research skills, human resource management

Staff development: Management of staff, training and capacity building, quality

Process evaluation: Data management, research skills, engineering standards, system modelling and simulation

Labour optimisation: Optimisation theory, system modelling and simulation, operational research, research skills, data management, human resource management, ethics in engineering, occupational health and safety, welfare, technical evaluation, engineering work study

Resource optimisation: Optimisation theory, system modelling and simulation, data management, operational research, research skills, management practice, finance, risk, quality, supply chain, planning, scheduling, sustainability, security

Process optimisation: Optimisation theory, system modelling and simulation, data management, operational research, research skills, planning, scheduling, sustainability, engineering standards, drawing interpretation, lean principles, inter-disciplinary learning, inter-faculty learning, engineering work study, management practice, finance, risk, quality, supply chain

System development: Data management, research skills, planning, system modelling and simulation, creative design

Cost optimisation: Optimisation theory, system modelling and simulation, dynamic programming, data management, operational research, research skills, management practice, finance, risk, quality, supply chain, management accounting, economics, accounting for engineers, budgeting, planning, scheduling, security, sustainability

For all cases, basic curriculum elements such as English language, physics, chemistry, mechanics, mathematics and so on, are not be listed. This is because such elements are standard.

4.3.3 Analysis of case 1

The Table 4.1 below gives a summary of the key curriculum elements that are derived from the industry needs of case 1. This summary provides a ranking of the knowledge scope.

Table 4.1: Summary of case 1 curriculum elements

data management	7	sustainability	3	lean principles	1
research skills	7	engineering standards	2	creative design	1
syst modelling & simulation	6	supply chain management	2	inter-disciplinary learning	1
quality management	4	security	2	inter-faculty learning	1
optimisation theory	4	performance evaluation	1	engineering work study	1
operational research	4	training and development	1	supply chain management	1
planning	4	ethics in engineering	1	budgeting	1
HR management	3	occupational health&safety	1	management accounting	1
management practice	3	technical evaluation	1	economics	1
financial management	3	engineering work study	1	accounting for engineers	1
risk management	3	drawing interpretation	1		
scheduling	3				

The ranking is obtained by summing the individual elements associated with each given curriculum activity (or molecule). It is shown that the posting of case 1 translates to the above listed curriculum elements. That said, the curriculum elements 'data management' and 'research skills' carry the most weight, as indicated by the frequency. The main reason behind this fact is that, because of the diverse span of industrial engineering job duties (spreading from the medical field even to aviation and other complex fields), there is critical need for advanced research skills in order to quickly and adequately master unique job demands; and research involves intensive data management. Looking deeper into case 1, the incumbent is responsible for planning of the utilisation of assets to improve efficiency of operations of a unique company with unique operational procedures, equipment/machinery as well as personnel. To fit into this position, the incumbent therefore requires first class research skills to understand the business process and recommend/develop the most suitable systems for the improvement of the business processes. As for the industry needs, case 1 presents the following: (1) staff evaluation, (2) staff development, (3) process evaluation, (4) labour optimisation (5) resource optimisation, (6) process optimisation and (7) system development. The synopsis of the second case is presented in Appendix B.

4.3.4 Multiple cases

As more cases are considered, data from each new case is merged with already available data. First, case 1 and case 2 are merged. The Table 4.2 gives a summary of the key curriculum elements that are derived from the industry needs of both case 1 and case 2, combined.

Table 4.2: Summary of case 1 and case 2

research skills	11	risk management	3	ethics in engineering	1
data management	7	scheduling	3	occupational health&safety	1
sys modelling&simulation	7	drawing interpretation	3	technical evaluation	1
sustainability	7	innovation	3	engineering work study	1
planning	6	oral skills	3	engineering work study	1
engineering standards	6	supply chain management	2	supply chain management	1
quality management	5	security	2	creative design	1
operational research	5	lean principles	2	management accounting	1
inter-disciplinary learning	5	budgeting	2	economics	1
inter-faculty learning	5	computer aided design	2	accounting for engineers	1
optimisation theory	4	design simulation	2	design analysis	1
creative design	4	metrology	2	manufacturing processes	1
written skills	4	problem solving	2	marketing	1
HR management	3	performance evaluation	1	engineering ethics	1
management practice	3	training and development	1	oral skills	1
financial management	3			legal factors	1

Table 4.2 shows that 'research skills' is the most prevalent curriculum element, with the same explanation and reason as given in Subsection 4.3.3. Two cases are however not enough to draw any meaningful conclusions.

4.3.4.1 Two hundred cases

The next step is to consider two hundred cases. The Table 4.3 gives a summary of the key curriculum elements that are derived from the industry needs from two hundred cases, including case 1 and case 2. This summary though, is consolidated manually, while the overall system automates the entire process.

Table 4.3: Skill ranking for two hundred cases

concept design	910	inter-disciplinary learning	570	facility layout	133
research skills	905	inter-faculty learning	570	reasoning	120
management practice	882	problem solving	524	reverse engineering	118
sys modelling&simulation	810	lean principles	478	ethics in engineering	99
optimisation theory	806	performance evaluation	444	accounting for engineers	92
data management	802	training and development	423	marketing	88
engineering standards	788	workflows	402	software development	79
financial management	755	risk management	319	negotiation	75
creative design	752	innovation	310	metrology	71
planning	744	written skills	299	supply chain management	67
HR management	740	oral skills	287	renewable energy	58
operational research	688	engineering work study	281	leadership	56
sustainability	652	budgeting	236	entrepreneurship	54
computer aided design	638	office skills	195	security	47
design simulation	632	manufacturing processes	192	economics	46
management accounting	630	automation	188	technical evaluation	45
drawing interpretation	618	scheduling	144	waste management	42
creative design	604	occupational health&safety	136	ergonomics	41
quality management	598			legal factors	40

At this point the top curriculum element is 'concept design', and accordingly, the explanation is that industrial engineering critically demands the incumbent to develop systems, processes, standards and specifications for various purposes. This requires strong competencies in understanding concepts and in designing or optimising concepts. Also high on the list, is 'research kills', already explained and justified.

The element of 'management practice' also appears high on the list as well, because industrial engineering jobs generally include management of resources, operations, processes, finances and so on. That of 'system modelling and simulation' appears high on the list as well because this element forms a critical pillar as industrial engineering work is heavily populated by tasks relating to the development or optimisation of various systems, and this requires modelling and simulation. Most industrial engineering tasks also involve improvement of systems or processes hence 'optimisation theory' also appears high on the list.

4.4 Entrepreneurship data

Data to model IE needs is also taken from freelance platforms to set out the unique requirements of the entrepreneurship industry. In Section 3.2.2.1, several freelance cases were discussed. Deficiencies in the curriculum in addressing IE entrepreneurial needs were also highlighted. The question to ultimately be answered is that, to what extent should entrepreneurial needs be allowed to affect the curriculum, through the curriculum management system? To answer this question, an understanding of IE entrepreneurship scope is required.

4.4.1 Characteristics of entrepreneurship

Before determining the scope of graduate entrepreneurship in industrial engineering, we discuss first, the characteristics of the entrepreneurship. The idea is to establish viability of the entrepreneurship path and to determine whether the industry (economy) has substantial need/demand for industrial engineering entrepreneurship.

4.4.1.1 Volumes of projects

The first characteristic analysed is that of the volume of jobs/projects available for the industrial engineering freelancers/entrepreneurs. The questions presented are; how much work is generally available and what are the trends? For this analysis, a ten-month purposive sample is selected from on-line freelance advertisement, which captures advertisement posts on a month-by-month basis for a single platform. For each month, only the first week (first seven days) are considered. The numbers given therefore reflect only projects posted within the first seven of the particular month, and can be projected on to the monthly scale as required. Figure 4.3 depicts the volumes of projects posted over a ten month period.

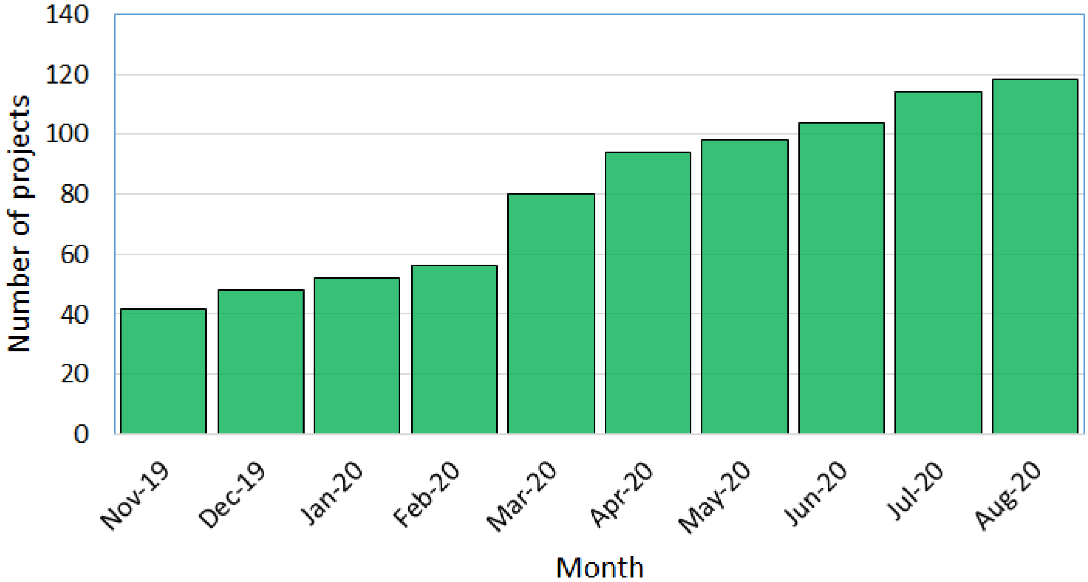


Figure 4.3: Volumes of freelance projects (from survey)

Figure 4.3 shows continuous increase in the number of freelance projects posted, from November 2019 to August 2020. While the increase may have been contributed to the global COVID-19 pandemic which drove most commerce electronic, the increase reflects positively on the viability of industrial engineering freelance in terms of work opportunity.

4.4.1.2 Job success

Having seen growth in the volumes of work and projects available for freelance industrial engineers, the next step is to analyse the job success rate of the engineers. The idea is to estimate how difficult or simple it is, to actually secure work and earn income. To do this, we revisit the selection of profiled industrial engineers discussed in Section 3.2.2.2 with the aim to find out how many have successfully completed projects and how many have not. Figure 4.4 depicts the performance of the profiled freelancers in terms of those with dead profiles and those with active profiles.

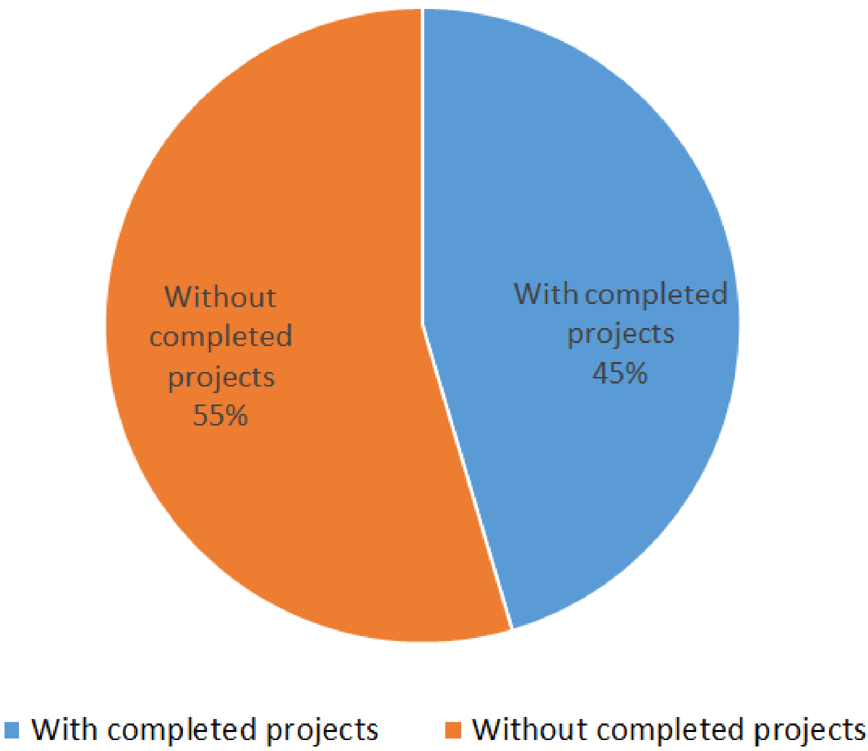


Figure 4.4: Job success (from survey)

It is shown that more inactive profiles exist (have not completed any project) than active profiles. Dead profiles constitute 55 percent. Further analysis shows that of that with active profiles, the following are common:

1. The profiles are strong, most including portfolios showcasing some designs or samples of engineering work.
2. Having completed the first and second projects, subsequent projects become seemingly easier to secure and complete.

This means that, if curriculum is structured to ensure that students graduate having created competitive profiles on an on-line freelance platform and having completed a few projects, the freelance potential for the student is substantial.

4.4.2 Distribution of demand

In this section, the distribution of the now proven demand for industrial engineering services, is examined. The entire spectrum of engineering disciplines is analysed. In simple terms, we establish the distribution of jobs across all engineering disciplines, according to industry demand. The Figure 4.5 illustrates the distribution of projects/jobs taken over a sample of 200 postings.

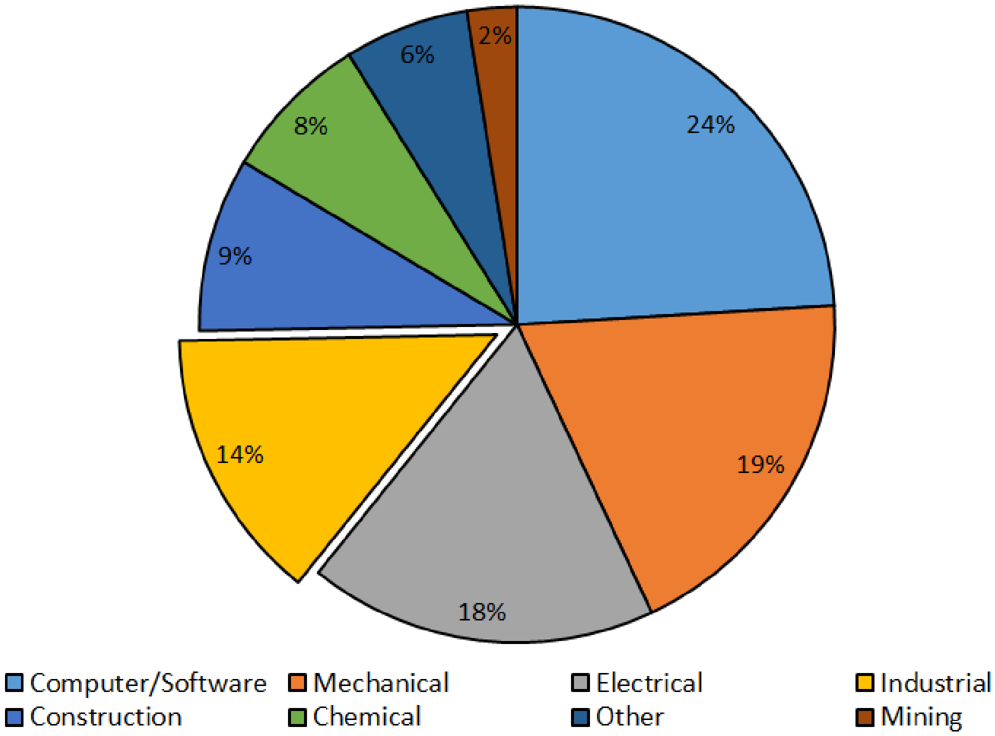


Figure 4.5: Distribution of engineering demand (from survey)

From Figure 4.5, approximately 13.9 percent of engineering freelance projects posted were related to industrial engineering. From a total of 200 projects postings of the day, 14 percent were of industrial engineering. This shows that industrial engineering work composition is fairly high, and presents optimism for IE job seekers. The number of projects however, gives no useful measure of scope of entrepreneurship in industrial engineering, without deeper understanding of the type of projects represented by the numbers, the skill requirements as well as the respective financial perspective. These factors are therefore investigated.

4.4.2.1 Project type

The aspect of project type is discussed in terms of whether a given project is short-term or long-term. As with employment contracts, long-term projects are preferable to the industrial engineer because of the security provided by such projects. The Figure 4.6 presents an analysis of project lengths, given 200 cases of project postings.

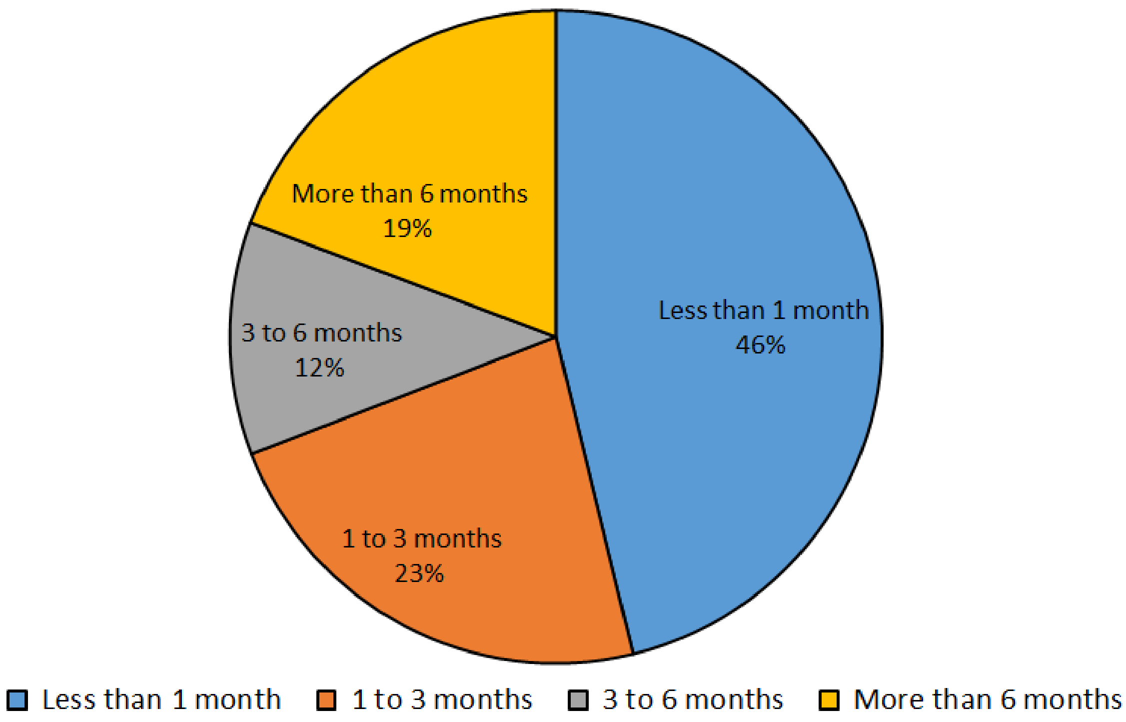


Figure 4.6: Project lengths (from survey)

Information regarding the project length is picked up from the advert, which states the lead-time associated with each job, as required by the job owner. It is shown that 46 percent of the 200 IE projects are actually short-term projects, less than one month in length. These projects typically involve design tasks, most demanding completion within a few days. The long term projects (more than 6 months) constitute 19 percent, with some stretching even to one year in length.

4.4.2.2 Skill level

The Figure 4.7 presents an analysis of the skill level requirement from the 200 cases of IE project postings. Each job advert carries a field which states the skill level that the job owner requires for the job. By analysing this information for all the adverts, it is possible to draw some conclusions from the data.

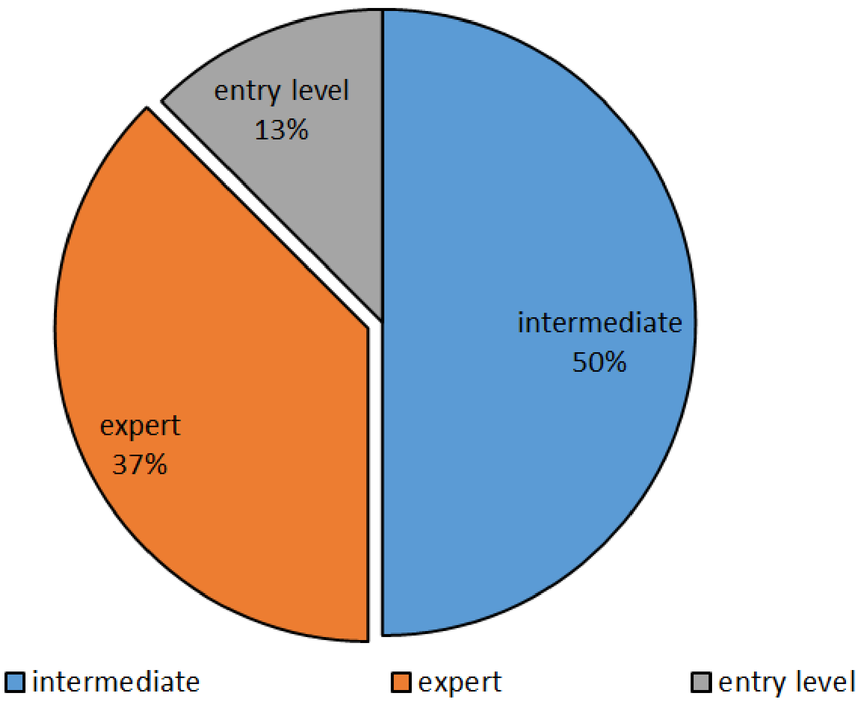


Figure 4.7: Skill level requirement (from survey)

This illustration shows that 50 percent of the IE project owners require intermediate skill level, for the completion of a project. This skill level typically translates to engineers with between one and five years of work experience. The graduate IE however, typically falls into the entry level bracket, which according to Figure 4.7 shrinks opportunity for the graduate to only 13 percent of the IE projects.

In this work, it argued that it is possible to widen the horizon of the graduate from 13 percent to 63 percent (13 plus 50 i.e. entry-level plus intermediate skill), purely from curriculum manipulation. It helps therefore, to study the opportunity horizon of the graduate in two parts; 'series A' (*13 percent opportunity horizon*) which speaks to a graduate without strong entrepreneurial curriculum exposure, and 'series B' (*63 percent opportunity horizon*) which speaks to that graduate with strong entrepreneurial curriculum exposure.

4.4.2.3 Financial perspective

This section investigates the financial perspective of the different IE projects considered. This investigation is useful in estimating the financial sustainability of the IE projects as viewed by the entrepreneur, and is illustrated by Figure 4.8. Each job advert has a price attached, indicating how much the job owner will pay for the work done. For better interpretation, the finances are translated from a project basis to a projected-monthly-income basis. This translation is made possible by the job turn-around-times which are indicated for each job.

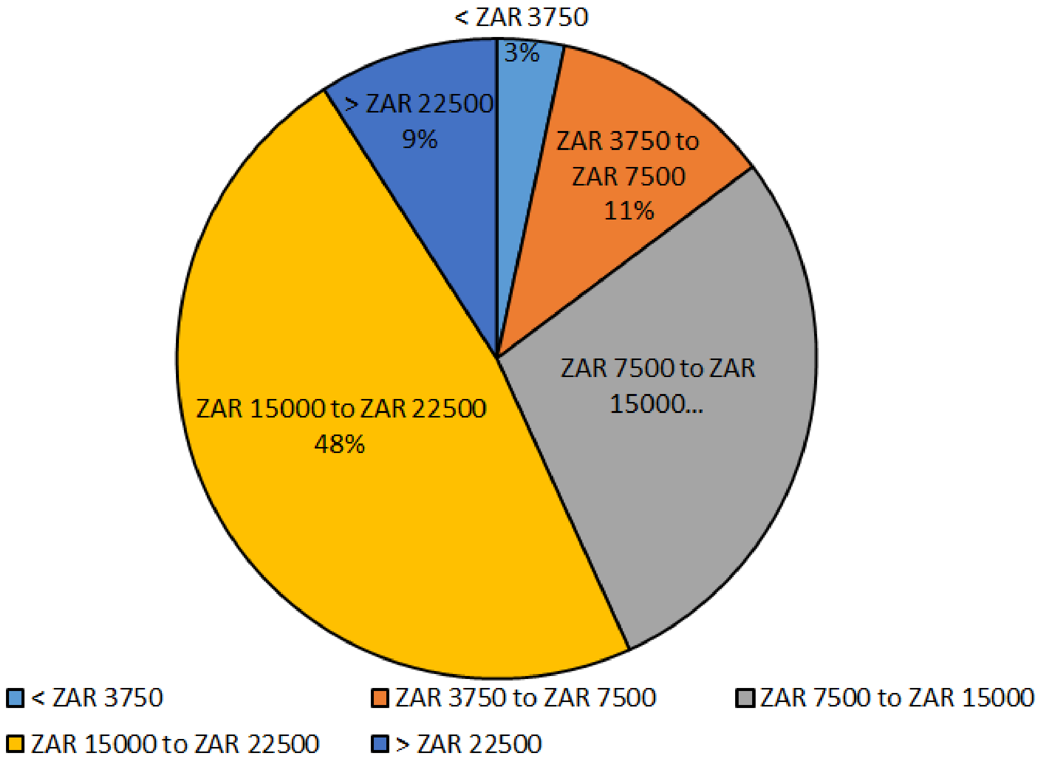
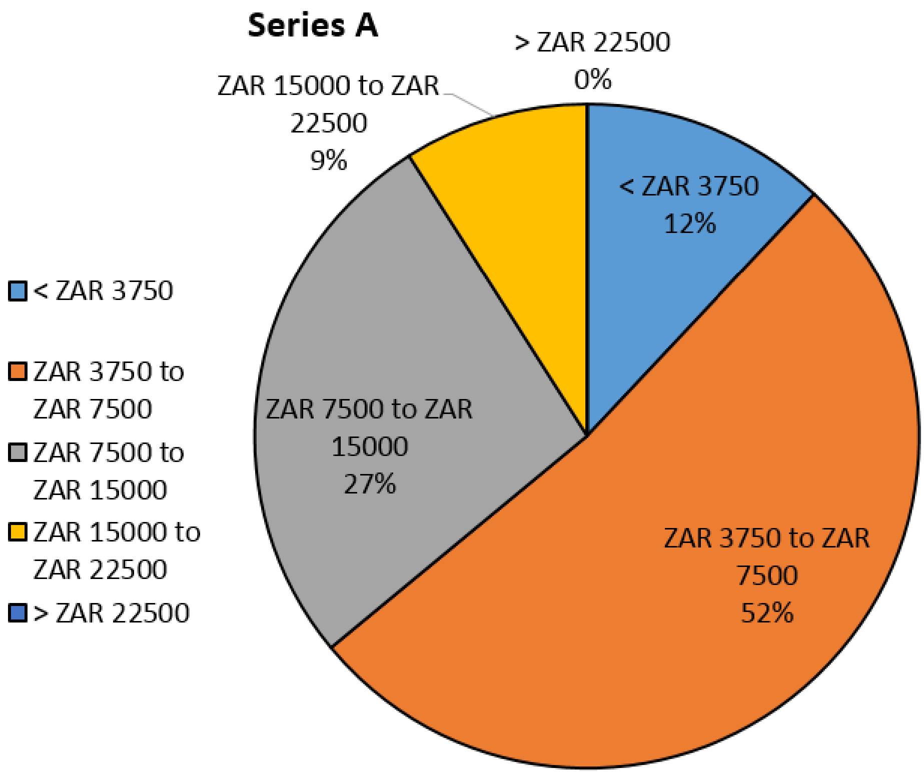


Figure 4.8: Overall financial perspective

It is shown that, in the general sense approximately 48 percent of the 200 IE job projects will reward the freelancer between ZAR 15,000 and ZAR 22,500 on a monthly scale, from an average 30 hours per week. This is across all skill levels, including projects that demand expert skill level. For comprehensiveness, the analysis is broken down to consider the projects that are more reasonably feasible for the graduate, that is the series A and B, as depicted by Figure 4.9.



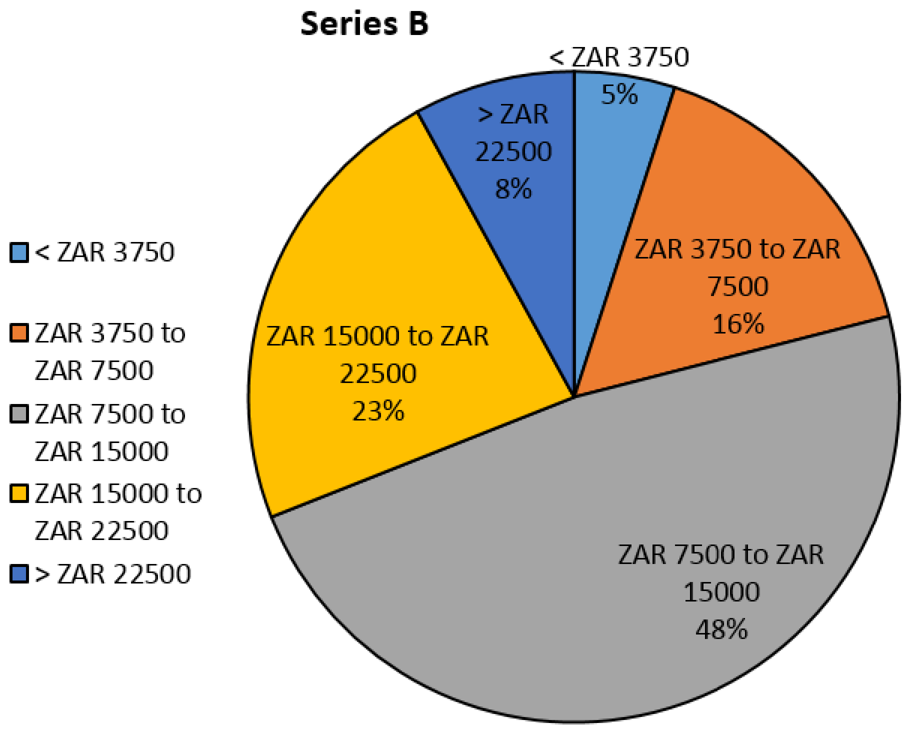


Figure 4.9: Series A and B financial perspective

It is shown that, it is possible, with some adjustments to curricula, to improve the entrepreneurial prospects of graduate Industrial Engineers significantly. To illustrate this finding more graphically, the distribution of the financial perspective is presented in Figure 4.10.

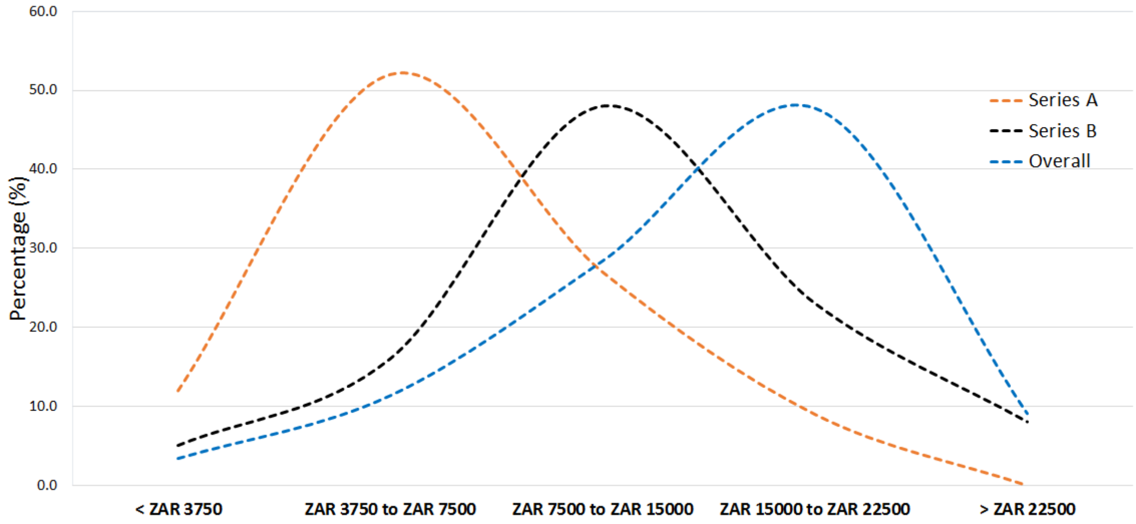


Figure 4.10: Financial perspective distribution

It is shown that curriculum can in fact shift the financial perspective distribution curve. Given the assumptions:

1. the graduate is competent and possesses the essential technical and entrepreneurial knowledge,
2. the graduate has created a compelling and comprehensive profile with strong portfolio,
3. the graduate has access to the relevant required software,

it can be concluded that if successful in securing work, a graduate IE entrepreneur will most likely secure several short-term projects/jobs, potentially earning between ZAR 15,000 and ZAR 22,500 per month. This information is however insufficient, to answer the question of the extent to which entrepreneurial needs should be allowed to affect the curriculum. To sufficiently answer this question, an evaluation is required, of entrepreneurial opportunities against employment opportunities.

To make this evaluation, 200 cases of recruitment adverts (employment) on the Indeed on-line platform are considered, for comparison against the 200 of entrepreneurship/freelance cases. The following facts are established from the employment cases:

1. All cases have offers valid for at least 12 months.
2. Only 7.5 percent of the cases are entry level (less than 2 years work experience). Intermediate skill level (2 to 8 years) calls for 85.5 percent while 7 percent of the cases demand more than 8 years experience.
3. 62 percent have a remuneration range up to ZAR 15,000 while the remaining 38 percent remunerate between ZAR 15,000 and ZAR 22,500 per month.

With this information, it is possible to compare the trends of employment opportunities with those of entrepreneurship opportunities. This comparison is summarised in Section 4.4.2.4.

4.4.2.4 Evaluation

Data to evaluate the trends of employment opportunities with those of entrepreneurship opportunities is presented in Table 4.4. The evaluation is based on a likelihood table, to say, given an industrial engineering employment or freelance job/project advert, what the odds are for the graduate engineer in either case.

Table 4.4: Likelihood table

Opportunity likelihood	**Employment**	**Entrepreneurship Series A**	**Entrepreneurship Series B**
Graduate opportunity	0.075	0.130	0.630
Contract length likelihood			
Less than 1 month	0.00	0.462	
1 to 3 months	0.00	0.230	
3 to 6 months	0.00	0.115	
More than 6 months	1.00	0.193	
Financial perspective likelihood			
< ZAR 3750	0.00	0.120	0.050
ZAR 3750 to ZAR 7500	0.00	0.520	0.160
ZAR 7500 to ZAR 15000	0.62	0.270	0.480
ZAR 15000 to ZAR 22500	0.38	0.090	0.230
> ZAR 22500	0.00	0.000	0.080

A few conclusions can be derived from the information presented by Table 4.4. The findings lead to the following hypotheses:

1. Graduate employment provides unmatched security in terms of length of the term of work, compared to freelance work which typical involves small but many projects. This is a downside to entrepreneurship.

2. However, the graduate has higher chances securing freelance work than graduate employment.

3. Graduate employment will typically guarantee the graduate monthly earnings between ZAR 7,500 and ZAR 22,500, while freelance work is more spread, stretching form as little as ZAR 1,500 to as much as ZAR 30,000.

4. Aligning the industrial engineering curriculum more strategically to promote entrepreneurship (freelancing) can increase work opportunity for the graduate fourfold. The diversity of freelance jobs further exposes the graduate to a widened range of projects thus building competence more strategically.

5. There is scope in manipulating IE curriculum to promote graduate entrepreneurship, hence entrepreneurial needs, to a large extent, should be allowed to affect the curriculum.

6. 200 posts on the entrepreneurship side were posted within a twelve-day period while the 200 of employment stretched beyond three months.

4.4.2.5 To what extent?

The question to be answered at this point is the second research question, that is to say, to what degree should graduate entrepreneurship prospects in industrial engineering be allowed affect the curriculum outcomes? The study conducted shows that entrepreneurial prospects in industrial engineering justify equal contribution to curriculum management, as with employment prospects. For this reason, the survey carried out in this study equally considers input from both employment and entrepreneurship sources.

4.4.2.6 Summary

It is noted that while the proposed curriculum management system is effective in the intended purpose of aligning curricula to industry, the system is however silent to some of the rather operational or tactical issues, which are otherwise better addressed by the conventional assessment system. These include factors such as those addressing class schedule optimisation, class distribution improvement, application process improvement, laboratory equipment adequacy and so on. This gives room for potential further improvement.

Curriculum adjustments to consider

It has been shown that with the 'suitable' curriculum, there is great potential to promote graduate employment and economic development through entrepreneurship. This 'suitable' curriculum has proposed in this work and is presented explicitly in Section 3.5.5. Additionally, an element of professional development is required in the curriculum to accompany the adjustment to promote entrepreneurship. This element ensures that graduates venturing into entrepreneurship gain some insight into professionalism, a characteristic otherwise gained through formal employment.

Now that the potential of entrepreneurship has been tabled, the next section proceeds to take a look at the entrepreneurship cases, for data collection.

4.4.3 Two hundred cases

Table 4.5 gives a summary of the key curriculum elements that are manually derived from two hundred cases of freelance posts.

Table 4.5: Summary of ranking from two hundred freelance cases

computer aided design	186	manufacturing processes	89	facility layout	29
creative design	185	drawing interpretation	76	management practice	27
product design	174	technical evaluation	74	ethics in engineering	26
problem solving	159	lean principles	66	ergonomics	22
concept design	158	metrology	52	HR management	19
sys modelling&simulation	154	quality management	47	written skills	19
product development	142	inter-disciplinary learning	45	financial management	18
research skills	140	optimisation theory	40	security	16
design simulation	134	engineering work study	39	budgeting	14
engineering standards	133	software development	38	legal factors	13
operational research	119	data management	34	training and development	12
inter-faculty learning	100	planning	33	occupational health&safety	10
innovation	99	performance evaluation	30	supply chain management	10
sustainability	97	marketing	30	economics	9

It can be observed that the top requirements from the perspective of freelance work are design oriented. Curriculum elements related to computer aided design, and design in general, therefore dominate the top of the list. It makes sense to say that strong engineering design skills are pivotal, for a successful IE entrepreneurial career. The artificial neural network is implemented to automate the process, which up to now has been executed manually.

4.5 Research design

The study of neural networks has evolved immensely over the past decades. In this work, the theory and formulae behind the Artificial Neural Network (ANN) are not presented because literature sufficiently covers both. Several books have been published, that discuss the topic of ANNs and the application of such systems, including such work as that of Nielsen [203]. ANNs go through some training (teaching) on how to solve a set of problem(s) such that the network independently solves related problems using the lessons learnt during training.

The study aims at aligning education to industry needs. In order to archive this alignment, an interpretation of on-line job advertisement posts into engineering curriculum elements that can be manipulated is required. The following assumptions are made:

1. Job advertisements posted on the relevant digital platforms are legitimate and valid.

False job postings, if listed on the job advertisement platform for any fraudulent reason, will result in the contamination of control data. This will affect the entire systematic process of curriculum mapping, consequently compromising the overall performance of the curriculum management system. In order to address this threat, an approach is taken, of cross-referencing the job posts listed on the job advertisement platform, to job post listings available on the official websites of the various employers.

2. The job summary/description provided with each job post is complete. Incomplete job details mean that data is lost before the process of curriculum mapping. This data is vital for the overall distribution of mapped curriculum elements. It is therefore critical to implement an approach where the more basic skill-set needs/requirements are accounted for by some default settings.

The neural network is made up of some layers, each layer having some neurons which receive or send information, or both. The idea is that a neuron receives some input, and if the input, after some computation, exceeds some threshold, then the neuron activates. The layers of the network are depicted by Figure 4.11.

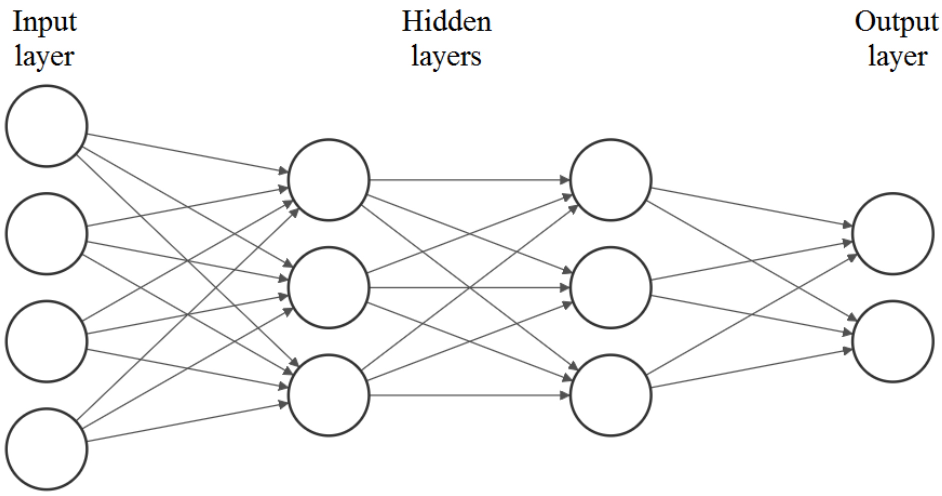


Figure 4.11: General neural network

The network comprises the *input* (input layer), which are denoted $x1$, $x2$ and so on; the *weights*, denoted $w1$, $w2$ and so on, which represent the importance of the respective inputs to the output, for each neuron (node); the *threshold*, a number which if exceeded by the computation of the sum of inputs and respective weights, gives an output of 1; and the *bias*, denoted $b1$, $b2$ and so on, which represents some 'modified' threshold, which gives a measure of how easy it is to get a neuron to activate (fire).

4.5.1 Cost function of the neural network

The aim is to align curriculum better to industry needs by teaching a neural net how to interpret job advertisements. Teaching the network involves measuring the difference between curriculum and industry needs, and then minimising this difference by minimising a cost function which represents this difference. The way the neural network works is one where the network is trained how to solve a particular problem until the network can independently solve related problems. In theory, this is realised by implementing some cost function on the difference between the set or intended outcome output and outcome given by the neural net, in terms of the network's weights and biases, and then adjusting these parameters to minimise the cost function. Figure 4.12 gives an illustration of the minimisation, to minimum.

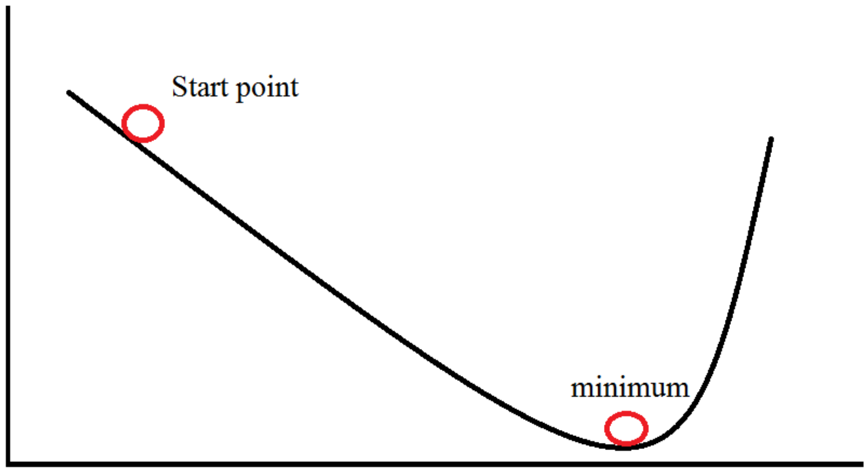


Figure 4.12: Minimisation illustration

As discussed in Chapter 2, a common algorithm to optimise this minimisation is the gradient descent optimiser, typically with a quadratic cost function as presented by equation 4.1 [203].

$$C(w,b) \equiv \frac{1}{2n}\sum_x \|y(x) - \alpha\|^2 \tag{4.1}$$

The idea is to therefore implement an algorithm to calculate a weight and bias set to minimise $C(w,b)$, such that the network output approximates to the intended outcome $y(x)$ for the full set of data x, used to train (teach) the system. From equation 4.1, w represents a weight vector, while b represents a bias vector, n represents the cumulative teaching input data entries for the network, α represents the outcome vector, while x is the input. The notation shows that the sum is in fact taken across all training inputs.

For simplicity, the cost function $C(w, b)$ can be presented as $C(v)$, with variables $v1$, $v2$ and so on, which represent the IE curriculum and the industry needs. If then, small changes are made in trying to minimise $C(v)$, for example a small change $\triangle v1$ in the $v1$ direction as well as a small change $\triangle v2$ in the $v2$ direction, the cost expression can be represented as (*the derivations that follow are referenced to [203]*):

$$\triangle C \approx \frac{\partial C}{\partial v_1}\triangle v_1 + \frac{\partial C}{\partial v_2}\triangle v_2 \tag{4.2}$$

To minimise $C(v)$, $\triangle C$ must be negative, and so $\triangle v1$ and $\triangle v2$ must be selected so as to make $\triangle C$ negative. The changes in v are therefore defined as a vector $\triangle v$ where:

$$\triangle v \equiv (\triangle v_1, \triangle v_2)^T \tag{4.3}$$

The gradient of C, which is a gradient vector denoted ∇C is then defined as a vector of partial derivatives:

$$\nabla C \equiv \left(\frac{\partial C}{\partial v_1}, \frac{\partial C}{\partial v_2}\right)^T \tag{4.4}$$

It is possible to express the change $\triangle C$ in terms of $\triangle v$ and ∇C, the gradient vector. Equation 4.2 can therefore be represented as:

$$\triangle C \approx \nabla C \cdot \triangle v \tag{4.5}$$

Equation 4.5 clarifies that ∇C represents the gradient vector, in the sense that ∇C relates changes in v to changes in C. Further, equation 4.5 also illustrates how $\triangle v$ can be selected in order to make $\triangle C$ negative. If therefore, $\triangle v$ is selected as:

$$\triangle v \equiv -\eta \nabla C \tag{4.6}$$

where η is some small positive parameter, referred to as the *Learning Rate*. Applying equation 4.5 means that:

$$\triangle C \equiv -\eta \nabla C \cdot \nabla C = -\eta \parallel \nabla C \parallel^2 \tag{4.7}$$

The fact that $\parallel \nabla C \parallel^2$ will always be greater than or equal to zero means that $\triangle C \leq 0$. In this way, C is set to only always decrease, as v is adjusted, and this is the goal of minimising the cost. So, equation 4.6 is used to calculate the value of $\triangle v$, then a move is made to the current position v on the cost function, with move magnitude:

$$v \rightarrow v' = v - \eta \nabla C \tag{4.8}$$

This rule is then used again to make another move, over and over, continuously decreasing C, until the global minimum is supposedly reached.

Gradient descent, in order to further optimise convergence, is typically upgraded to stochastic gradient descent. As discussed in Section 2.6.1, stochastic gradient descent while fairly slow, achieves higher convergence quality. To determine the gradient ∇C, the algorithm calculates gradients ∇Cx separately for each training input, x, and then calculates an average from the gradients. Stochastic gradient descent takes the approach of estimating the gradient ∇C by calculating ∇Cx for some small class or sample of randomly selected training inputs. The algorithm then averages over this small class of input sample and in turn quickens gradient descent and consequently, the learning.

In this work, the idea is to investigate the potential to further increase accuracy of the stochastic gradient descent as well as improve time efficiency of stochastic gradient descent. An algorithm is proposed to this end, and implemented on the curriculum management system developed in this work. The proposed algorithm runs on the basis of manipulation of the learning rate.

4.5.2 Learning-rate setting

It has been mentioned that the learning-rate determines the step-size taken with every iteration as the algorithm seeks the minimum of the loss function to be minimised. Generally, learning-rates set too low result in slower convergence at minima, and in fact, typically cause convergence at local minima instead of global minima, while learning-rates set too high typically cause overshooting of the minimum and may in fact cause divergence from the minimum, as illustrated by Figure 4.13.

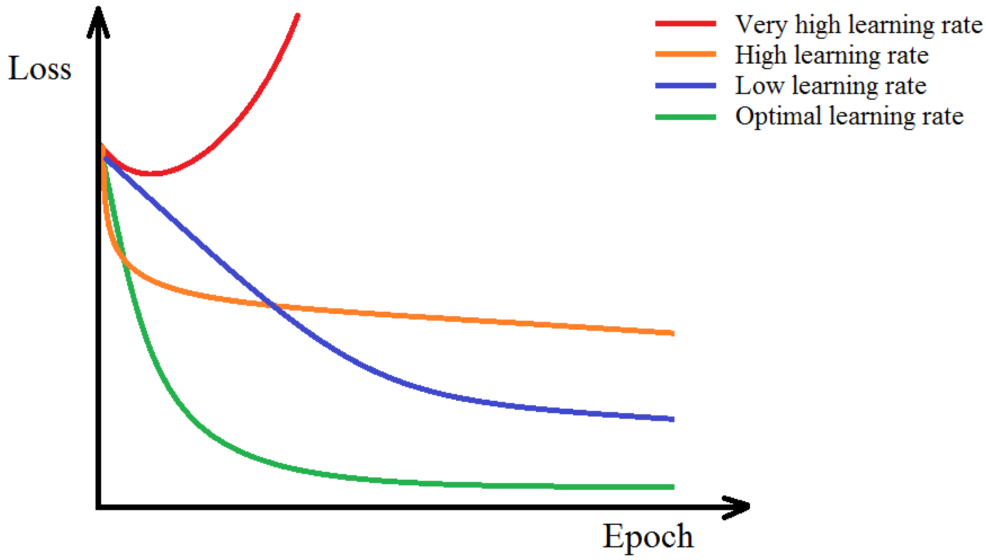


Figure 4.13: Effect of different learning rate settings

The idea therefore is to implement an adaptive learning rate, to optimise gradient descent, respective of accuracy and efficiency, measured by how difficult the network would be to train. The window-shopper approach is proposed and investigated. The window shopper is therefore evaluated to determine overall accuracy and efficiency according to how difficult or easy the window-shopper network is to train.

4.5.3 Window-shopper algorithm

To reiterate, the motivation is to develop and implement an algorithm for the curriculum management system and then evaluate to determine performance against stochastic gradient descent respective of accuracy as well as efficiency.

In this study, a window-shopping inspired algorithm is proposed. A window-shopper walks into several shops, to have a quick survey of the different options available across the board, before finally deciding which shop has the best offer. The idea is therefore to use a hopping technique, to quickly estimate the minima of the cost function. Local minima are estimated by prediction, based on a few steps taken then, once a prediction of acceptable confidence is reached, the learning rate is increased so that another point, out of the region of the determined local minimum is reached, and the process is repeated. After determining some number of minima, the least is automatically selected and optimised. This concept is illustrated, in simple terms, by Figure 4.14 where the minima estimation begins at point A, then B and finally C.

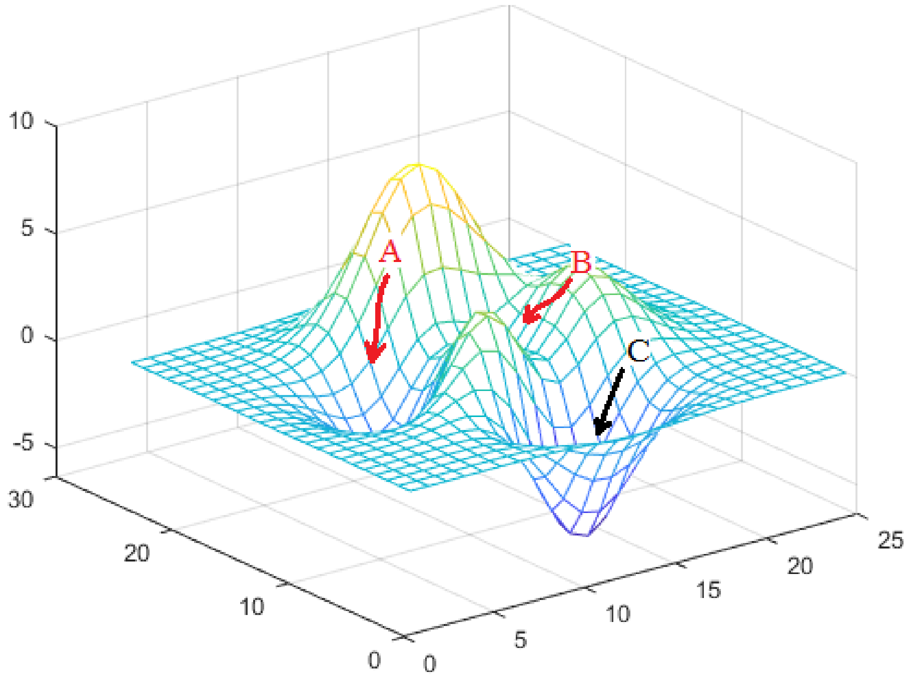


Figure 4.14: Illustration of the hopping algorithm (drawing)

Point C gives the global minimum, and is therefore calculated and optimised. The idea is to predict the minima using a few steps. Figure 4.15 shows how minima are predicted and by abstractly increasing the learning rate, how the algorithm jumps to a different zone to estimate another minimum. In reality, the cost function is much more complex, having thousands of different parameters.

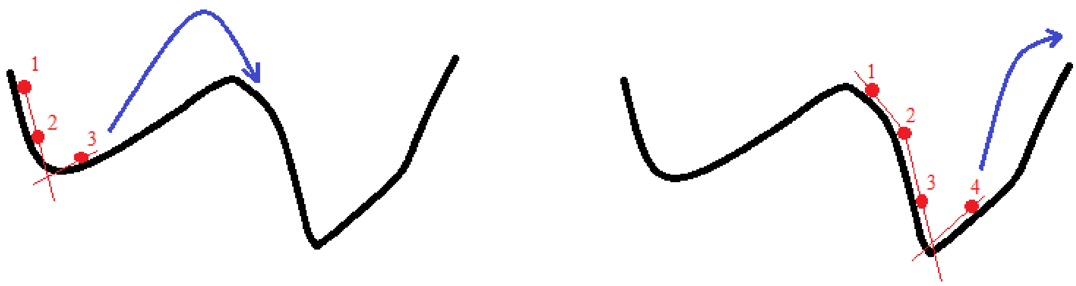


Figure 4.15: Quick minimum prediction

In this way, the algorithm is able to survey the cost function, exploring minima, before deciding on the global minimum. It is well appreciated that stochastic gradient descent is the typical technique for neural network learning, and is in fact the basis for most of the applied learning [203]. The expression for stochastic gradient can be presented in terms of the weights of the network (w) and the biases (b), with stochastic gradient descent then picking out some randomly selected training input mini-batch (m):

$$w \rightarrow w' = w - \frac{\eta}{m}\sum_j \frac{\partial C_{x_j}}{\partial w} \tag{4.9}$$

$$b \rightarrow b' = b - \frac{\eta}{m}\sum_j \frac{\partial C_{x_j}}{\partial b} \tag{4.10}$$

The idea is to adjust the learning rate so that steps taken in minimising the cost function are gradient-proportional, becoming smaller and smaller as the minimum is approached, as illustrated by Figure 4.16.

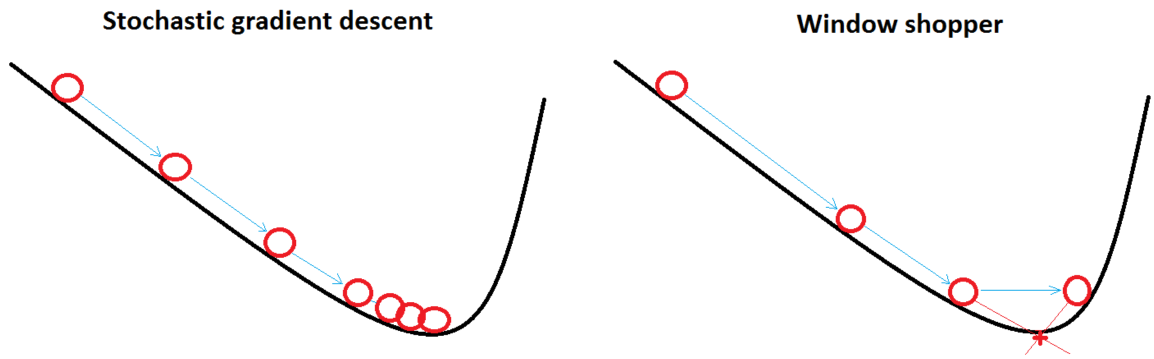


Figure 4.16: Minimisation approach

It is therefore expected for the window shopper to navigate the cost function for minima through an initial general survey of the cost function.

To implement the window shopper, a modification is made to the stochastic gradient descent algorithm, where a *Supervisor* is designed to monitor the gradient descent. The supervisor therefore represents a 'Gradient monitor', which triggers manipulation of learning-rate, according to gradient. The reasons behind the use of a supervisor include ease of implementation (typically through 'if' commands which can be programmed on existing architectures conveniently) as well as the respective flexibility of the supervisor in manipulating the learning rate.

4.5.4 Supervisor

Supervisory control is a 'switch' based control method. The method takes a mathematical logic approach to regulate the quality of a control system. This typically applies to cases where a controller designed and optimised for some particular operating point does not meet the quality requirements for other points [204]. With a control supervisor therefore, the supervisor makes decisions to switch from one controller to the other, or one control parameter to the other, based on results from processing some output and input data from the system. The typical architecture of supervisory control is illustrated by Figure 4.17.

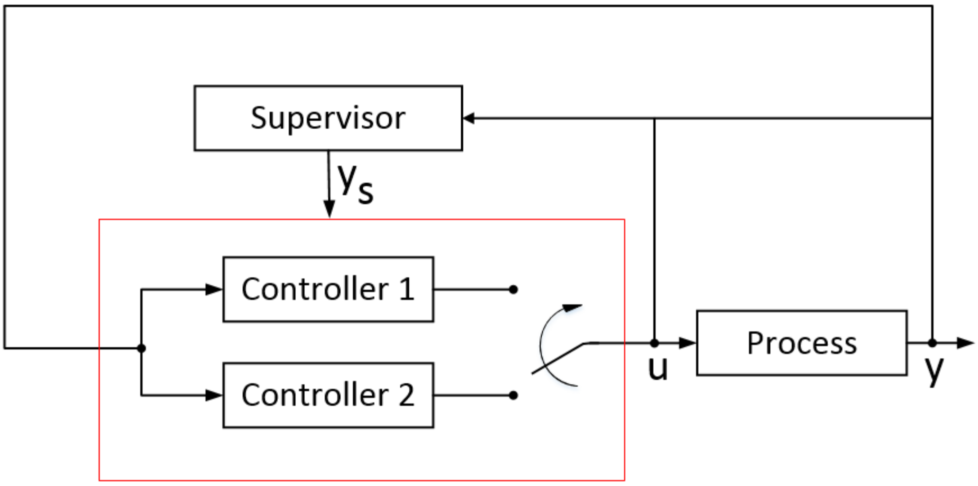


Figure 4.17: Supervision architecture

The notation u represents the control input, while y_s represents the supervisory switching signal and y represents the system output. The typical forms of supervisory control are:

1. Estimator-based supervision; which estimates a process model using output and input data, and then selects the controller to put on-line based on the estimated model.

2. Sequenced supervision; which adopts some defined sequence in switching from one controller to the other until the required performance quality is reached.

3. Performance-based supervision; which switches from one controller to the other based on system performance as indicated by some measured performance data.

For this research, performance-based supervision is implemented because the intended supervision is performance oriented, characterised by supervising the learning rate according to cost function gradient. The cost function is expressed in terms of several parameters which must be manipulated to produce a parameter-configuration which minimises the error carried by the networks output prediction. The final network for the curriculum management system comprises fifty-six outputs and thirty-six inputs, as well as two hidden layers with eighteen neurons each, giving a total of 2072 parameters (weights and biases).

To implement the network, the PyTorch library is used, mainly because of the available support for dynamic computational graphs which promotes efficient model optimisation. PyTorch supports deep learning, in an open-source manner, allowing designers to execute computations on graph-type models effectively and also efficiently. The PyTorch suite is accompanied by an application programming interface with classes that improve the design experience. Pytorch is therefore a powerful ANN development and evaluation tool, and is used across various applications, for both research and commercial purposes. Appendix D outlines the network design process. The hidden layer activation is executed by the rectified linear activation function (ReLU). this function is selected above other potential functions because the rectified function overcomes the challenge of vanishing gradient [205]. The final network structure is established by utilising the approach to initially start huge then shrink the network structure in terms of the hidden layers and the neurons there present, while monitoring performance. This approach, referred to as *dropout and early stopping*, has been proven in several contexts, including [206].

The window-shopper algorithm is designed to manipulate the learning rate by supervising cost function gradient. The algorithm seeks to establish local minima of the cost function. The algorithm is illustrated by Figure 4.18.

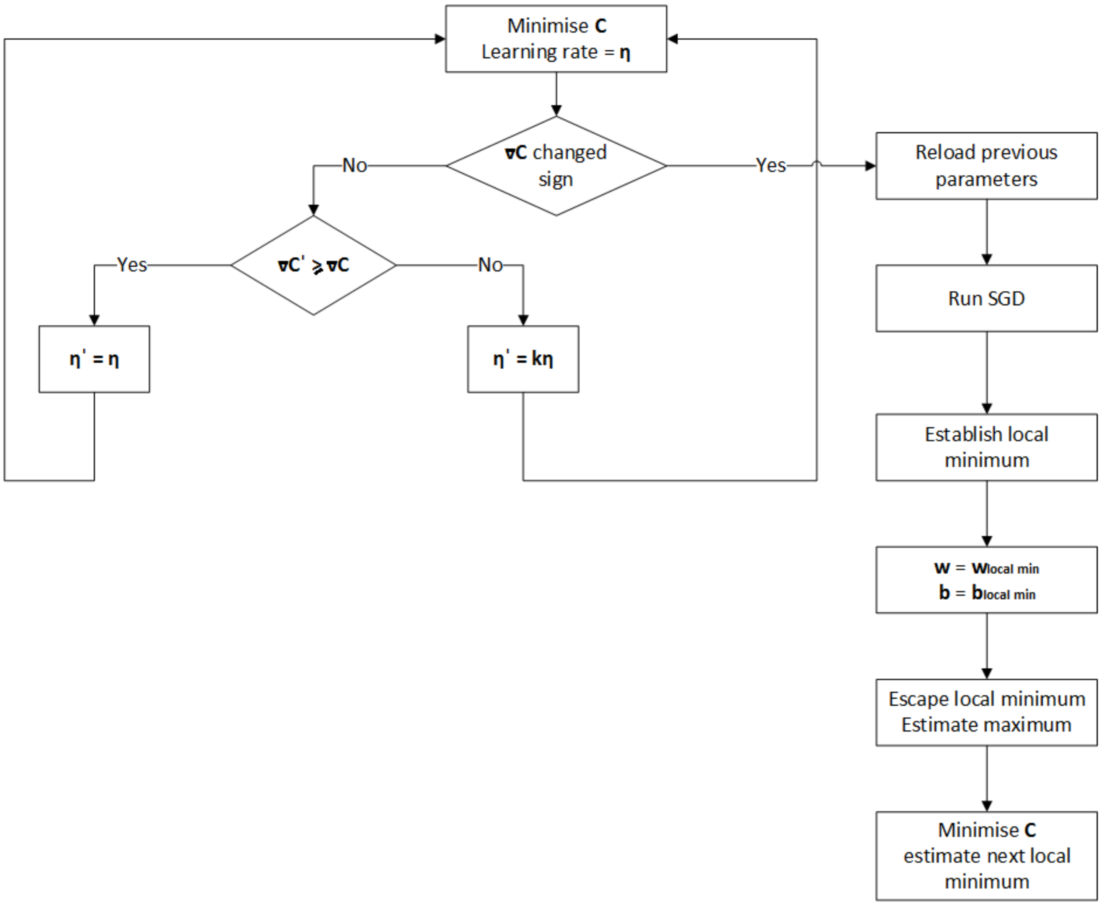


Figure 4.18: Proposed window-shopper algorithm

With this algorithm, the modified stochastic gradient descent algorithm (window-shopper) is run on the curriculum management system. The system is then evaluated for performance, against stochastic gradient descent.

Chapter 5

Results, analysis and discussion

Hypothetically, the window-shopper algorithm, being a potential improvement to stochastic gradient descent is expected to perform with better or at least equal quality. The neural network training process is a viable opportunity to evaluate the performances of the system.

5.1 First test

The first test evaluates accuracy. Initial training of the network is carried out using the data set in Section 4.4.3. This initial training attempt reveals that the window-shopper algorithm, as presented in Figure 4.18, exhibits unsatisfactory performance compared to the original stochastic gradient descent. The initial set up is one such that the neural network has no 'skip connections'. The theory behind skip connections (residual neural network) is presented in detail by Panda et al. [207], who discuss the application of skip connections towards improving accuracy during training. Skip connections generally manipulate loss function curvature (convexity), depicted by Figure 5.1.

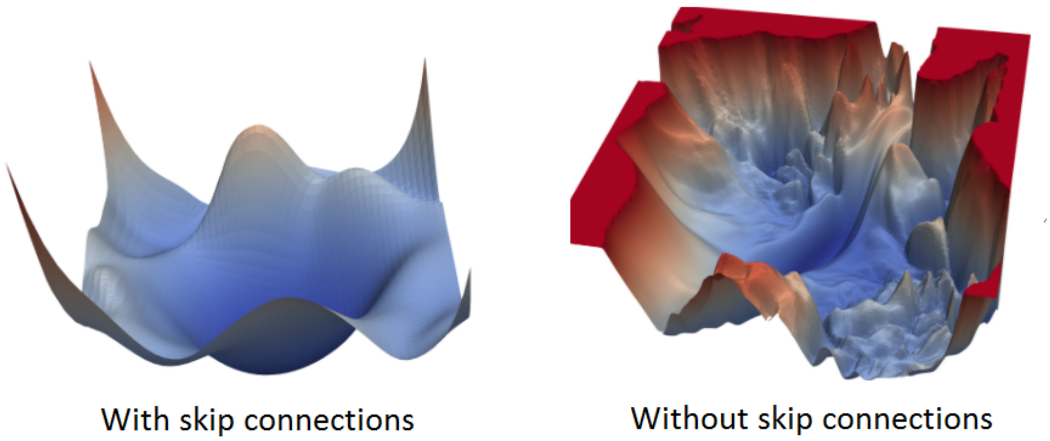


Figure 5.1: How skip connections affect curvature [207]

Simon et al. [208] also provide a detailed study of the effects of skip connections. Network architecture (skip connection or not) is proven to have an effect on the loss landscape, consequently affecting training. Skip connections result in convexification of the loss function landscape. This phenomenon is therefore investigated for the window-shopper and stochastic gradient descent case. Tests are run to establish the effect or contribution of skip connections, especially with respect to the window-shopper version of stochastic gradient descent. The reason for this test is that initial tests with the window shopper, carried out on a structure without skip connections, yield poor training results. Only until skip connections are implemented does the window-shopper version begin to yield improved results. Figure 5.2 depicts the skip connection test results.

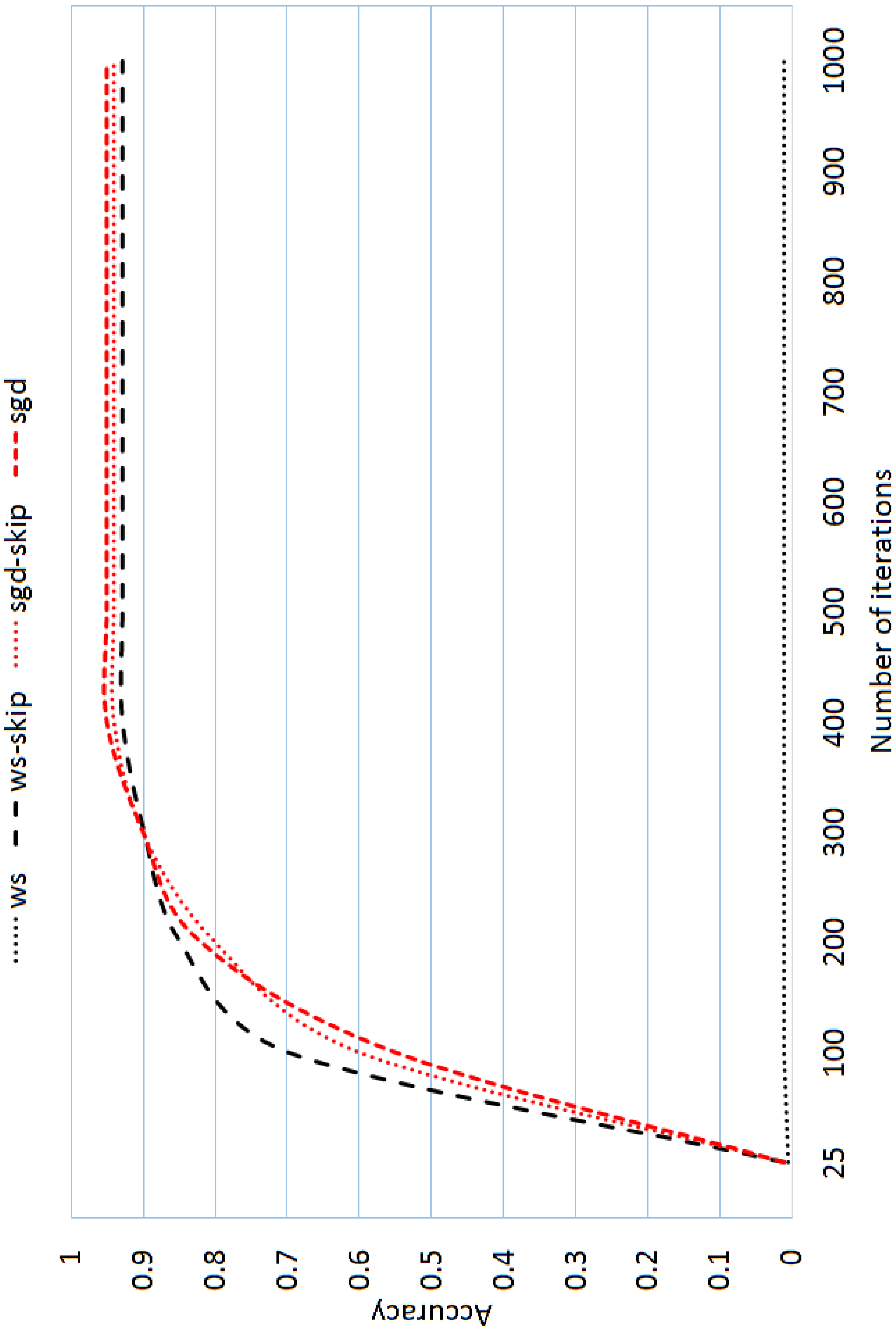


Figure 5.2: Skip connection test results

The notation ws denotes the window-shopper without skip connections, $ws - skip$ denotes the window-shopper with skip connections, sgd denotes stochastic gradient descent without skip connections and $sgd - skip$ denotes stochastic gradient descent with skip connections. It is shown that skip connections drastically improve the performance of the window-shopper, while, for stochastic gradient, skip connection have little effect on the training performance of the network.

5.2 Second test

An experiment is required, one that can potentially distinctly differentiate the performance of the window-shopper from that of stochastic gradient descent. This second test is desired to evaluate efficiency, and is based on assessing the effect of training sample. Already, Figure 5.2 shows that the two potentially perform equally. A more efficient system is one that is easier to train as this would also translate to time effectiveness. This efficiency is determined by network configuration, although, given the same configuration, the training sample size also affects training efficiency.

The curriculum management system network comprises fifty-six outputs (given in Table 5.4) and thirty-six inputs from the input of employment and entrepreneurship data. This presents a wider horizon of training possibilities. As an example, training can be on 1-case basis, where one on-line job post case study is used in a sample, for example 'case 1' of the employment data, (Section 4.3.1). For 'case 1' the training sample is depicted by Figure 5.3.

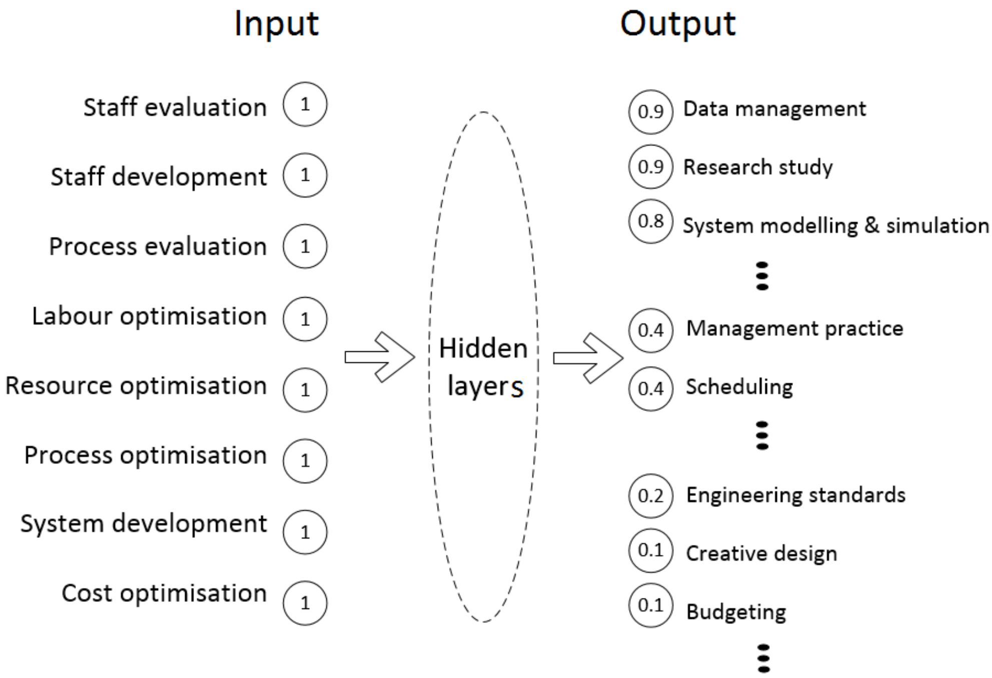


Figure 5.3: Training sample example

Having a wide range of training possibilities means that training can be on a 1-case basis, or 2-case or 50-case and so on. This presents another opportunity to contrast the two ANN designs against each other. Multiple experiments are run with different sample sizes, to determine how sample size affects system accuracy.

Determining accuracy

A uniform approach to measuring the accuracy is required across all the experiments. The approach used in this work to determine accuracy is given by Equation 5.2:

$$accuracy = \frac{correctpredictions}{totalpredictions} \tag{5.1}$$

The reason for choosing this approach is viewed in terms of the objective of the system, that is to say, the purpose of the curriculum management system. This purpose is to align curriculum to industry need, doing so by minimising the difference between the priority given to particular topics of industrial engineering within the education system and the demand of these topics in industry. The methodology therefore narrows down to evaluating the prioritisation criterion. The curriculum management system predicts the curriculum elements that need to be prioritised, in order to align education to industry need. It therefore makes sense to determine accuracy in terms of the proportion of the correct predictions.

The problem is that the comparison (calculation) is not a simple one. There is a list of fifty-six curriculum elements representing the correct (expected) element prioritisation, then a list of system prioritisation prediction as depicted by Table 5.1.

Table 5.1: Correct and predicted prioritisation - *the numerical index given for each curriculum element indicates the demand of the element, on a 0 to 1 scale*

Correct		Predicted	
concept design	1.0	concept design	0.9
research skills	1.0	research skills	0.4
sys modelling&simulation	1.0	sys modelling&simulation	0.2
creative design	0.9	creative design	0.5
engineering standards	0.9	engineering standards	0.9
management practice	0.9	management practice	0.9
optimisation theory	0.9	optimisation theory	0.8
data management	0.8	data management	0.6
computer aided design	0.8	computer aided design	0.2
operational research	0.8	operational research	0.4
planning	0.7	planning	0.6
financial management	0.7	financial management	0.7
design simulation	0.7	design simulation	0.2
HR management	0.6	HR management	0.3
sustainability	0.6	sustainability	0.9
drawing interpretation	0.6	drawing interpretation	0.4
problem solving	0.6	problem solving	0.4
inter-faculty learning	0.6	inter-faculty learning	0.9
quality management	0.6	quality management	0.2
management accounting	0.6	management accounting	0.8
inter-disciplinary learning	0.6	inter-disciplinary learning	0.1
salesmanship	0.5	salesmanship	0.8
lean principles	0.5	lean principles	0.7
performance evaluation	0.5	performance evaluation	1.0
training and development	0.5	training and development	0.3
workflows	0.5	workflows	0.8
innovation	0.4	innovation	0.0
engineering work study	0.4	engineering work study	0.4
risk management	0.4	risk management	0.7
written skills	0.3	written skills	0.5
oral skills	0.3	oral skills	0.5
manufacturing processes	0.3	manufacturing processes	0.4
budgeting	0.3	budgeting	0.7
office skills	0.3	office skills	0.1
automation	0.3	automation	0.5
facility layout	0.3	facility layout	0.2
occupational health & safety	0.3	occupational health & safety	0.2
scheduling	0.3	scheduling	1.0
ethics in engineering	0.2	ethics in engineering	0.5
metrology	0.2	metrology	0.8
reasoning	0.2	reasoning	0.7
technical evaluation	0.2	technical evaluation	0.8
marketing	0.2	marketing	0.3
reverse engineering	0.2	reverse engineering	0.3
software development	0.2	software development	0.4
entrepreneurship	0.1	entrepreneurship	0.6
accounting for engineers	0.1	accounting for engineers	0.8
supply chain management	0.1	supply chain management	0.7
negotiation	0.1	negotiation	0.7
security	0.1	security	0.9
ergonomics	0.1	ergonomics	0.7
renewable energy	0.1	renewable energy	0.3
leadership	0.1	leadership	0.7
economics	0.1	economics	0.3
legal factors	0.1	legal factors	0.3
waste management	0.1	waste management	0.9

Difference indices can be calculated systematically for each curriculum element. From the indices, accuracy can then be determined. This means that some criterion is required, to classify a particular difference index as accurate or inaccurate. The set criterion will affect the general behaviour of the developed curriculum management solution. The criterion is either set to be ”strict” or ”lenient”, or somewhere in-between. Table 5.2 outlines the implications of the two possibilities.

Table 5.2: Strictness and lenience of the classification criterion

	Implication
Strict	High overall performance accuracy; Low time effectiveness as more iterations are required
Lenient	Reduced overall performance accuracy; Increased time effectiveness as less iterations are required

In order to refine the data classification process, a relatively strict criterion is set, one which accepts a minimum pass mark of 80 percent. Table 5.3 illustrates a classification outcome, calculated systematically according to the set criterion.

Table 5.3: Determining accuracy

Correct		Predicted		Difference	Accepted
concept design	1.0	concept design	0.9	0.1	Yes
research skills	1.0	research skills	0.4	0.6	No
sys modelling&simulation	1.0	sys modelling&simulation	0.2	0.8	No
creative design	0.9	creative design	0.5	0.4	No
engineering standards	0.9	engineering standards	0.9	0.0	Yes
management practice	0.9	management practice	0.9	0.0	Yes
optimisation theory	0.9	optimisation theory	0.8	0.1	Yes
data management	0.8	data management	0.6	0.2	Yes
computer aided design	0.8	computer aided design	0.2	0.6	No
operational research	0.8	operational research	0.4	0.4	No
planning	0.7	planning	0.6	0.1	Yes
financial management	0.7	financial management	0.7	0.0	Yes
design simulation	0.7	design simulation	0.2	0.5	No
HR management	0.6	HR management	0.3	0.3	No
sustainability	0.6	sustainability	0.9	-0.3	No
drawing interpretation	0.6	drawing interpretation	0.4	0.2	Yes
problem solving	0.6	problem solving	0.4	0.2	Yes
inter-faculty learning	0.6	inter-faculty learning	0.9	-0.3	No
quality management	0.6	quality management	0.2	0.4	No
management accounting	0.6	management accounting	0.8	-0.2	Yes
inter-disciplinary learning	0.6	inter-disciplinary learning	0.1	0.5	No
salesmanship	0.5	salesmanship	0.8	-0.3	No
lean principles	0.5	lean principles	0.7	-0.2	Yes
performance evaluation	0.5	performance evaluation	1.0	-0.5	No
training and development	0.5	training and development	0.3	0.2	Yes
workflows	0.5	workflows	0.8	-0.3	No
innovation	0.4	innovation	0.0	0.4	No
engineering work study	0.4	engineering work study	0.4	0.0	Yes
risk management	0.4	risk management	0.7	-0.3	No
written skills	0.3	written skills	0.5	-0.2	Yes
oral skills	0.3	oral skills	0.5	-0.2	Yes
manufacturing processes	0.3	manufacturing processes	0.4	-0.1	Yes
budgeting	0.3	budgeting	0.7	-0.4	No
office skills	0.3	office skills	0.1	0.2	Yes
automation	0.3	automation	0.5	-0.2	Yes
facility layout	0.3	facility layout	0.2	0.1	Yes
occupational health & safety	0.3	occupational health & safety	0.2	0.1	Yes
scheduling	0.3	scheduling	1.0	-0.7	No
ethics in engineering	0.2	ethics in engineering	0.5	-0.3	No
metrology	0.2	metrology	0.8	-0.6	No
reasoning	0.2	reasoning	0.7	-0.5	No
technical evaluation	0.2	technical evaluation	0.8	-0.6	No
marketing	0.2	marketing	0.3	-0.1	Yes
reverse engineering	0.2	reverse engineering	0.3	-0.1	Yes
software development	0.2	software development	0.4	-0.2	Yes
entrepreneurship	0.1	entrepreneurship	0.6	-0.5	No
accounting for engineers	0.1	accounting for engineers	0.8	-0.7	No
supply chain management	0.1	supply chain management	0.7	-0.6	No
negotiation	0.1	negotiation	0.7	-0.6	No
security	0.1	security	0.9	-0.8	No
ergonomics	0.1	ergonomics	0.7	-0.6	No
renewable energy	0.1	renewable energy	0.3	-0.2	Yes
leadership	0.1	leadership	0.7	-0.6	No
economics	0.1	economics	0.3	-0.2	Yes
legal factors	0.1	legal factors	0.3	-0.2	Yes
waste management	0.1	waste management	0.9	-0.8	No

table 5.3 shows a particular case where 26 elements have been predicted accurately by the curriculum management system. This translates to accuracy:

$$accuracy = \frac{26}{56} = 0.46 \tag{5.2}$$

Experiment runs

The following are experiment runs for different sample sizes, to assess the performance of the window shopper algorithm against stochastic gradient descent.

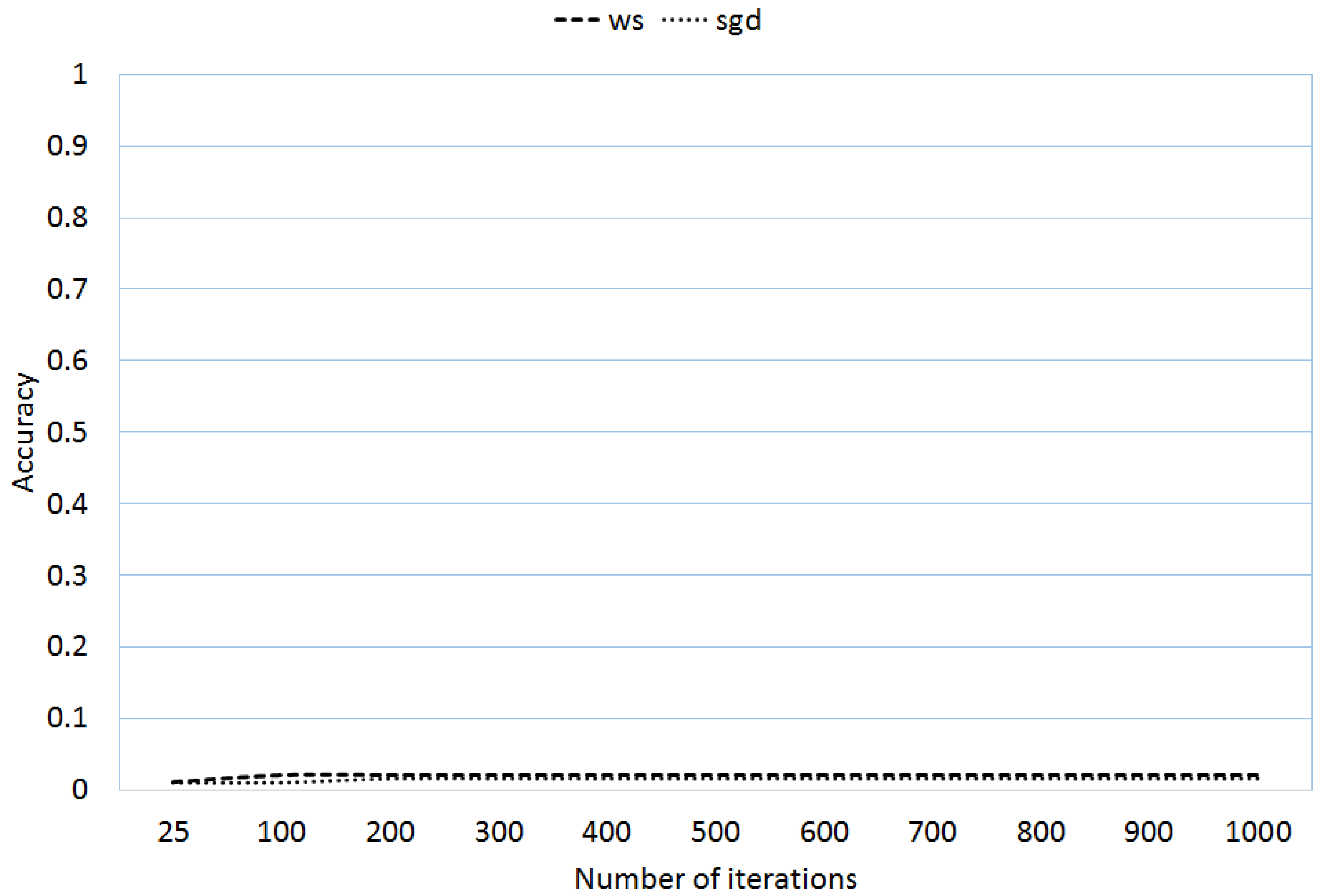


Figure 5.4: Training sample size = 2

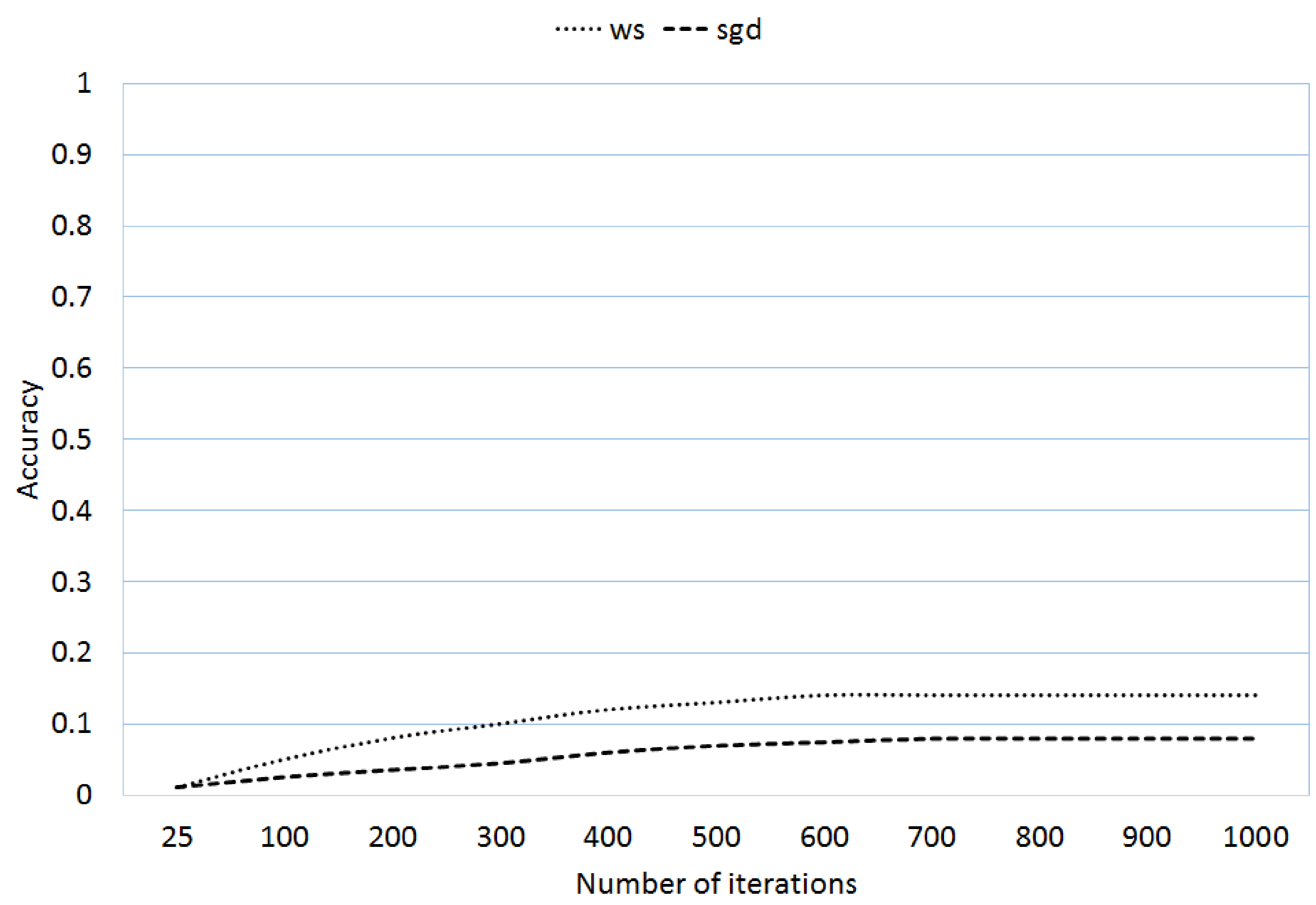


Figure 5.5: Training sample size = 5

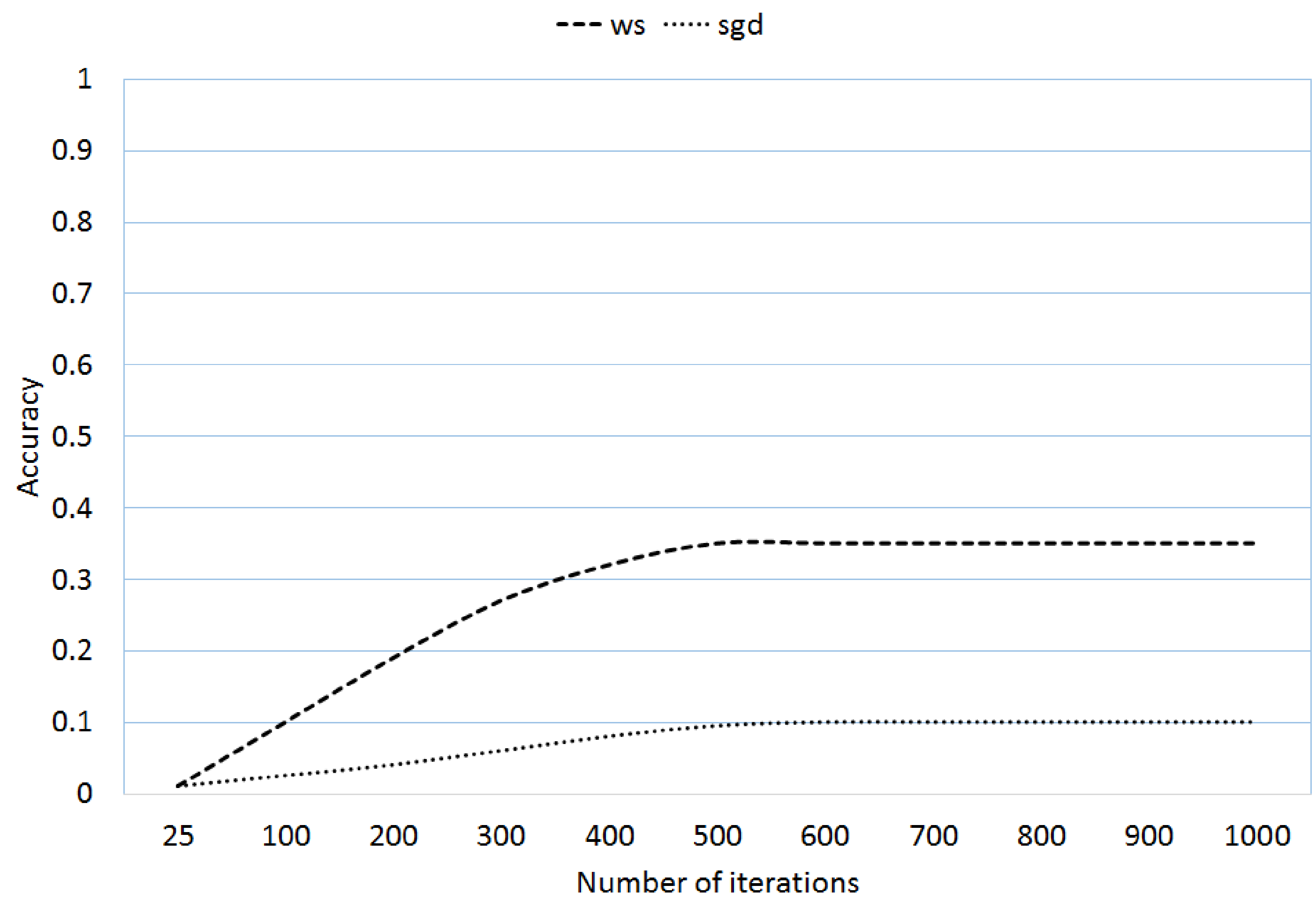


Figure 5.6: Training sample size = 8

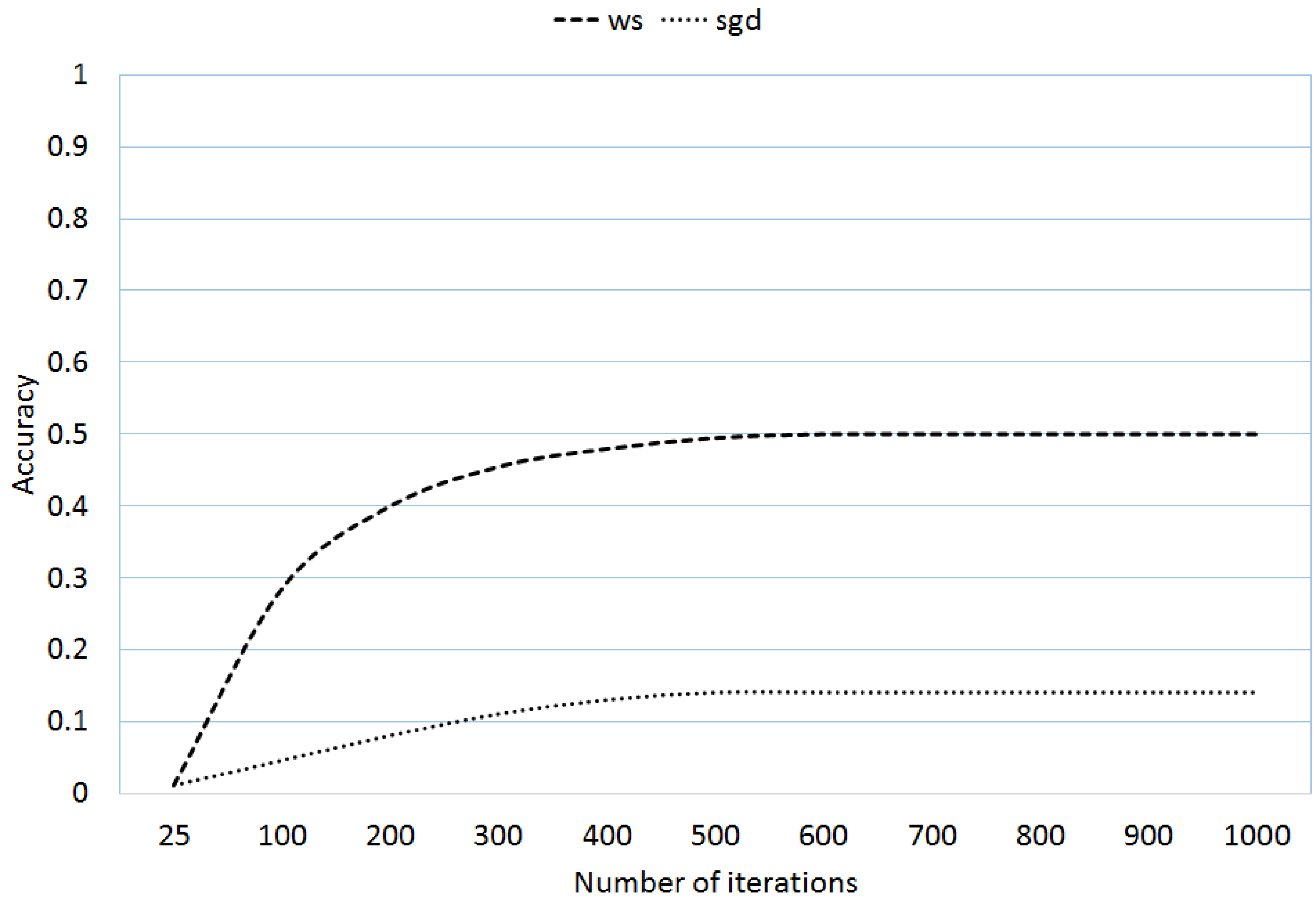


Figure 5.7: Training sample size = 10

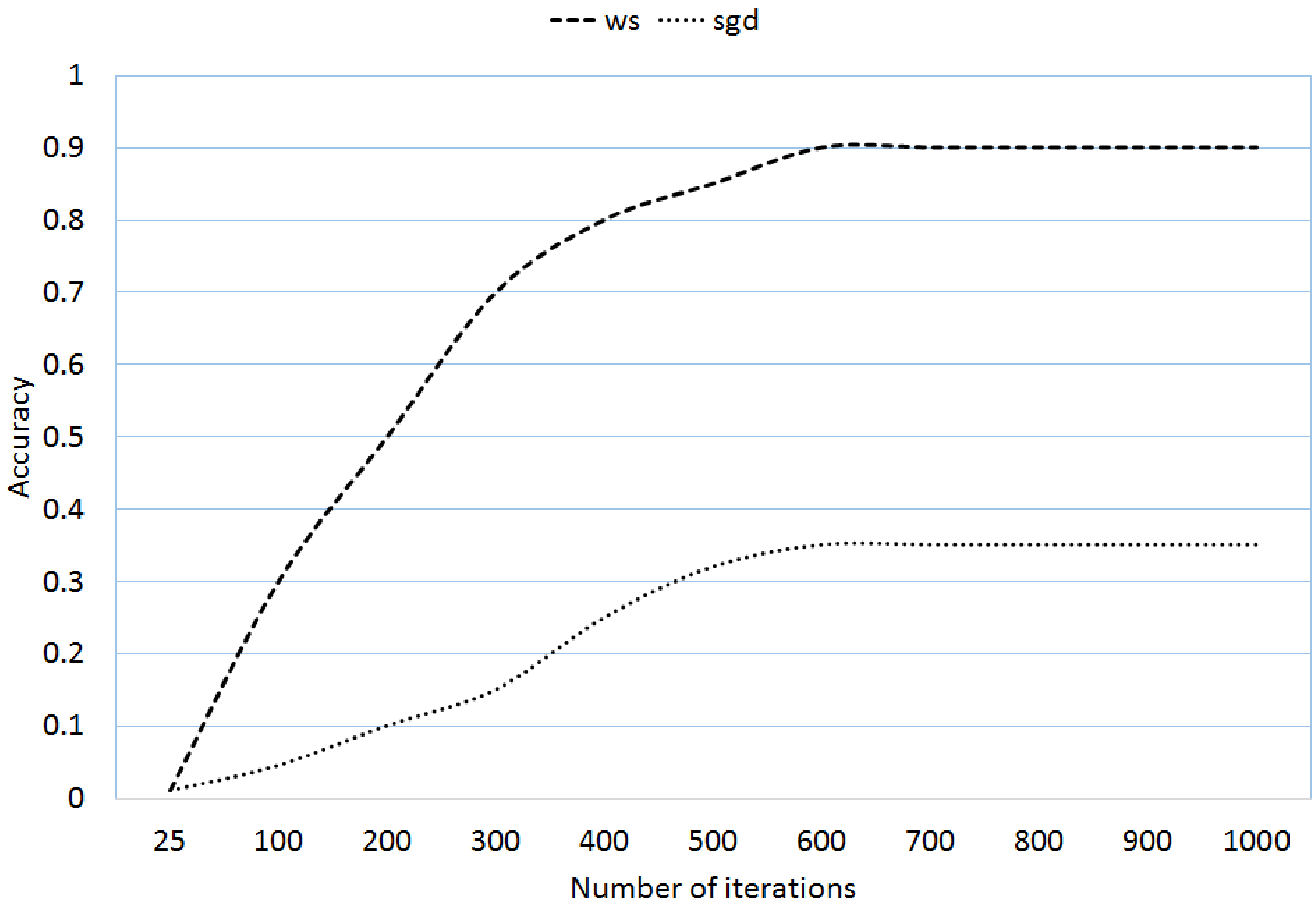


Figure 5.8: Training sample size = 14

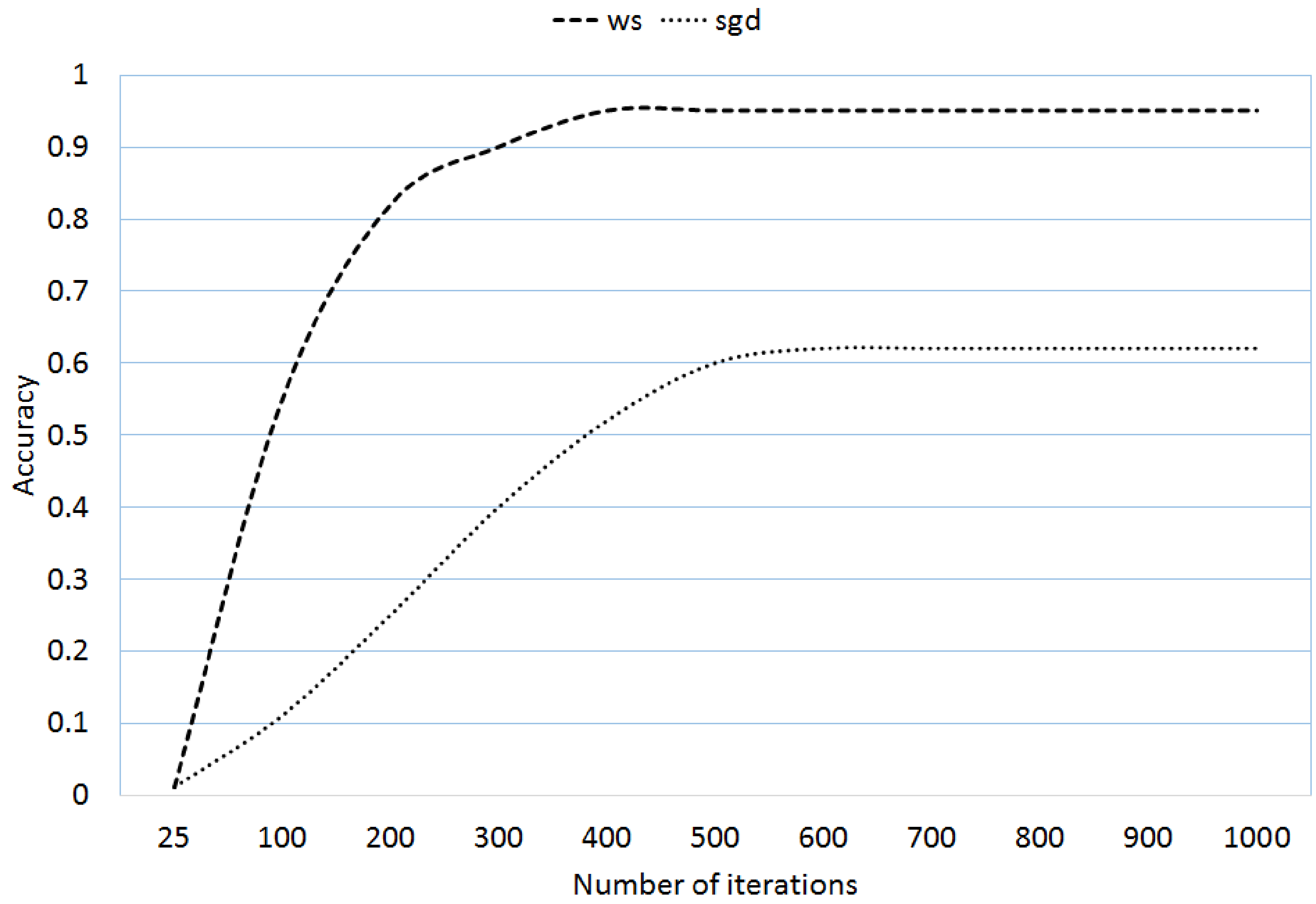


Figure 5.9: Training sample size = 16

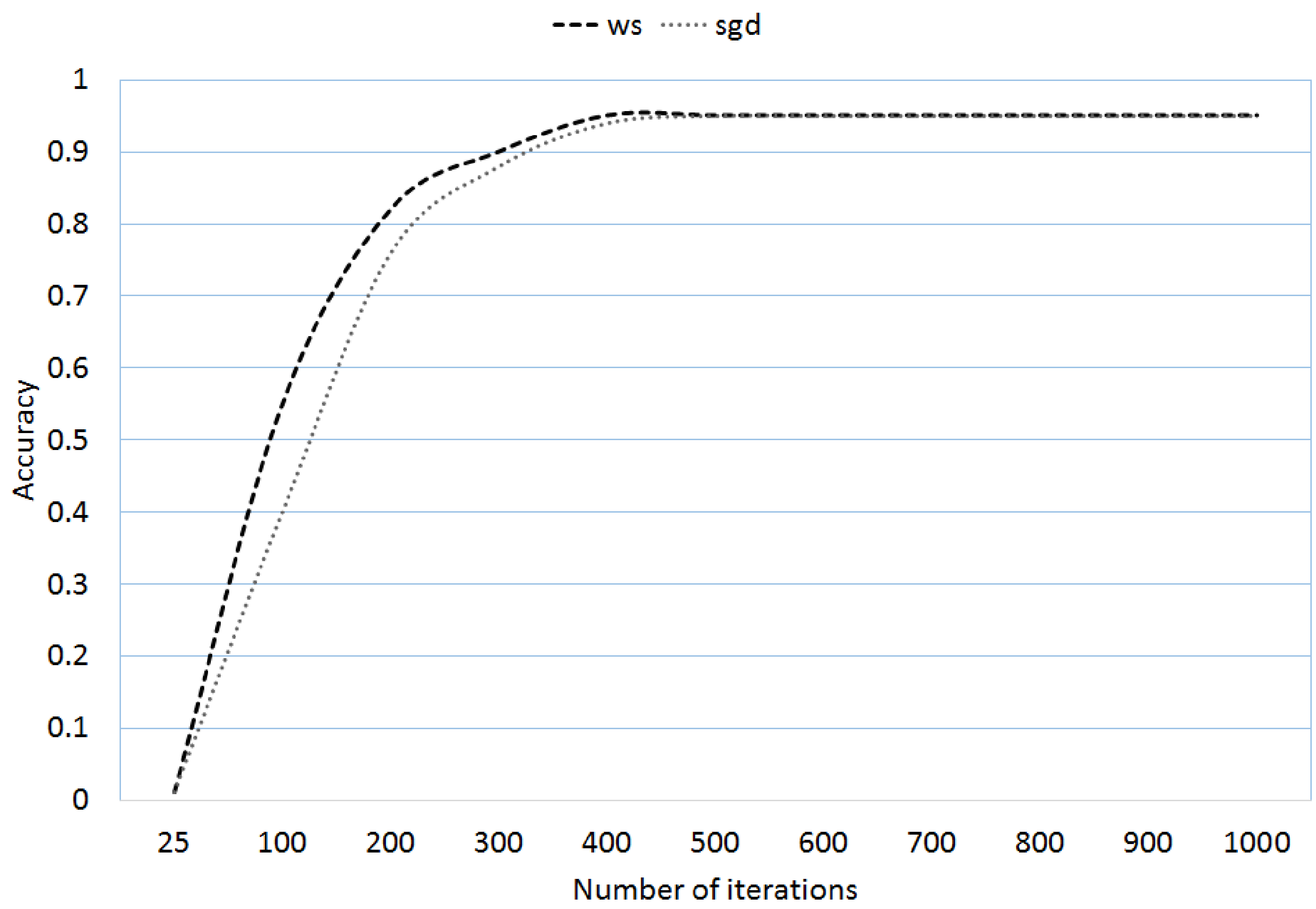


Figure 5.10: Training sample size = 20

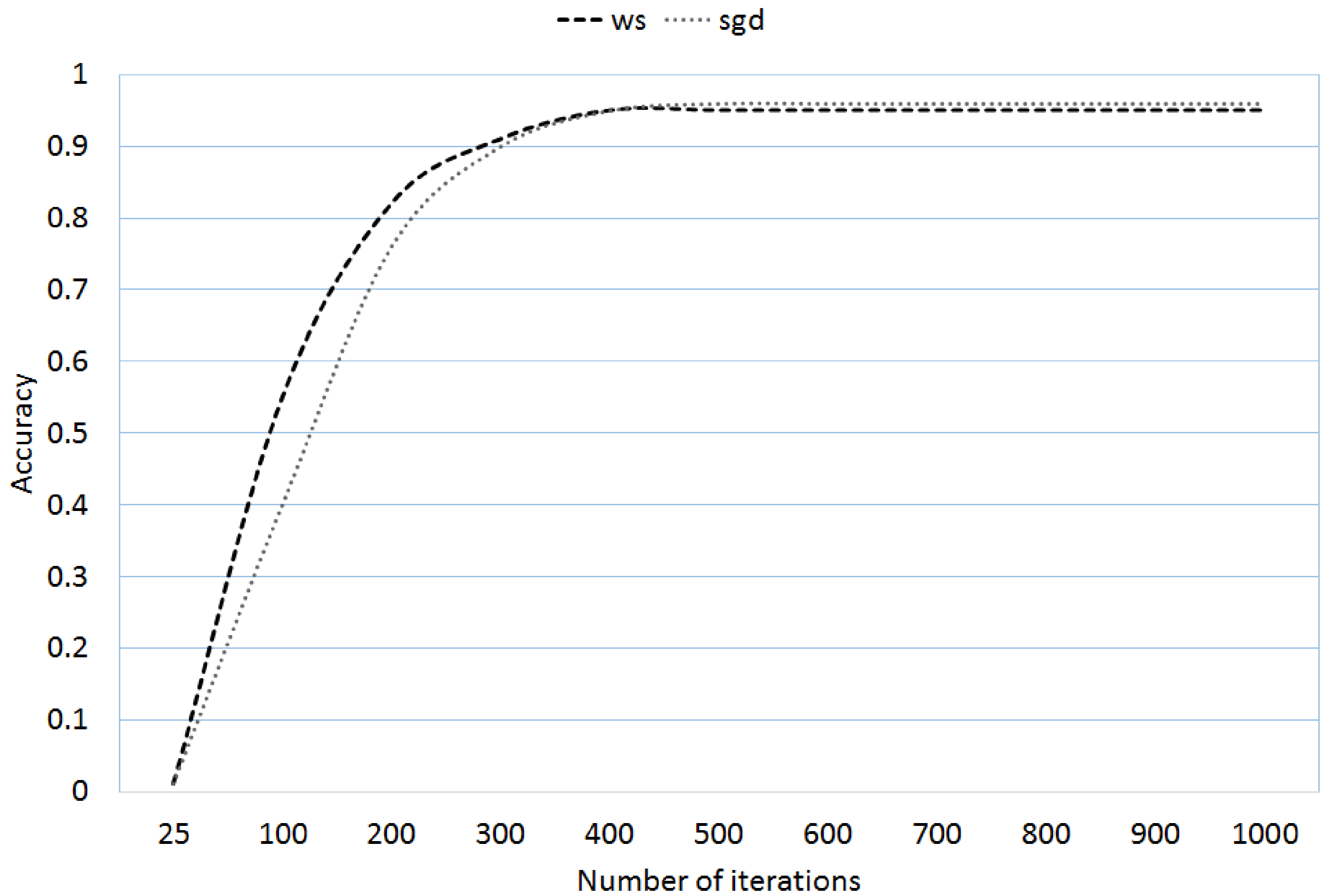


Figure 5.11: Training sample size = 22

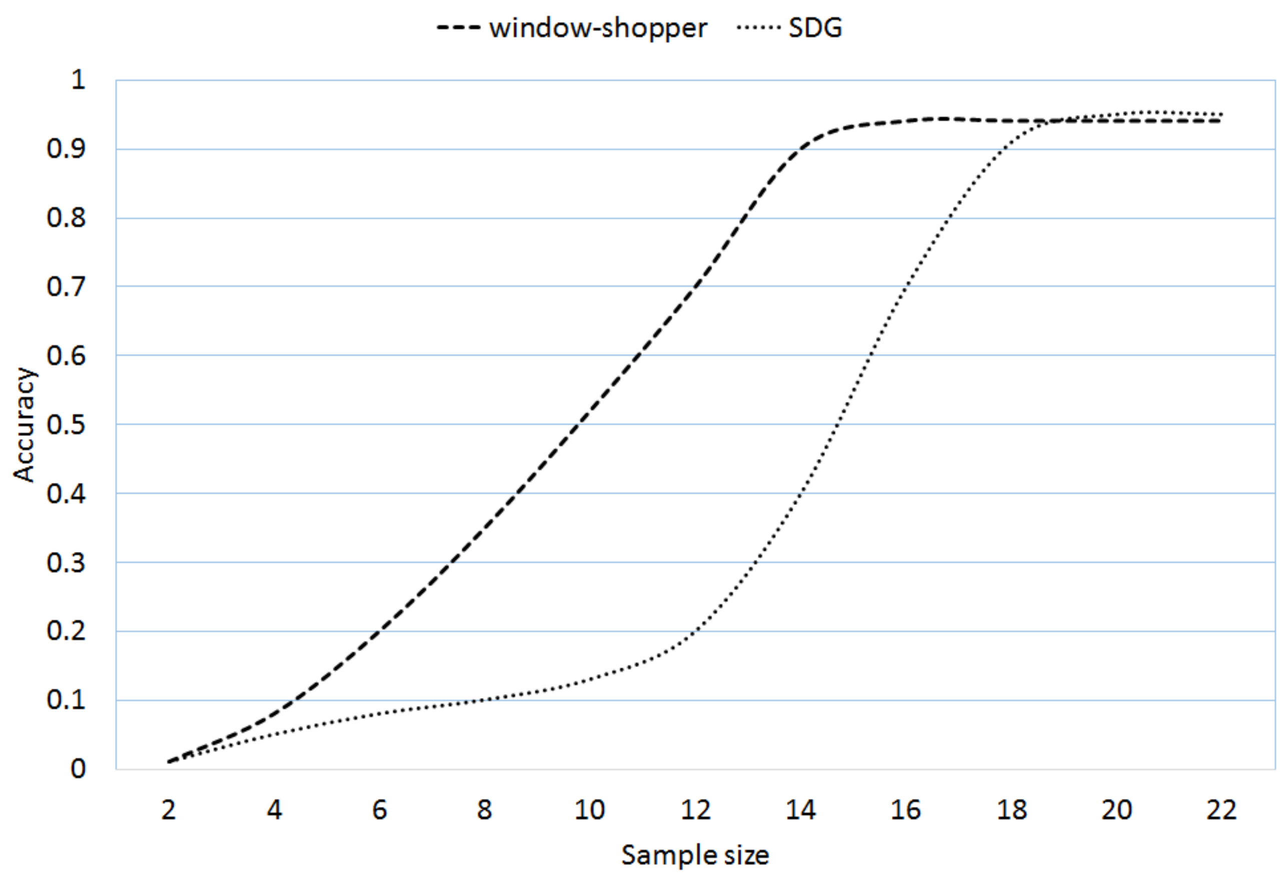


Figure 5.12: Effect of sample size

Figure 5.12 summarises the training sample experiments , to illustrate the effect of sample size on the quality of both the window shopper and stochastic gradient descent.

Figure 5.12, shows that the window-shopper extension makes training of the ANN easier, with respect to sample size. Smaller training sample sizes translate to easier and more convenient the network is to train, considering that the individual samples must be merged for each training run. The accuracy achieved by utilising a size 18 sample size with stochastic gradient descent can be achieved by a size 14 of the window-shopper modified version, and size 14 to size 10 respectively.

5.3 System run

The neural network is trained not only by employment data, but both employment and entrepreneurship cases. In this way, the system gives a precise representation of the industry needs. A consolidation of two hundred employment cases and two hundred entrepreneurship cases is used to train the network. The final system indexes are as follows:

1. Data usage: 90 percent training, 10 percent evaluation.
2. Accuracy: 0.92

Table 5.4 depicts the system output.

Table 5.4: Decomposed automated system output

concept design	1.0	management accounting	0.6	scheduling	0.3
research skills	1.0	inter-disciplinary learning	0.6	ethics in engineering	0.2
sys modelling&simulation	1.0	salesmanship	0.5	metrology	0.2
creative design	0.9	lean principles	0.5	reasoning	0.2
engineering standards	0.9	performance evaluation	0.5	technical evaluation	0.2
management practice	0.9	training and development	0.5	marketing	0.2
optimisation theory	0.9	workflows	0.5	reverse engineering	0.2
data management	0.8	innovation	0.4	software development	0.2
computer aided design	0.8	engineering work study	0.4	entrepreneurship	0.1
operational research	0.8	risk management	0.4	accounting for engineers	0.1
inter-faculty learning	0.7	written skills	0.3	supply chain management	0.1
financial management	0.7	oral skills	0.3	negotiation	0.1
design simulation	0.7	manufacturing processes	0.3	security	0.1
HR management	0.6	budgeting	0.3	ergonomics	0.1
sustainability	0.6	office skills	0.3	renewable energy	0.1
drawing interpretation	0.6	automation	0.3	leadership	0.1
problem solving	0.6	facility layout	0.3	economics	0.1
planning	0.6	occupational health & safety	0.3	legal factors	0.1
quality management	0.6			waste management	0.1

The curriculum management system is able to decompose and manipulate curriculum to align to industry need. The system reasonably interprets on-line job/project advertisements to manipulate curriculum at the level of curriculum elements that span across the entire program course list. Table 5.4 shows the distribution of skill and knowledge demand on the basis of curriculum elements, highest demand indicated by red bars. If the molecular approach were used, the system output is as depicted by Table 5.5.

Table 5.5: Non-decomposed automated system output

Operational research	1.0	Safety management	0.6	Descriptive writing	0.3
Qualitative techniques	0.9	Info & comm technology	0.5	Electrical Eng.	0.2
Research methods	0.9	Eng. Work study	0.5	Business development	0.2
Mech. Eng. Design	0.8	Risk management	0.5	Manufacturing tech.	0.2
Eng. Methamatics	0.8	Production Eng.	0.4	Software development	0.2
Mech. Eng. Drawing	0.8	Management accounting	0.4	Automation	0.2
Management practice	0.7	Asset management	0.4	Materials	0.1
Financial management	0.6	Environment design	0.4	Electrical engineering	0.1
HR management	0.6	Eng. Programing	0.3	Mechanics	0.1
Industrial Eng. Practice	0.6	Economics	0.3	Chemical eng.	0.1
Quality assurance	0.6				

The uniqueness of decomposed (atomic) curriculum management demonstrates superiority in the sense that industry needs can be addressed in an integrated manner. The decomposed curriculum elements are interrelated and mostly available in multiple courses.

5.3.1 Summary

It can be concluded that the window-shopper algorithm, as an extension to the stochastic gradient algorithm can improve control quality, from the perspective of accuracy. The window-shopper is shown to improve ease of training the curriculum management system by approximately 22 percent at best. The window-shopper however, unlike stochastic gradient descent, is limited to the skip-connection type of network.

5.4 Implementing the alignment

This section discusses how the curriculum manipulation/adjustment is executed, in order to better align the curriculum to industry, based on the output of the management system. As stated in the introduction of Chapter 4, the actual alignment is executed at topical level, that is to say, at an atomic level rather than course (molecular) level. To therefore manipulate the curriculum to emphasize for example the 'concept design' element, the following is done:

1. The 'concept design' element is highlighted for prioritisation across all applicable courses/modules.
   These courses include Mechanics, Mechanical Engineering Drawing, Mechanical Manufacturing Engineering, Electrical Engineering, Eng. Work Study, Automation and so on.

   For the identified courses, the following aspects of the study program are then adjusted to prioritise the 'concept design' element:
2. course material/content.
3. student assignments.
4. laboratory/practical exercises.
5. examinations and tests.
6. course projects.

Such is the expected outcome of the management system. Based on on-line advertisement information, the system computes recommendations for the appropriate management of curriculum. The system, which is based on artificial intelligence algorithms, is therefore designed to automate the curriculum management process.

There are two advantages associated with the proposed curriculum management system which adopts atomic curriculum manipulation. These advantages are:

1. Uniformity and consistency. Executing curriculum manipulation atomically ensures uniformity and consistency across the board of educators within the institute, in terms of priority study areas according to industry need. While the educators may be different in such factors as background, experience level, age and so on, this does not have to result in curriculum misalignment, because all educators are guided by a common management system.

2. Effectiveness. Atomic manipulation makes curriculum management a more integrated process. The curriculum is dealt with as a combination of multiple distinct elements, which are highly interlinked. This means that curriculum manipulation is executed at the level of the Industrial Engineering program rather than the level of courses that make up the Industrial Engineering program.

The process of curriculum manipulation, as guided by the output of the management system starts at the output of the neural network, as presented by Table 5.4. The process is outlined by Figure 5.13, showing how the output from the curriculum management system (curriculum elements) is passed down to the individual courses, via a coordinator. In this way, the intended manipulation is carried out according to the system recommendations and across all courses of the program (as indicated as an example, for the Electrical Engineering course). As standard, the curriculum for each year consists of courses (modules or subjects). Each course then consists of several themes. Each theme then comprises several topics.

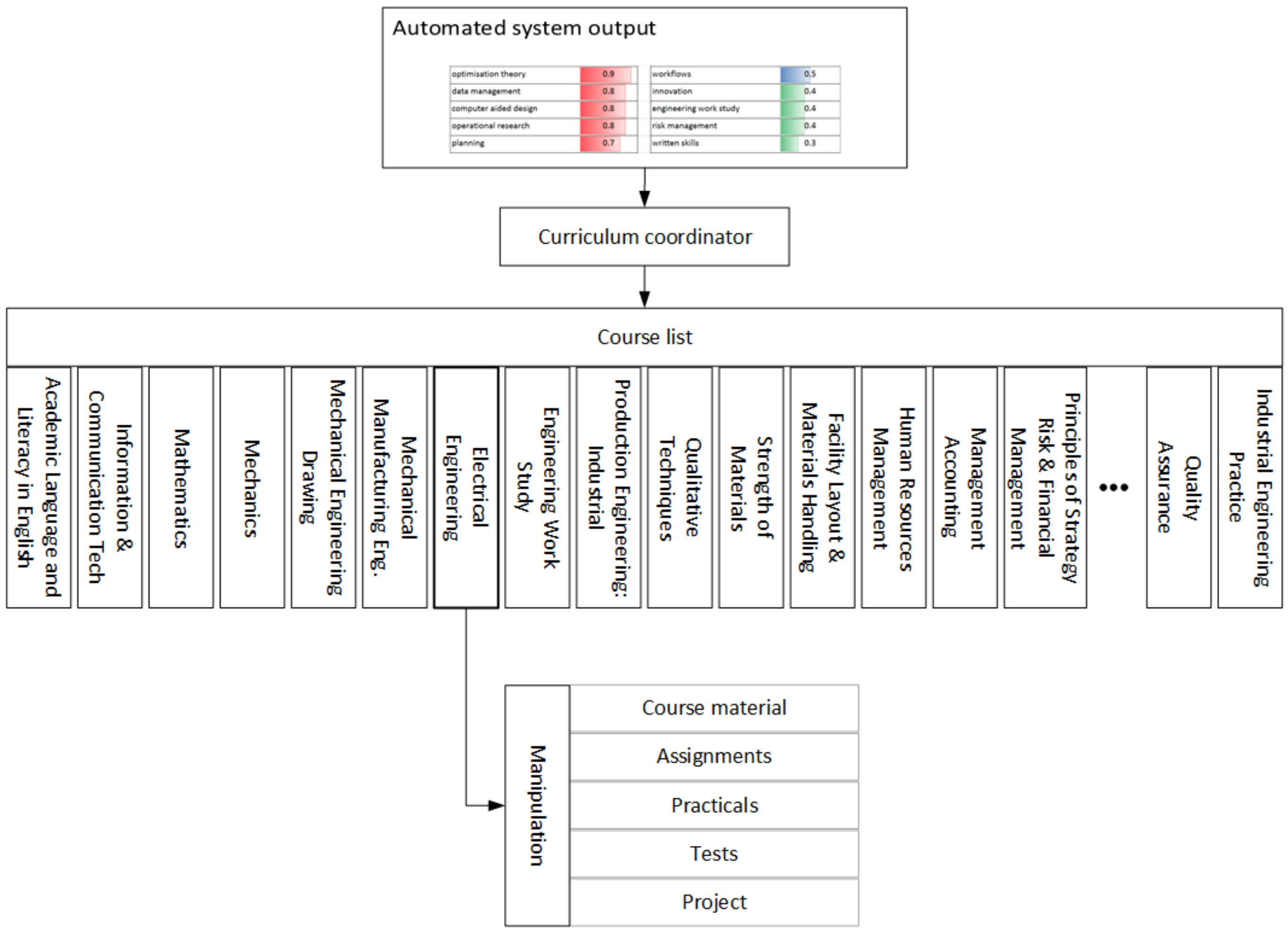


Figure 5.13: Curriculum management process outline

To demonstrate the superiority of atomic manipulation, the complete cycle of manipulation is investigated, for both atomic and molecular manipulation according to Table 5.4 and Table 5.5. The initial investigation analysis is given by Table 5.6.

Table 5.6: Atomic and molecular manipulation evaluation

	Atomic	**Molecular**
Prioritisation recommendation	13 curriculum elements across 22 courses	7 courses
Number of affected courses	22	7
Educators involved	20+	7

It can be seen that atomic manipulation is a more inclusive and integral approach, one that treats curriculum in wholeness and doing so communally involving more educators of the different program courses.

This analysis can be presented graphically. Figure 5.14 gives a graphical presentation of the analysis of the impact of atomic and molecular curriculum management in terms of the total number of courses/modules affected.

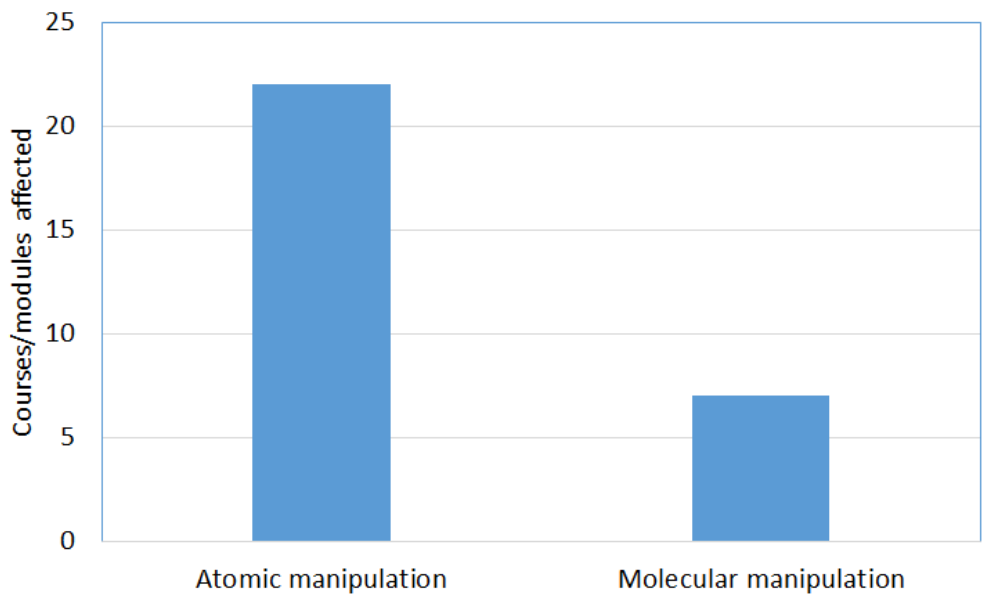


Figure 5.14: Impact analysis - courses affected

Figure 5.15 gives a graphical presentation of the analysis of the impact of atomic and molecular curriculum management as viewed with respect to the total number of courses or modules affected.

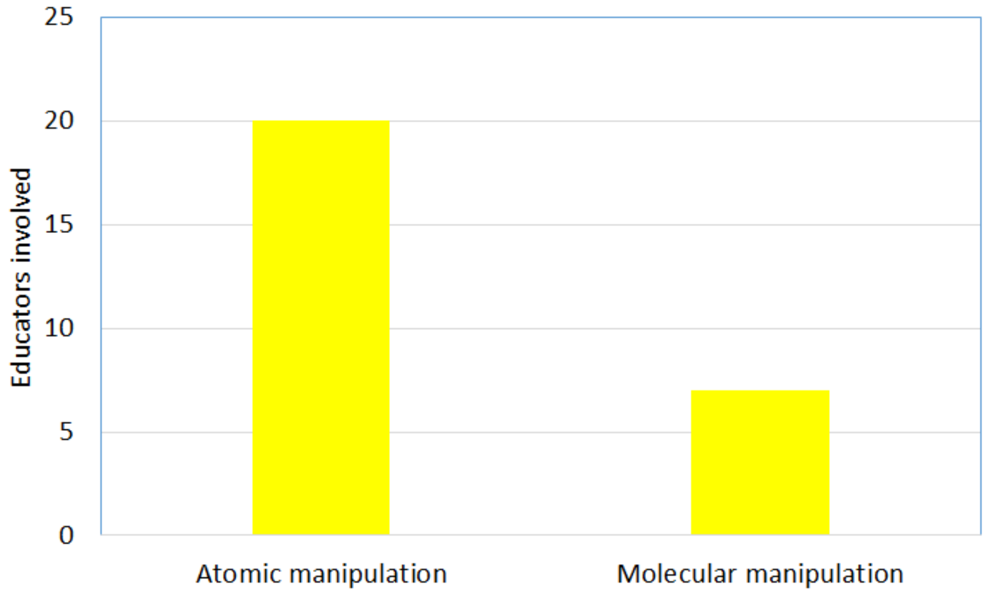


Figure 5.15: Impact analysis - educators involved

Figure 5.14 and Figure 5.15 show that atomic curriculum manipulation results in more comprehensiveness, where in the case considered, the adjustments recommended by atomic manipulation are implemented across three times more courses/modules, than molecular manipulation. In the same way, this implementation involves all the educators associated with the program.

The benefits presented by Figure 5.14 and Figure 5.15 cannot be undermined. In literature review, the work of Zimmer and Keiper [31] highlights that one cause of curriculum misalignment is the diversity of teaching staff. This diversity comes in the form of varying backgrounds, strengths and weaknesses, interests, nationalities and so on. If therefore, curriculum management is executed all-inclusively, this is expected to promote consistency and curriculum alignment.

Implementation of the proposed curriculum management system is discussed first, through a lower level analysis of the implications of the system, then secondly, through a higher level analysis. This hierarchy classifies low level as the level of the scope of the teacher, and the high level as the scope of the actual curriculum courses and related topics.

5.5 Lower level implications

To best evaluate the proposed curriculum management system, the output of the system (Table 5.4) is analysed in terms of output implications. The idea is to analyse the implications of the curriculum recommendations produced by the management system from a teacher perspective; the teacher being the gateway to the realisation of the recommendations.

A discrete approach is taken, measuring the impact of the atomic and molecular manipulation according to two select teachers, (1) 'Mechanical engineering design' teacher and (2) 'Automation' teacher. The reason for selecting these two is the need illustrate the comprehensiveness of atomic manipulation, where, according to Table 5.5 which represents molecular manipulation, course (1) is recommended directly for prioritisation while course (2) is not, and then from atomic manipulation, we expect coverage of all courses from the system recommendations.

For the 'Mechanical engineering design' teacher

The molecular curriculum management system (Table 5.5) recommends the teacher to improve teaching methods and content based on the high industry demand for mechanical engineering design skill. The atomic curriculum management system as depicted by Table 5.4 recommends the teacher to improve and enhance on the following elements of the mechanical engineering design course:

1. concept design
2. research skills
3. system modelling and simulation
4. creative design
5. engineering standards
6. data management
7. computer aided design operational research
8. inter-faculty learning
9. design simulation

through assignments, laboratory/practical exercises, examinations, tests and course projects. This too is based on the industry demand.

For the 'Automation' teacher

The molecular curriculum management system (Table 5.5) is more silent to the Automation teacher. The atomic curriculum management system however recommends the teacher to improve and maximise on the same elements as listed above. This is in fact complemented across all the courses.

5.6 Higher level implications

A full view of the curriculum management system is required, one that can explicitly elaborate the practicality of atomic curriculum manipulation. To demonstrate this practicality, an approach is taken to investigate a case study. The study is conducted for a specific course, with the aim to analyse the design of curriculum after processing the proposed curriculum management system. This curriculum is cross-referenced to the default curriculum.

5.6.1 Course material

The first investigation refers to the course material, and is detailed below for the case of the Electrical Engineering I course. By default, this course is structured as follows:

Unit I Safety and wiring
safe work procedures
wiring principles
electrical accessories
grounding (earthing)
electrical generation, and how electricity is transmitted and distributed

Unit II Magnetic Circuits
magnetic theory
simple and complex circuits
Principles of Faraday
the science of emf

electrical inductance

Unit III DC Machines
design and layout
operational principles
principles of emf
principles of direct current motors
electrical equations
principles of equivalent circuits
inductors
torque

Unit IV AC Machines
transformers
induction motors
generators

Following the proposed curriculum management system as presented by Table 5.4, the default course structure is adjusted to include elements of:

1. engineering standards for electrical engineering
2. electrical engineering design simulation

It shown that the curriculum management system does not affect the delivered course material, in terms of adding or subtracting topics. This presents two advantages. First, this means that curriculum remains standardised, and secondly, it means that adjustments to curriculum are mainly attached to course activities (assignments, laboratory exercises, examinations, projects) rather than course teaching material, and this in turn advances research skills of students and minimises the so called ”spoon-feeding”.

5.6.2 Assignments

Student assignments are a vital tool in enhancing the learning process of students. The Electrical Engineering I course typically has the following assignments:

Assignment I
Magnetic circuitry problem solving

Assignment II
Application of Faraday's Laws

Assignment III
Torque calculations

Following the proposed curriculum management system as presented by Table 5.4, the assignment set up is adjusted to enhance, as much as possible, the elements of:

1. concept design
2. research skills
3. system modelling and simulation
4. creative design
5. engineering standards
6. computer aided design
7. inter-faculty learning,

by manipulating the assignment set up to:

Assignment I
Circuit design for power control

Assignment II
Wire layout design for a two-bedroomed house

Assignment III
Specification design for borehole solar electricity supply

This approach exploits the opportunity presented by assignments, to genuinely enhance research skills in students, given that assignments are executed outside the classroom and independently from the teacher. Moreover, because assignments may be assigned as group work, an opportunity to enhance inter-faculty learning and communication skills is directly realised. Further, assignment II for example, encourages consultation with fellow students from the department of civil engineering. Effectively, the proposed approach drives assignment education to a more practical and less theoretical dimension.

5.6.3 Laboratory work

An investigation into the laboratory work/exercises for the Electrical Engineering I course is also carried out, and is detailed below.

Lab I
Load tests - direct current generator.

Lab II
Load tests - different types of direct current motors.

Lab III
Load tests - transformer.

Lab IV
Principles of alternators.

Lab V
Mathematical problems.

From the laboratory exercises, an opportunity is presented to data management skills as well as concept design skills through experiment design practices. This is derived from an analysis of the actual curriculum available at the university.

5.6.4 Examination and project

With output from the proposed curriculum management system, the examination and project work are aligned to highlight the competences prescribed by the system. This ensures better alignment in the sense that what the education system passes, does in fact pass in industry as well.

5.7 Validation

This research proposes curriculum decomposition as a means to achieve more effective and more efficient higher education alignment to industry. The proposed system is validated to determine practicality and usefulness in genuinely supporting decision making for curiculum management. Qualitative research is typically considered more difficult to validate than quantitative research, in fact, in some cases authors present the case that qualitative research is impossible to validate [209]. The research presented in this curriculum management study is a mixed methods type of research, with a strong element of qualitative research.

To validate the proposed curriculum management system, a reliable method to assess impact is required, one which can indicate the effectiveness of the overall system, with respect to the significance of curriculum atomisation for improved curriculum alignment. The idea is to determine how strongly each curriculum element has been pronounced throughout the course. Possible ways to make this determination, include:

1. directly from the curriculum by analysing the course plan and credit allocation.
2. from a student survey (student exit survey) to determine how much of each curriculum element they have learnt.
3. from a teacher survey to establish how much emphasis the teacher placed on the related curriculum elements.

From the above stated, the student exit survey is selected as the method to measure emphasis on curriculum elements, during the learning process. This is because the student survey takes account of that which the student (the customer) has actually absorbed and is ready to take to the industry. To therefore measure the degree of realisation of the system output (recommendations), a survey is conducted, which measures the weight of each curriculum element based on how much emphasis was put on each curriculum element right through the entire study programme.

5.7.1 Exit survey

A student exit survey, in this context, is an assessment of the knowledge percentage attainment, from the perspective of the student. While this study is based on a UNISA programme, the exit survey is conducted based on Zimbabwean data, obtained from graduates from the University of Zimbabwe (Bachelor of Science in Industrial Engineering) and also graduates from National University of Sciences and Technology (Bachelor of Science Industrial and Manufacturing Engineering) who are involved in the industry of Zimbabwe. The reasons for this initiative are:

1. Ease of access to data, given the prevailing global health crisis.
2. The delicacy of the validation process requires a pragmatic approach, to allow adequate interfacing between the researcher and the respondents.
3. It is considered sufficient to validate the working process of the proposed system, rather than the actual output from the system.

The exit survey involves twelve graduates of the year 2020. The survey follows the outline of the output of the proposed curriculum management system. This is done on the basis of assigned weights, allocated to each curriculum element, relative to all curriculum elements. The weight can be a factor of how much:

1. emphasis exists on the curriculum element throughout the study programme
2. time is spent on the curriculum element throughout the study programme.

Accordingly, it makes more sense to work with how much emphasis is put on the curriculum element rather than the amount of time spent (even though time spent is more measurable) because the idea of emphasis translates more directly to course outcome which determines student knowledge and skill. The indicated indices are averaged for all twelve respondents.

The student exit survey is carried out on the basis of the industry needs representation, depicted by Table 5.4, to establish how each curriculum element contributed to the eventual and overall knowledge base of the student. For each curriculum element, a value on the scale 1 - 10 is given as to how much the overall study program accounted for each curriculum element (referred to in some contexts as the 'usefulness rating'), from a student perspective, as depicted by Table 5.7 where the value 10 represents the highest emphasis while the value 1 represents minimum emphasis.

Table 5.7: Twelve-student exit survey

computer aided design	10	planning	5	inter-faculty learning	3
design simulation	9	operational research	5	innovation	3
lean principles	9	management accounting	5	office skills	3
problem solving	8	engineering work study	5	marketing	3
automation	8	budgeting	5	supply chain management	3
quality management	7	ethics in engineering	5	renewable energy	3
manufacturing processes	7	concept design	4	leadership	3
facility layout	7	research skills	4	salesmanship	2
sys modelling & simulation	6	data management	4	oral skills	2
financial management	6	HR management	4	software development	2
drawing interpretation	6	sustainability	4	negotiation	2
engineering standards	6	training and development	4	entrepreneurship	2
performance evaluation	6	risk management	4	ergonomics	2
workflows	6	written skills	4	metrology	1
scheduling	6	occupational health & safety	4	security	1
accounting for engineers	6	reasoning	4	economics	1
management practice	5	reverse engineering	4	technical evaluation	1
optimisation theory	5	inter-disciplinary learning	3	waste management	1
creative design	5			legal factors	1

Table 5.7 therefore shows for example that, with a value of 10, the 'computer aided design' element is highly emphasised, during the study program. Referencing against the needs of industry, depicted by Table 5.4, the 'computer aided design' element does appear high on the demand list, however, a curriculum element such as 'concept design' raises a flag, where the industry demand quantitatively outweighs relative curriculum emphasis of this element. This comparison is facilitated by scaling the student-survey curriculum-element values to the industry-needs scale. While this approach provides efficient measurement of student competency according to the set curriculum elements, it is noted that as curriculum elements increase in quantity, so does the complexity of estimating the respective indices by the survey respondents.

When the values for industry-needs and for curriculum-emphasis have been scaled, it is possible to determine how aligned or misaligned these two are. The idea is to calculate the 'misalignment' on the basis of Equation 5.3:

$$misalignment = F_{IE} - F_{CE} \tag{5.3}$$

Where F_{IE} is the industry needs factor calculated from the management system output and F_{CE} is the curriculum emphasis factor, calculated from the exit survey (Table 5.7). In taking this approach, the output gives positive, negative and medium misalignment. Positive misalignment, depicted by Figure 5.16, means that a particular curriculum element is demanded by industry more than that same element has been emphasised by curriculum, relative to the full curriculum spectrum.

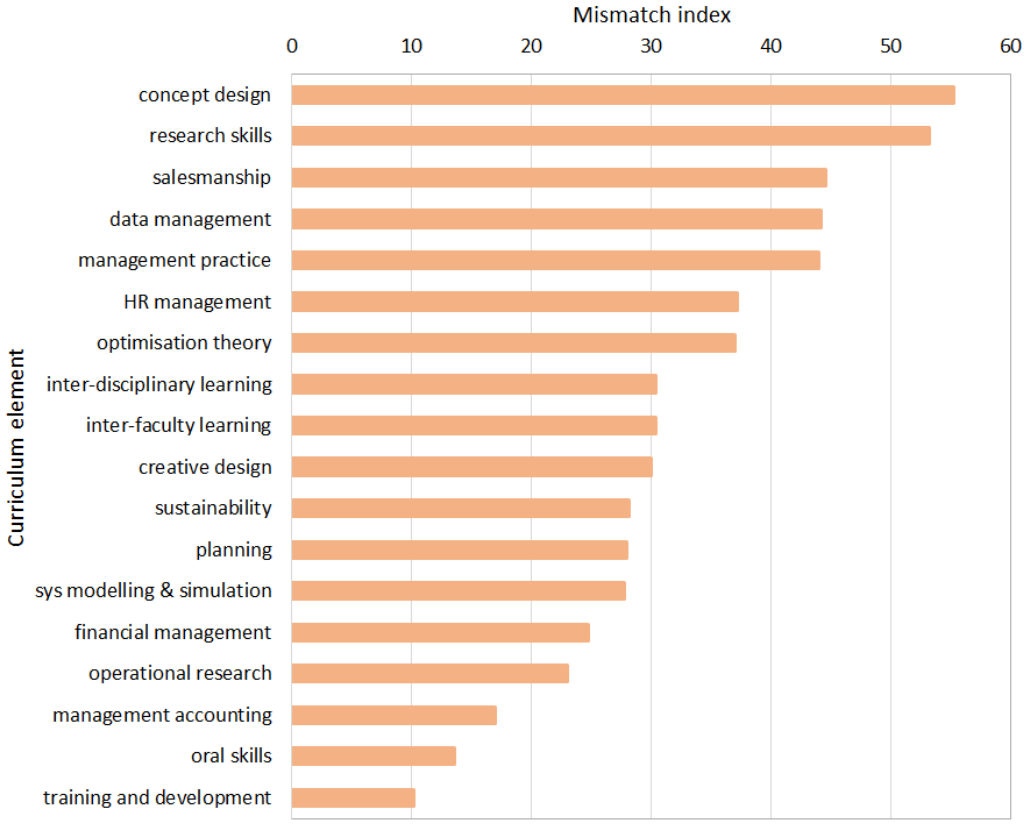


Figure 5.16: Elements with positive misalignment

Positive misalignment therefore reflects poorly on the developed management tool. The developed solution is therefore designed to close this gap to achieve close alignment of curriculum to industry. Figure 5.16 already is a cause for concern, showing critical curriculum elements that have not received sufficient emphasis during the study programme, yet the elements are key pillars in the work of an industrial engineer.

Medium misalignment, depicted by Figure 5.17, means that a particular curriculum element is reasonably equally demanded by industry as emphasised by curriculum, relative to the full curriculum spectrum.

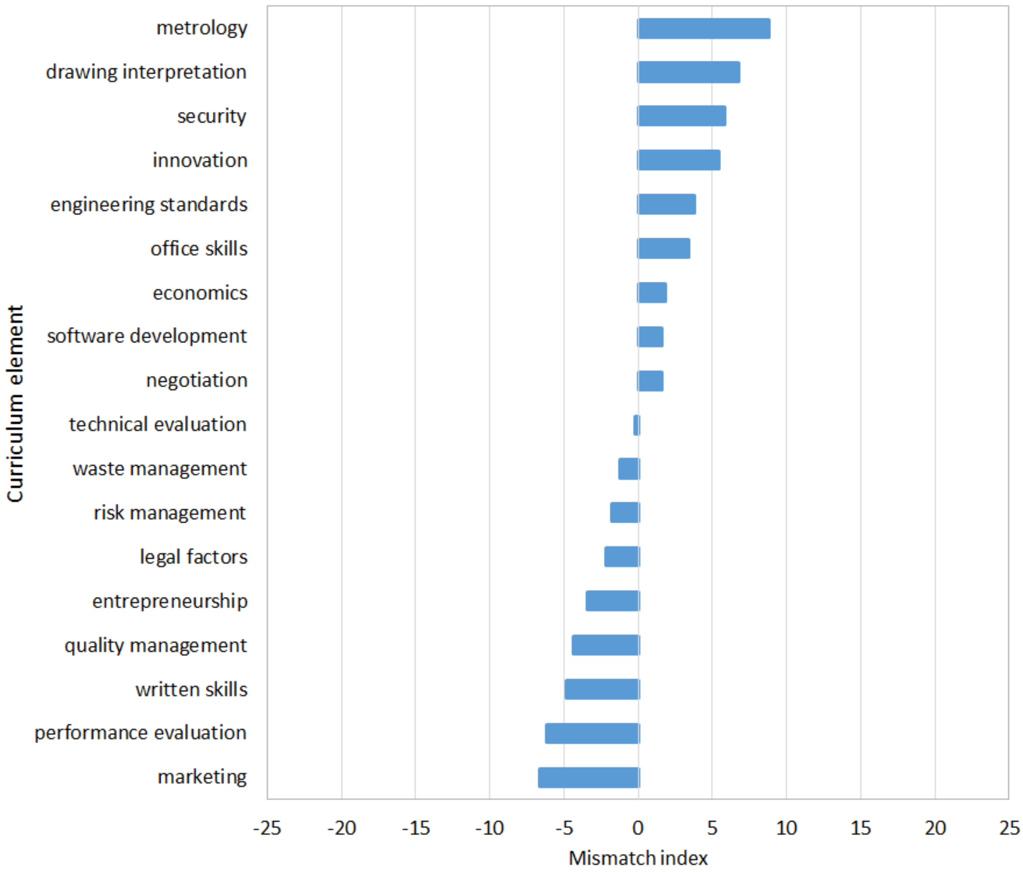


Figure 5.17: Elements with medium misalignment

Negative misalignment, Figure 5.18, means that a particular curriculum element has emphasised more by curriculum than that same element is demanded by industry, relative to the full curriculum spectrum.

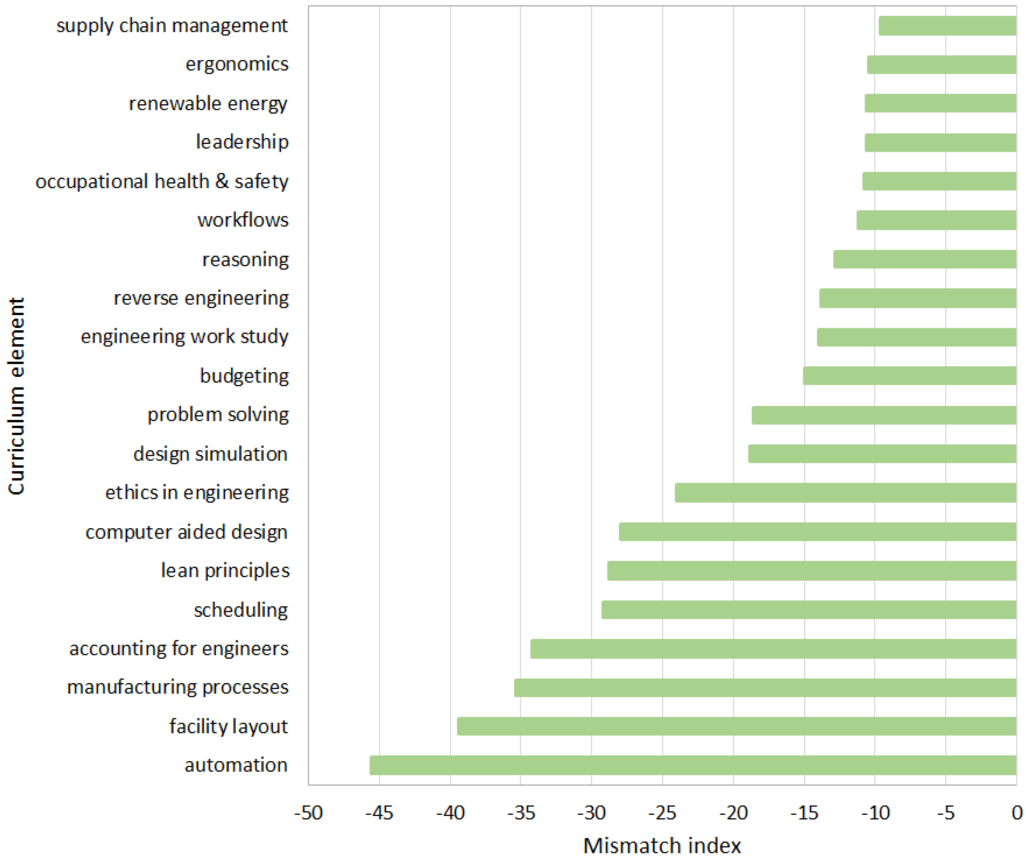


Figure 5.18: Elements with negative misalignment

Using this criterion, it is possible to determine the performance of the system. Medium misalignment means that output of the management system is implemented and realised sufficiently. The formula presented above demonstrates a reasonable means to validate the proposed system.

5.7.2 Industry survey

The proposed system is further validated according to the requirements of the industry. The exit survey presented in section 5.7.1 validates the proposed system from the student perspective, while this section crosses over to the industry for further validation.

The approach followed is to obtain information, through a survey, from industrial engineers regarding the top skill-sets demanded by the line of work of IE. The test conducted takes the output of the proposed atomic curriculum manipulation solution to industry to obtain an assessment of how closely the output aligns to the reality of the profession. Emphasis is placed on maintaining high levels of accuracy during the assessment.

5.7.2.1 Full survey

The validation survey virtually engaged sixty-four Zimbabwe-based industrial engineers who were asked to review the curriculum elements of the IE study program (Table 5.4) and then to rank the elements according to real industrial need and applicability. With over fifty curriculum elements to review and supposedly busy day-to-day schedules of the industrial engineers, this full survey approach only returned sixteen complete responses, which showed no meaningful trends. The survey was therefore simplified to become more targeted rather than full.

5.7.2.2 Targeted survey

A targeted survey is proposed, one which takes only six curriculum elements for review and sorting by the IE specialists, as depicted by Table 5.8.

Table 5.8: Elements of the target survey

concept design	management accounting	scheduling
research skills	inter-disciplinary learning	ethics in engineering
sys modelling&simulation	salesmanship	metrology
creative design	lean principles	reasoning
engineering standards	performance evaluation	technical evaluation
management practice	training and development	marketing
optimisation theory	workflows	reverse engineering
data management	innovation	software development
computer aided design	engineering work study	entrepreneurship
operational research	risk management	accounting for engineers
inter-faculty learning	written skills	supply chain management
financial management	oral skills	negotiation
design simulation	manufacturing processes	security
HR management	budgeting	ergonomics
sustainability	office skills	renewable energy
drawing interpretation	automation	leadership
problem solving	facility layout	economics
planning	occupational health & safety	legal factors
quality management		waste management

From the system-run based on industry data, the order of priority of the target curriculum elements is illustrated by Table 5.4, and if this order matches that returned by the targeted survey, it can be concluded that the proposed solution is successful in aligning curriculum to industry need. Ninety-eight industrial engineers are engaged and seventy-three responses returned, through various means including telephone calls, social media, instant messaging, google-forms and so on.

The six target elements selected mean that a total of 720 possible combinations are expected from the survey. Of the seventy-three responses and 720 possible combinations of the six targeted elements, thirty-five responses (48 percent) matched the order of priority given by the system-run of the proposed system. While this already indicates a positive validation on the proposed solution, the study takes a step further to put these facts into better perspective, through an analysis of individual statistics relating to how closely the responses were congruent to the solution system-run, as depicted by Table 5.9.

Table 5.9: Targeted survey analysis of response match

	Responses	**Percent**
1	Responses that matched the first priority element	100
2	Responses that matched the first and second priority elements	100
3	Responses which matched the first, second and third priority elements	96

Table 5.9 illustrates that the proposed solution successfully serves the purpose of providing close alignment of curriculum to needs of industry. The proposed system is shown to interpret industry data and to provide acceptable outcome recommendations that promote improved alignment of education to industry needs.

5.7.2.3 Follow up targeted survey

An additional follow up survey is carried out with six different curriculum elements, and another twenty-six different responses. This additional survey provides a cross-validation to verify the initial validation. Table 5.10 presents the analysis of how responses of the follow up survey matched the output of the proposed system solution.

Table 5.10: Targeted survey analysis of response match

	Responses	Percent
1	Responses that matched the first priority element	100
2	Responses that matched the first and second priority elements	100
3	Responses which matched the first, second and third priority elements	100
4	Responses which matched the first, second, third and fourth priority elements	88

The validation of the proposed solution goes on to evaluate the practicality of the solution from the perspective of the academic institute.

5.7.3 System evaluation

An evaluation is made, to determine the usefulness of the proposed curriculum management system, with respect to the conventional Assessment System. From this evaluation, it is possible to measure the scope of the proposed curriculum management system. Ultimately, usefulness of either system is dependent on the output that the particular system produces.

5.7.3.1 Assessment System

As part of the evaluation, reference is made to a typical conventional curriculum Assessment System. An engineering Assessment System review report [210] is analysed. This report culminates from information gathered from alumni, current students, employers, staff and engineering bodies. Of interest, is the output from this typical Assessment System, which produced recommendations such as:

1. Review engineering software.
2. Review adequacy of laboratory equipment.
3. Improve elective course selection list.
4. More attention on Written and Oral Communication Skills.

The full list of recommendations is given in Appendix C, showing the scope of such Assessment Systems.

5.7.3.2 Proposed management system

Section 5.7.1, outlines the output from the proposed curriculum management system. This output directly aligns curriculum to the needs of the industry and produces recommendations such as:

More emphasis on the following elements (proportionally to 1 - 5 scale):

1. Concept design (5)
2. Research skills (5)
3. Salesmanship (4)
4. Optimisation theory (3)
5. Sustainability (2)
6. Oral skills (1)

This emphasis, as mentioned in Section 5.4, is then realised/implemented by biasing course projects, assignments, laboratory work, tests and examinations accordingly, across all possible courses.

5.7.4 Usefulness analysis

The conventional assessment system is more generic (more academic) whilst the proposed curriculum management system is more industry oriented. The proposed management system speaks directly to the needs of the industry, in terms of skill and knowledge. The conventional assessment system will recommend design projects to address more realistic (real life) problems but the management system will recommend the particular realistic problems that need to be addressed at topic level. A graphical analysis of the impact of either system, against industry needs, is required to make a comprehensive evaluation. This analysis shows the degree to which both the conventional assessment system and the curriculum management system can align curriculum to the specific skill/knowledge needs of the industry. Figure 5.19 presents this analysis from a general point of view.

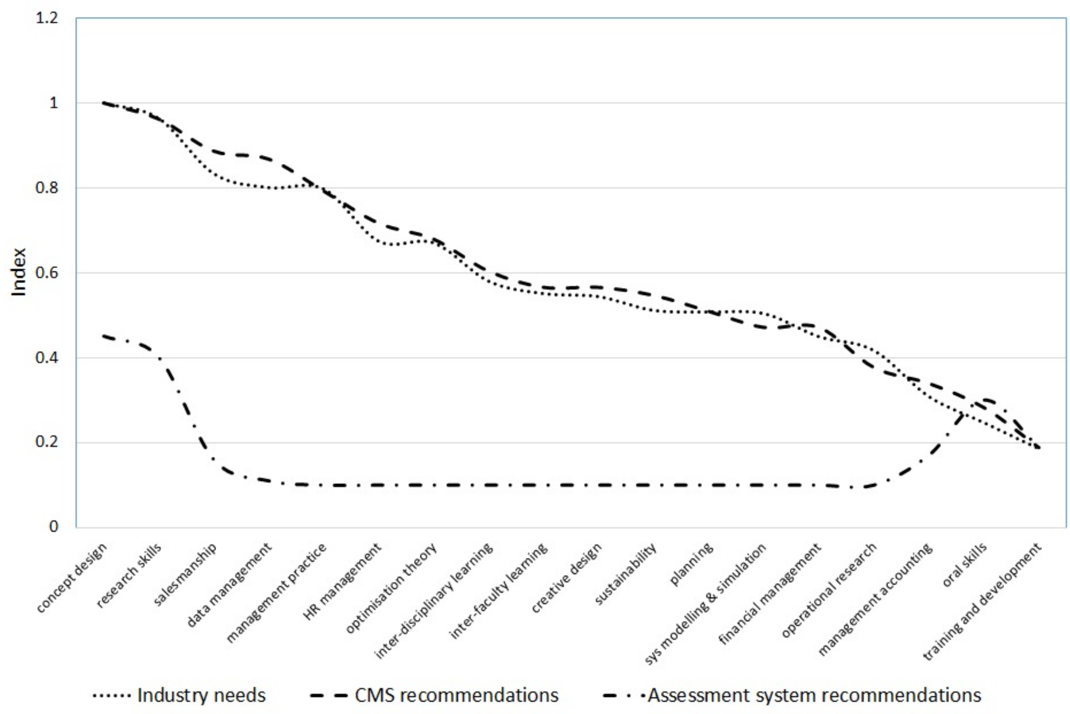


Figure 5.19: Industry need alignment potential

Figure 5.19 shows that compared to the proposed system, the conventional Assessment System is generally silent to the elementary requirements of the industry, although sufficiently addressing academic-type requirements. The proposed curriculum management system, on the other hand, is industry focused and flexible enough to adjust curriculum specifically to meet industry needs.

For the purpose of aligning curriculum to industry needs, the proposed curriculum shows reasonable potential and effectiveness. The perceived benefits of the proposed strategy:

1. Curriculum is treated according to the highly integral nature of curriculum, with high interdependency and interconnectivity.
2. Implementation of the system is practical and measurable.

The curriculum management system is an effective way to align curriculum to the needs of industry. When complimented by the proposed framework, the developed curriculum management system becomes even more strategic, not only aligning curriculum to industry, but also ensuring that as students meet the needs of industry, the students remain flexible and capable of professionally adapting to prevailing industrial conditions.

5.7.5 Validation summary

To conclusively validate the proposed curriculum management system, two questions are asked:

1. does the proposed system work?
2. if the proposed system works, how useful is the system?

Based on the validation exercise, it is shown that the proposed system does indeed work, in aligning curriculum to industry needs, closely. Atomic curriculum manipulation is shown to successfully serve the purpose of aligning higher education to industry need, with substantial robustness and meticulousness. In terms of how useful the proposed curriculum management system is in aligning education to industry, the validation shows that atomic curriculum manipulation significantly enhances curriculum management. The proposed system successfully interprets industry needs from on-line advertisements and translates these needs into a hierarchy of decomposed curriculum topics, ranked according to industry demand.

5.8 Summary

Atomic manipulation is shown to improve effectiveness and efficiency of curriculum management. Atomic curriculum manipulation provides comprehensiveness in curriculum management. Atomic manipulation allows curriculum to be adapted to industry needs in an all-inclusive fashion, where courses and teachers are no longer partitioned and treated distinctly, but rather curriculum manipulation is executed to effect the desired adjustments throughout the full range of program courses. In this way, the curriculum management process becomes more interactive and meticulous. The process, because the full staff compliment is involved, also promotes uniformity and consistency in implementation. Atomic manipulation provides an improved approach to view curriculum management and curriculum alignment to industry needs.

Chapter 6

Conclusion

The conclusion is structured to provide an overview of the study and the resultant knowledge contributions. This chapter also gives some research limitations and some recommendations for future work.

This study proposes an artificial intelligence, AI-based management system to support decision making in better aligning curriculum of the industrial engineering program at UNISA to the needs of the industry. At full scale, the system serves as a quality management system, designed to identify the difference between graduate competences and industry-required competences. It is understood that the industry is dynamic due to influences from advances in the technological and scientific world, as well as political, societal, economic and also environmental influences. Industry has in fact always been dynamic, with literature traces showing that engineering competence needs have significantly evolved over the past century. Consequently, higher education too, has evolved and continues to evolve today, in order to remain aligned to industry so that student graduates have adequate skills and knowledge to fit into the work environment and make the expected contributions. The problem is that the gap between higher education knowledge outcomes and the actual knowledge required by industry is sometimes wide; so wide in fact, that some graduates face difficulties in meeting the knowledge, skill and competence demands of industry, as revealed by literature survey. This, in a way, translates to unemployment, currently with African graduates having to go unsuccessful in attaining employment for as long as three to four years after graduation.

To realise the dynamic education system, curriculum management systems are implemented. While curriculum management systems can be non-autonomous, this study shows that autonomy in curriculum management is a more comprehensive and effective approach to manipulate curriculum. Autonomous curriculum management systems, such as that discussed in this study, utilise industry data to enable a continuous manipulation cycle thus ultimately making curriculum management more robust. The industry data is in this case collected through a survey of job postings on on-line job advertisement platforms, related to industrial engineering. This study develops a system to expose curriculum misalignment, by taking an approach of decomposing curriculum into interrelated micro-curriculum elements which are then manipulated (atomic curriculum manipulation). A system that can handle multiple inputs and outputs in a highly interrelated in sophisticated manner is developed. To carter for the sophistication, artificial intelligence is implemented as the control system for the curriculum management system, in the form of an artificial neural network, based on a window-shopper inspired algorithm. The artificial neural network is able to learn industry needs from job advertisements.

The study shows that this decomposition (atomisation) approach improves curriculum alignment. The approach interprets the skill/knowledge needs of the industry at topical-element-level of the study program, rather than the course-level or module-level. Elements that require more attention are then prioritised across all courses rather than implementing prioritisation at course level, referred to in this context as molecular curriculum manipulation. Atomic curriculum manipulation is shown in this study to promote uniformity in terms of how the individual, unique teacher executes the available curriculum. A comparison is made of the proposed system against the conventional method. The conventional method of managing curriculum (the assessment system) is shown to be rather generic, that is to say, too academic, whilst the proposed atomic curriculum management system is more industry specific. The proposed management system directly addresses the needs of the industry, in terms of skill and knowledge requirements, in a manner that is practical, especially from the perspective of the educator(s). The complexity of the process of managing curriculum requires a system that is robust and intelligent.

6.1 Research summary

In addressing the aim of the study, this study asks the question of whether or not it is beneficial to allow the entrepreneurial space to affect curriculum, and if beneficial, then to what extent. It is argued that the contribution of small to medium enterprises has substantial economic influence. It is therefore necessary to allow curriculum to be affected by entrepreneurial needs. It is concluded in this study that, while traditional curriculum primarily focuses on preparing students for employment, it is vital to create balance and to equally prepare students for entrepreneurship. Studies carried out show that with some strategic adjustments to curricula, it is possible to improve the entrepreneurial prospects of graduate Industrial Engineers as much as fourfold.

As part of this study, improvements are proposed for the Industrial Engineering curriculum at UNISA. These improvements are set to manipulate curriculum in a manner that accepst the composition of multiple, interlinked topical elements that can be adjusted, but without affecting the overall year-to-year or semester-to-semester program structure. This means that the manipulation does not include addition or subtraction of program courses. It is concluded that while surrendering the ability to add or remove courses from the conventional curriculum may limit the span of control of a curriculum management system, the decomposition approach discussed makes up for this limitation by maintaining the integrity of curriculum. It is understood from experience, general knowledge and literature that industrial engineering curriculum is highly diverse, interdisciplinary and integrated. Management of such a system is therefore complex especially when the dynamic nature of industry, technology and economics is considered.

From the discussions presented, the conclusion is that ANNs are an effective tool to form the basis of a curriculum management system. This is however not a plug-and-play solution. As with most artificial intelligence control systems, this is a solution that requires optimisation in the form of adequate configuration and/or modification, in order to meet the required performance indices. In this study, a 'window-shopper' inspired technique is implemented to optimise the manner in which the ANN performs. This solution, is an extension to the stochastic gradient descent method and is compared against stochastic gradient descent in terms of performance, where the proposed solution is show to outperform general stochastic gradient.

As part of this study, the effect of skip connections on the curriculum management system neural network is looked into. Without skip connections, the network performs poorly while, with skip connections, the network meets the required performance index. It is concluded that the proposed window-shopper optimiser's cost function is critically sensitive to function smoothness. This tallies with the high inter-relativity and interdependence of the curriculum elements that are handled by the system. It is also shown that the size of the training samples for the neural network has strong impact on the training efficiency of the ANN. The extreme margins of the range of training sample sizes decrease efficiency while a carefully calculated sample size, positioned more centrally results in optimum efficiency. The approach used in this study is to run multiple tests with gradually increasing sample size, then using interpolation to estimate the optimum sample size.

The practicality of the proposed curriculum management solution is investigated. The proposed solution implements an across-the-board approach, where manipulation of curriculum is executed across the entire study course value chain for each decomposed curriculum element. While this approach decentralises curriculum to the educator level from the faculty/school level, this approach is shown to improve practicality of curriculum management, as the process begins to incorporate the entire teaching staff, although in a highly organised and transparent manner. Consequently, this results in improved uniformity and consistency in curriculum management, yet still, the individual teacher maintains freedom in terms of course structuring, according to the applicable regulations and standing instructions. With the proposed approach, a curriculum management recommendation moves from being directed to a particular teacher in charge of the most relevant course/module to the recommendation, to being directed to all teachers, each then addressing the recommendation through their individual teaching plan. This study reveals that the outcome of the proposed curriculum management system with atomic manipulation, has an effective teacher-involvement rate 300 percent higher than that of the conventional approach. In the same way, the implementation of the outcome of the proposed system has an effective course/module reach that is three times higher than that of the conventional method. This demonstrates substantial improvement in curriculum management effectiveness.

Overall, this is not implemented to affect or change the layout or arrangement of courses or modules, but rather, the components that make up the courses, such as student assignments, group discussions, projects and so on. It is concluded that this approach optimises curriculum alignment to industry, without compromising the chances of students who may not be interested in pursuing the local industry but rather foreign work or even further study.

6.2 Contributions

This research contributes a comprehensive solution that is based on artificial intelligence algorithms to implement decomposed curriculum management in order to better align industrial engineering curriculum to the needs of industry by interpreting industry needs from relevant job advertisement platforms. A window-shopper inspired optimiser is proposed as an extension to the stochastic gradient descent optimiser, and is proven to improve the neural network learning efficiency. This study contributes a framework for improved effectiveness of curriculum management for the industrial engineering program. The framework is set to improve intimacy between industry and education in order to produce more competent and more industry-ready graduates. From literature, it was shown that the global economy is volatile and highly dynamic as affected by politics, social factors, technology advancements, environmental factors and so on. These dynamics are passed on to industry, ultimately affecting the needs of industry, thus the proposed framework for curriculum management is developed. The proposed framework ensures that while curriculum is managed according to decomposed manipulation at the teacher-level, the curriculum gains flexibility yet maintaining national/international standards, leading to the conclusion that the proposed framework holds high potential and is an avenue worthy of investment and fine-tuning.

6.3 Limitations

As the full cycle of the proposed curriculum management system is explored, some limitations have been identified. These limitations originate from some two assumptions made for the methodology part of this research. These assumptions are that the job advertisements posted are legitimate and valid; and that the job summary/description provided with each job post is complete. This shows that the overall performance of the system is limited to the nature and also quality of the information that is fed in, as collected from the relevant job advertisements platforms. This data is utilised to compute output recommendations.

Measures are taken though, to minimise the effects of these limitations on the overall performance of the curriculum management system. While the system is fully functional as intended, in better aligning IE education to the economy and business environment, the system cannot be transferred for use on a different engineering or non-engineering study program without significant design and structural adjustment. This entails that the system is limited to the study program of interest. The limitation however, in-turn, allows for a more thorough analysis of the curriculum and alignment there of.

6.4 Future work

In future, it is desired to expand the proposed curriculum management system. This will be characterised by modifying the system to allow more autonomy in terms of data collection and data preparation from relevant job advertisements. This will also be characterised by modifying the system for ease of deployment and compatibility to not a single, but multiple curriculum cases. Ultimately, the solution will be packaged as an off-the-shelf tool, with a user interface that allows some minimum data input. Future work will incorporate an automated system to track the implementation indices of the teachers, to better facilitate how the output of the curriculum management system is realised practically. The proposed approach in this study leaves the teacher at the front line of the implementation of the outcomes of the curriculum system. This is a further benefit in the sense that consistency and uniformity of teachers' understanding and implementation of curriculum is further improved.

Future work will also include a fusion of data related to post graduate short professional courses. Trends in professional course enrolment provide vital information as to the state of industry and the professional requirements there of. Such information, if collected and analysed accordingly, potentially provides space for further curriculum improvement in terms of alignment to industry. In vice-versa, short courses may in fact be manipulated too, according to certain dynamics in industry.

6.5 Concluding remarks

Curriculum misalignment is a reality that has seen higher learning institutions investing substantially in curriculum management. With advances in technology decade after decade, advanced curriculum systems have surfaced, which automate the process of curriculum management in order to achieve improvement in robustness. A curriculum management tool is delivered, to align industrial engineering curriculum closer to the industry needs. To complement the proposed system, a framework is also designed and presented.

The proposed curriculum management system adopts a concept of decomposed curriculum manipulation. This concept involves atomizing the entire program curriculum into key topical elements. These elements are then manipulated at element level, according to the needs of the industry and this approach is shown to be more meticulous and holistic. The motivation for this is that curriculum courses are highly interrelated, with common elements across different courses or modules, and in this way, atomic curriculum manipulation improves quality of curriculum management towards alignment to the skill or knowledge needs of the industry. Artificial intelligence is proven to be an effective control algorithm for such a system, given the complexity and high interdependency of the control data. The proposed system achieves the objective of managing curriculum in a manner that maintains integrity and interconnectivity of the multiple variables involved.

Appendix A

General curriculum outline

A.1 Advanced Diploma in Industrial Engineering

First level
Academic Language and Literacy in English
Ethical Information and Communication Technologies for Development Solutions
Mathematics I (Engineering)
Mechanics I (Practical)
Mechanical Engineering Drawing I
Mechanical Manufacturing Engineering I (Theory)
Mechanical Manufacturing Engineering I (Practical)
Elementary Mechanics

Second level
Electrical Engineering I (Theory)
Electrical Engineering I (Practical)
Engineering Work Study I
Mechanical Manufacturing Engineering II (Theory)
Mechanical Manufacturing Engineering II (Practical)
Production Engineering: Industrial I
Qualitative Techniques
Strength of Materials II (Theory)
Strength of Materials II (Practical)

Third level

Engineering Work Study II
Facility Layout and Materials Handling
Human Resource Management for Line Managers
Introduction to Management Accounting
Principles of Strategy, Risk and Financial Management Techniques
Mechanical Manufacturing Engineering III
Production Engineering: Industrial II
Quality Assurance

Fourth level

Automation
Engineering Work Study III
Financial Management IV
Industrial Engineering Practice I
Industrial Engineering Practice II
Mechanical Engineering Design II
Management Practice IV
Operational Research

Appendix B

Employment cases

B.1 Case 2

The second case is a posting to recruit an industrial engineer a manufacturing company. The position summary states that the incumbent must perform a range of engineering work in the planning of engineering activity, including overseeing research and development, as well as taking lead over the design and manufacturing wing, overseeing the product testing, assembly and maintenance, for the production of electronic equipment systems. The job functions are listed as:

1. Design analysis and review.
2. Make design contribution to products.
3. Generate design specifications of complex projects.
4. Deliver technical presentations for product design and review.
5. Develop and maintain a system or database to track project progress.
6. Direct interface with customers to review compliance to meeting requirements and specifications.

For the second case, the industrial needs, together with the corresponding key curriculum elements are given below:

Design evaluation: Computer aided design, design simulation, design analysis, creative design, drawing interpretation, innovation, inter-disciplinary learning, inter-faculty learning, operations research, written skills, oral skills, metrology, sustainability

Product design: Computer aided design, design simulation, creative design, problem solving, innovation, inter-disciplinary learning, inter-faculty learning, operational research, written skills, oral skills, metrology, engineering standards, sustainability

Product development: Manufacturing processes, lean principles, quality management, marketing, budgeting, planning, problem solving, innovation, inter-disciplinary learning, inter-faculty learning, operational research, engineering standards, sustainability, legal factors, salesmanship

Design specification: Drawing interpretation, inter-disciplinary learning, inter-faculty learning, operations research, written skills, oral skills, engineering standards

Communication: Engineering ethics, written skills, oral skills

System development: Data management, research skills, planning, system modelling and simulation, creative design

B.2 Analysis of case 2

The Table B.1 below gives a summary of the key curriculum elements that are derived from the industrial needs of case 2.

Table B.1: Summary of case 2 curriculum elements

inter-disciplinary learning	4	computer aided design	2	quality management	1
inter-faculty learning	4	design simulation	2	marketing	1
research skills	4	drawing interpretation	2	budgeting	1
written skills	4	metrology	2	engineering ethics	1
engineering standards	4	problem solving	2	oral skills	1
sustainability	4	planning	2	operational research	1
creative design	3	design analysis	1	sys modelling&simulation	1
innovation	3	manufacturing processes	1	legal factors	1
oral skills	3	lean principles	1		

From case 2, the top curriculum elements pointed out are (1) inter-disciplinary learning, (2) inter-faculty learning, (3) research skills, (4) written skills, (5) engineering standards and (6) sustainability. The reason behind the prevalence of (1) and (2) is that, as a position involving a range of engineering work and critical planning, the incumbent is expected to engage and work effectively with other staff members from different departments of the company, as well as external contacts, including customers. As for the industrial needs, case 2 presents the following: (1) design evaluation, (2) product design, (3) product development, (4) design specification, (5) communication and (6) system development. It is noted that 'system development' to this point, has already appeared twice, in the two cases discussed. As more cases are discussed, the data becomes more refined.

Appendix C

Recommendations

C.1 Assessment System recommendations

Review engineering software.
Review adequacy of laboratory equipment.
Improve elective course selection list.
More attention on Written and Oral Communication Skills.
More attention on problem solving and research.
Create an Engineering core concentration.
Change ENVR course suffix to ENGR.
Eliminate engineering minors and create specialisations.
Eliminate the Water Pollution and Treatment course.
Change course name from Design of Structures to Structural Design I and Structural Design II and improve scope.
Change course name from Robotics to Mechatronics.
Change course COMSC490 from three credit to four credit course.
Replace two required courses with electives.
Create a laboratory component to the Mechatronics course and also change credits from three to four.
Make Structural Analysis a requirement for the Electronics qualification.

Appendix D

Network design

D.1 Implementation of the network

The ANN is implemented by means of the PyTorch tool, a framework that is well supported in terms of digital community contributions. Reference is made to [211], for the development stages of the ANN. The general process comprises three main steps, listed as:

1. installation,
2. data preparation,
3. training,
4. evaluation,
5. prediction.

The steps listed above are expanded to provide further detail in the subsections that follow below. This illustrates the procedure reflected by Chapter 4 which outlines the research methods, including the design.

D.2 Installation

The installation process starts with downloading the executable from $https://pytorch.org/get-started/locally/$. For this study, the stable build (version 1.9.0) is used, on a Windows operating system, running the pip package in Python language. The full installation guide is available on $https://pytorch.org/get-started/locally/$.

D.3 Data preparation

This step is characterised by loading the experimental data obtained from the job advertisements, as to the needs of the industry, in terms of graduate skills. In this way, numeric input and output data is loaded in comma-separated value file format, as presented under Section 4.3.2.1.

A sample of dataset class is given below:

dataset definition
class CSVDataset(Dataset):
loading
def _init_(self, path):

self.X = Cost optimisation
self.y = Optimisation theory, system modelling and simulation, dynamic programming, data management, operational research, research skills, management practice, finance, risk, quality, supply chain, management accounting, economics, accounting for engineers, budgeting, planning, scheduling, security, sustainability

...

number of rows in the dataset
def _len_(self):
return len(self.X)

indexing
def _getitem_(self, idx):
return [self.X[idx], self.y[idx]]

Data preparation is then followed by model definition, characterised by defining the layers of the model as highlighted in Section 4.5.4 and a $forward()$ function is used to allow forward propagation of input right through the set layers of the network model.

D.4 Training

The training stage demands that the loss function discussed in Section 4.1 be defined. The optimization algorithm as well, is also defined. As highlighted, the mean squared loss function is used and the stochastic gradient descent optimizer. These two are packaged and represented in PyTorch by the MSELoss() and SDG() functions respectively. The training process is summarised by:

1. Clearing the last error gradient,
   optimizer.zero_grad() function.

2. Forward passing input through the model,
   output = model(inputs).

3. Calculating loss,
   loss = criterion(output, desired outputs).

4. Back-propagating error through the model,
   loss.backward() function.

5. Updating the model to reduce loss,
   optimizer.step() function.

PyTorch provides various functions that can be used in developing network models of varying complexity.

D.5 Evaluation

The model is evaluated to determine the fitness of the model. The dataset is distributed between training and evaluation as specified in Section 5.3.

D.6 Prediction

As intended, the network is then used to make predictions of the key curriculum topics (atoms) that require prioritisation, according to the demands of industry. Such predictions are given in Chapter 5.

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