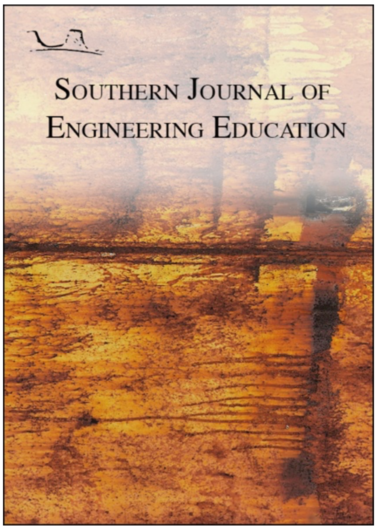

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Strengthening South Africa's maritime industry through higher education in naval architecture and marine engineering

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Strengthening South Africa's maritime industry through higher education in naval architecture and marine engineering

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The maritime industry is inherently global, with seafarers and skilled expatriate engineering graduates employed worldwide, away from the places where they grew up and obtained their specialist qualifications. Consequently, any higher education qualification in the maritime sector must ensure that graduates are equipped to compete internationally for employment opportunities and be academically prepared for the engineering challenges of the future arising from technological advancements. This paper presents a study on naval architecture and marine engineering (NAME) higher education in South Africa and compares it to three international marine education universities. A qualitative content analysis methodology was employed to analyse the module content of each selected international institution. Patterns that emerged from the analysis were used to compare these with the curriculum of the current Bachelor of Engineering Technology in Marine Engineering degree programme that has been offered by the Nelson Mandela University in South Africa since 2018. This analysis of the international programmes identified 18 themes that a quality NAME programme should encompass to meet the academic requirements for the future engineers in the global maritime sector. The study recommends the addition of a fourth-year Honours degree and a fifth-year taught Master's degree to the existing three-year undergraduate Bachelor of Engineering Technology in Marine Engineering degree. The proposed curriculum, unique in the South African higher education environment, will enable graduates to apply mathematical and scientific principles to the 'design, development and operational evaluation of self-propelled, stationary or towed vessels operating on or under the water, including inland, coastal and ocean environments' (Department of Education, 2008).

Keywords: Academic qualification; naval architect; marine engineer; qualitative analysis

Introduction

The South African government is committed to strengthening the national economy by harnessing opportunities related to the ocean and associated fields. Through the initiative Operation Phakisa (meaning 'hurry up' in Sesotho), the government facilitated an Oceans

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Economy Lab from 15 July 2014 to 15 August 2014. The lab, which included over 180 delegates from government, the private sector, civil society and academia, highlighted the need for maritime skills development and the establishment of a maritime educational framework (Findlay, 2018; Department of Planning, Monitoring & Evaluation, 2014).

In South Africa (SA), the broader marine engineering field (naval architecture, ship/vessel design, maintenance, offshore oil rigs), has largely stagnated at higher education (HE) levels (University of Stellenbosch, 2017). From the early 2000s up to 2018, there were no institutions offering any HE qualifications in this field other than seafarer education, which is focused on the operations and management of ships (Cape Peninsula University of Technology, 2017; Durban University of Technology, 2020). As a result, HE in South Africa in naval architecture and marine engineering (NAME), encompassing design, manufacture and development engineering, from the early 2000s to 2018, was non-existent (Heimann et al., 2011). With the focus on ocean economic development, it was identified through Operation Phakisa that NAME is a scarce skill as most of the expertise used in SA is sourced abroad. These are skills that SA once possessed, but the country has lost many of these skills over time and now needs to rebuild them (Funke et al., 2017). Therefore, there is a need for urgent development at the HE level to support the envisioned growth in ship design and building as South Africa begins to invest in the manufacturing and high-value maintenance of ships and vessels.

The purpose of this study was to evaluate if the HE framework in SA can adequately provide the academic foundation needed to develop and build a globally competitive maritime industry in ship design, construction and maintenance, and then propose a framework to address any existing gaps. Using thematic qualitative content analysis, focusing on subjects/modules and content, this study firstly evaluated the current framework of NAME in South African HE. Then a detailed evaluation of three international university NAME qualifications was done to analyse the content and standards of international NAME HE. Various themes of the content that emerged from the international study were compared against the current South African framework. The final analysis highlighted what needed to be added to the South African marine engineering qualifications to ensure that South African graduates would meet the requirements for an internationally recognised qualification in NAME.

Literature review

Marine engineering and naval architecture higher education in South Africa

In SA there are only three universities that have a specialised marine engineering qualification. Durban University of Technology (DUT), Cape Peninsula University of Technology (CPUT) and Nelson Mandela University (NMU) offer accredited three-year seafarer qualifications (NQF 5–7). The South African Maritime Safety Authority (SAMSA) is the accrediting body for seafarer qualifications related to manning and operating ships and related vessels. The (then) Department of Education via its National Qualification Framework (NQF) defines the following levels of education: school exit level = NQF 4; three-year degree = NQF 7; Honours degree = NQF 8; and Master's degree = NQF 9 (Isaacs, 2000).

The Bachelor of Engineering Technology Degree in Marine Engineering from NMU is the only qualification that comprehensively incorporates an academic foundation for design, manufacture and development in NAME, and is accredited by the Engineering Council of South Africa (ECSA). Figure 1 shows the current framework for marine engineering at universities in South Africa, also showing that NMU is accredited by both ECSA and SAMSA.

NAME is an area of study which prepares individuals to apply mathematical and scientific principles to the design, development and operational evaluation of self-propelled, stationary or towed vessels operating on or under water, including inland, coastal and ocean environments; and the analysis of related engineering problems such as corrosion, power transfer, pressure, hull efficiency, stress factors, safety and life support, environmental hazards and factors, and specific use requirements (Department of Education, 2008). There are only a few experts – likely fewer than ten naval architects (Mukandila, 2018) – in the whole of the South African maritime industry. Most are operating independently, with the majority of their projects being for international northern hemisphere clients (Urban Soul Group, 2017). South Africa has also lost many of its expert marine engineers and naval architects to the international market over the last 20 years, and there has been very little investment to maintain these skills (Department of Transport, 2017).

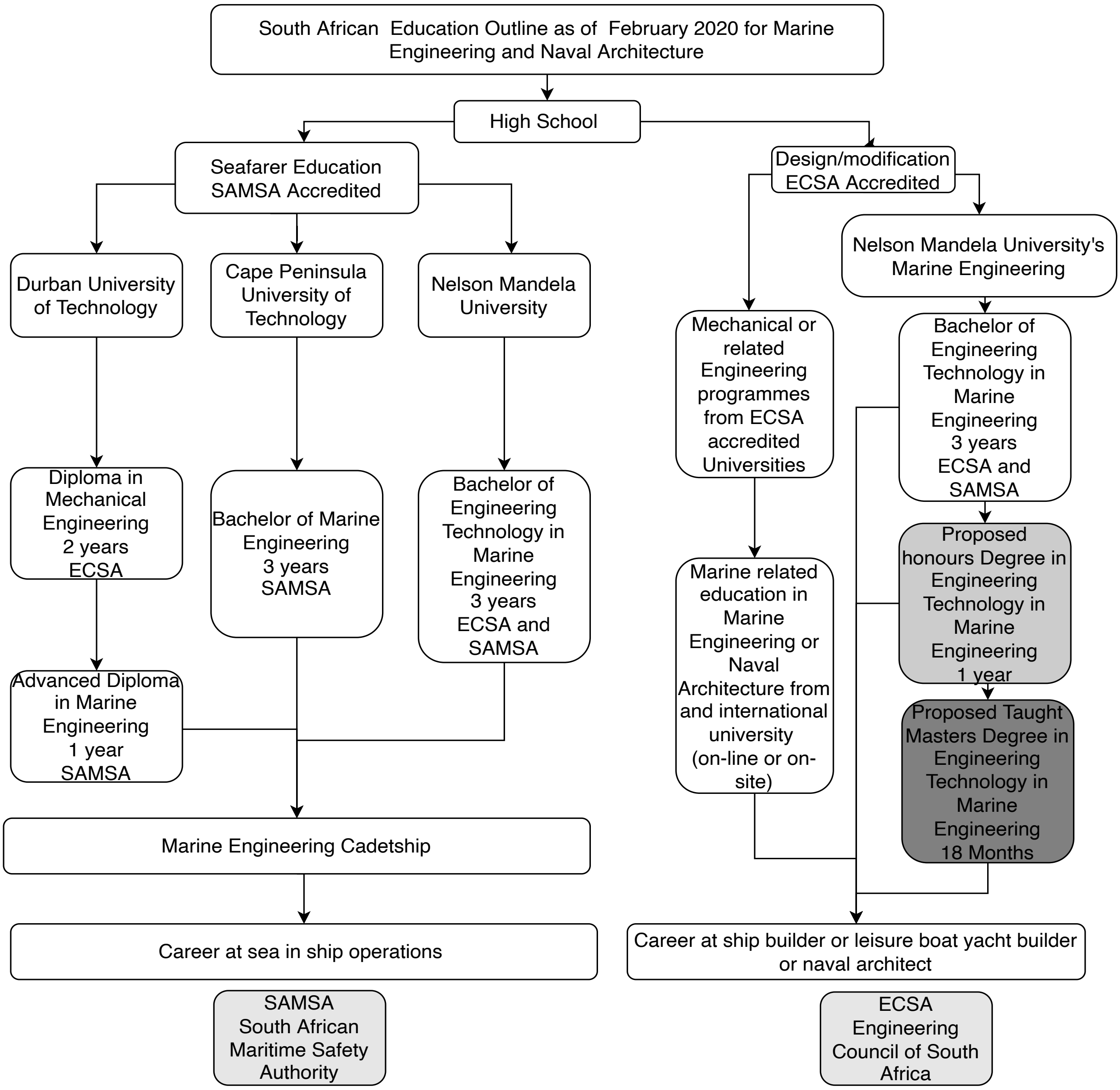


Figure 1*: Flow diagram of marine education in South Africa, February 2021 (Theunissen, 2021).*

Added to the shortage of design skills and expertise in the South African maritime sector is the lack of research related to designing vessels specifically for operation off the South African coastline and in Southern Ocean conditions. Landmass in the northern hemisphere is 68% compared to the 32% in the southern hemisphere (Mendez, 2017), with wave characteristics and frequencies in the latter tending to higher waves with greater gaps between them compared to the former. These wave frequencies impact the sea-keeping and performance of vessels, affecting their comfort, speed, and load capabilities. A vessel designed for northern hemisphere conditions will not operate optimally in southern oceans (MacHutchon, 2006). Potgieter (2014) describes the southern hemisphere operational problems experienced by South African Navy strike craft:

> Owing to operational problems and shortcomings experienced with strike craft, the new ships had to be bigger. Their small size, limited sea-keeping and lack of endurance made strike craft unsuitable for South African conditions. Their endurance is drastically reduced in heavy seas, speed must be reduced and crew fatigue increases. The cramped and often demanding conditions on board were not conducive to attracting and retaining highly-qualified personnel (pp. 183–202).

The sustainability of the maritime industry depends on the skills in the various maritime-related fields. To develop and grow the sector designing and building boats, ships and marine structures in South Africa, there needs to be a focus on the source of the skills, namely the universities. In any given career, the normal flow is mentorship of university-educated graduates by industry professionals, which is an important process in an engineer's career development. ECSA requires that a graduate registers as a Candidate Engineer under mentorship of a professional engineer before applying to be registered as a professional engineer (ECSA, 2020). These professionals pass on their experience to their mentees. As these graduates grow in their skills, they then transfer their skills on to the next generation of professionals. However, as noted in the introduction, there is a critical shortage of skills in South Africa in the design and building of boats, ships and marine structures. In addition, there are no local universities training new graduates in these skills. Therefore, there is limited transfer of NAME skills, and these skills are slowly being lost.

Stellenbosch University has proposed to reintroduce a Master of Engineering in Marine Engineering that was offered from the early 1970s until the late 1990s. The course focused on hydrodynamics, ship stability and sea-keeping. However, this course is still not available (University of Stellenbosch, 2017). Therefore, since the early 2000s and prior to 2018, the only marine engineering higher education in South Africa was for seafarer training and development in the transport sector offered at DUT and CPUT. These qualifications are focused on seafaring, operations and maintenance. There has been no programme that focused on marine design until January 2018, when the Nelson Mandela University introduced the ECSA-accredited Bachelor of Engineering Technology (BEngTech) in Marine Engineering. This paper only focuses on the Bachelor of Engineering Technology in Marine Engineering at NMU and will make recommendations of what modules and content need to be added to the qualification to meet the academic requirements for graduates to register as a recognised naval architect with the professional body, RINA (Royal Institute of Naval Architects).

International standards and requirements for naval architecture and marine engineering

To accomplish this, the authors collaborated with Prof Philip Wilson, who has over 40 years' experience as a lecturer/professor in naval architecture at the University of Southampton. He noted that it was not possible just to add a few marine-related modules to a mechanical engineering qualification to adequately prepare a graduate for a career in NAME. There were fundamental educational concepts and foundations that needed to be established within the curriculum, or additional subjects/modules added to the overall curriculum to ensure that these principles were covered. Mathematics is fundamental to naval architecture. The University of Southampton even allows first degree graduates with a mathematics background to enter its MSc in Marine Engineering. Therefore, for a naval architecture qualification to be relevant, it needs to have a significant mathematical component (Weymouth, 2020).

Wilson (personal communication, May 29, 2020) recommends that the relevant mathematic requirements for naval architecture need to include the following:

- First course in Ship Stability – Marine Engineering
  - Basic integration and differentiation.
  - Ability to integrate linear shapes in 2-D and in 3-D. Integrate parabolas to find areas. Integration for finding moments and volumes of known shapes.
  - Numerical integration using Simpson's Rule.
  - Basic algebraic manipulation.

- Ship Dynamics – Naval Architecture (RINA)
  - Second order linear differential equation methods of solution. This is to apply Newton's Laws and find solutions.
  - Probability theory, including an introduction to probability and various theorems, for example, binomial theorem, introduction to probability density functions using Rayleigh distribution.
  - Setting up coupled differential equations and decoupling where possible.

Further, Wilson (personal communication, May 29, 2020) confirms that to build on the foundation that is laid by the required mathematics, any design-focused NAME qualification will need modules that cover maritime specialities, not just general engineering-related content. For example, (Wilson, 2019) includes:

- Ship Stability – Marine engineering-related speciality modules considering:
    - Marine Hydrodynamics
    - Ship Design and Economics
    - Structural Design and Production
    - Materials and Marine Composites
    - Offshore Engineering for platform specialists
- Ship Dynamics – Marine Engineering, building towards naval architecture-related speciality modules, considering:
    - Marine Hydrodynamics
    - Sea-keeping and Manoeuvring
    - Ship Resistance and Propulsion
    - Advanced Marine Engineering
    - Computational Analysis applied to CFD and FEA
    - Marine Structure
- Further electives for specialities, related to South African industry:
    - Small Craft Performance
    - Renewable Energy and Environmental Flows

Therefore, any qualification that lays the academic foundation for a career as a design-focused marine engineer and RINA-accredited naval architect needs to cover the above content at the Bloom's taxonomic levels of Analyse, Evaluate and Create (Anderson & Sosniak, 1994).

Evaluation of three European universities offering NAME qualifications, in relation to South African higher education

To do a comparative benchmark of the BEngTech at NMU, three international universities were selected for evaluation and comparison. This paper is limited to these three institutions but acknowledges that future research possibilities could include other programmes. These institutions provided a suitable foundation for this paper. The selection of these university programmes was based primarily on the established relationships and contacts with the institutions, supported by the similarity of these institutions' offerings to the South African institutions.

The approach of these institutions to their NAME courses is applicable to the South African context as follows:

- The University of Southampton in Southampton, United Kingdom, offers a four-year Master's in Engineering qualification.
    - The Southampton engineering degree is fully recognised by RINA.

- Chalmers University of Technology, in Göthenberg, Sweden, offers a two-year postgraduate Master's programme that a graduate would consider after completing an undergraduate engineering qualification
    - This institution was chosen as it resembles the programme structure that Stellenbosch University in South Africa proposed to implement for their Naval Architecture Master's degree.

- Solent University, in Southampton, United Kingdom, is an applied engineering university with a three-year Bachelor of Engineering (Honours) and a four-year Master of Science degree.
    - This institution is very similar to the Nelson Mandela University structure with a large focus on applied engineering, although the Solent courses are only partially recognised by RINA.

The University of Southampton undergraduate Bachelor and Master of Engineering

The University of Southampton is one of the top 100 global universities (Quacquarelli Symonds, n.d.) and is a global leader in maritime education with global alumni. The Southampton undergraduate ship science programmes are based on the broad foundation of a mechanical engineering degree with a focus on marine engineering. The programmes aim to provide the students with the necessary academic foundation for a career that covers the design, construction, maintenance and operation of marine vessels and structures (Keane, 2020).

Note that the University of Southampton uses the descriptor 'Ship Science' to broadly describe their naval architecture and marine engineering qualifications. Speciality pathway streams that an undergraduate can elect are as follows:

- Bachelor of Engineering (three years) – BEng (Keane, 2020)
  - Ship Science

- Master of Engineering (four years) – MEng (Keane, 2020)
  - Ship Science
  - Ship Science/Naval Architecture
  - Ship Science/Yacht and High Performance
  - Ship Science/International Naval Architecture
  - Ship Science/Marine Engineering and Autonomy
  - Ship Science/Ocean Energy and Offshore Engineering
  - Ship Science/Advanced Computational Engineering

Table 1: *Modules and structure of the Southampton Naval Architecture Pathway*

<table>
<tr><td rowspan="7">Year 1</td><td>Semester 1</td><td>Semester 2</td></tr>
<tr><td colspan="2">Basic Naval Architecture</td></tr>
<tr><td colspan="2">Design and Computing</td></tr>
<tr><td colspan="2">Mechanics, Structures and Materials</td></tr>
<tr><td colspan="2">Thermofluids</td></tr>
<tr><td colspan="2">Electrical and Electronic Systems</td></tr>
<tr><td colspan="2">Mathematics for Engineering and the Environment</td></tr>
<tr><td rowspan="6">Year 2</td><td>Semester 3</td><td>Semester 4</td></tr>
<tr><td colspan="2">Engineering Management and Law</td></tr>
<tr><td colspan="2">Hydrodynamics & Sea-keeping</td></tr>
<tr><td>Mathematics for Engineering & the Environment</td><td>Materials and Structures</td></tr>
<tr><td>Resistance and Propulsion</td><td>Ship Structural Design and Production</td></tr>
<tr><td>Systems Design and Computing for Ships</td><td>Ship Design and Economics</td></tr>
<tr><td rowspan="5">Year 3</td><td>Semester 5</td><td>Semester 6</td></tr>
<tr><td>Individual Project (core)</td><td></td></tr>
<tr><td>Marine Craft Concept Design</td><td>Ship Manoeuvring and Control</td></tr>
<tr><td>Marine Engineering</td><td>Marine Hydrodynamics</td></tr>
<tr><td>Finite Element Analysis in Solid Mechanics</td><td>Marine Structures</td></tr>
<tr><td rowspan="7">Year 4</td><td>Semester 7</td><td>Semester 8</td></tr>
<tr><td>Group Design Project (core)</td><td></td></tr>
<tr><td>Maritime Safety and Law</td><td></td></tr>
<tr><td>Advances in Resistance and Propulsion</td><td>Marine Structures in Fluids</td></tr>
<tr><td>Composite Engineering, Design and Mechanics (Optional)</td><td>Design Search and Optimisation (optional)</td></tr>
<tr><td>Offshore Engineering and Analysis (optional)</td><td>Renewable Energy from Environmental Flows (optional)</td></tr>
<tr><td>Maritime Robotics (optional)</td><td>Failure of Materials and Components (optional)</td></tr>
</table>

Southampton's flexible structure, as shown in Table 1, with options in year 4, ensures a core framework of naval architecture and marine engineering while allowing the choice of a specialist pathway. The first two years, common across the specialities, cover the fundamentals of basic engineering and ship science. The programme ensures that design is emphasised throughout all the levels of the academic qualification, both in a general and a marine context. Additionally, there is also a focus on computational methods as a tool for engineering problem analysis.

Southampton Postgraduate MSc in Maritime Engineering Science

The University of Southampton includes a pathway to a postgraduate Master of Science in Maritime Engineering Science for graduates who have engineering, scientific or mathematical backgrounds (University of Southampton, n.d.; Weymouth, 2020). This is a one-year (two semester) Master's degree, which suits postgraduate students who would like to pursue a career in the maritime sector after studying a non-marine related qualification. However, the previous qualification must have been in been in engineering, science or mathematics, for a candidate to be eligible to take the MSc.

Chalmers University of Technology in Sweden – Master in Naval Architecture and Ocean Engineering

Chalmers University in Sweden, ranked globally at 125 (Quacquarelli Symonds, n.d.), offers a Master of Science in Naval Architecture and Ocean Engineering degree taken over two years. Entry into the course requires a bachelor's degree in science, engineering, technology or architecture. As with the University of Southampton, Chalmers notes that mathematics is important and must include linear algebra, multivariable analysis, mathematical statistics and numerical analysis. Additional foci required include mechanics, fluid mechanics and strengths of materials or solid mechanics.

The Naval Architecture and Ocean Engineering course focuses on the 'conception, planning, design and analysis of large marine structures considering hydromechanics and strength through a holistic approach' (Chalmers University, 2020). Table 2 outlines the course content with the optional electives (Chalmers University, 2020).

Table 2: *Two-year postgraduate programme structure and optional modules for Chalmers University Master in Naval Architecture and Ocean Engineering*

	Semester 1	**Semester 2**
Year 1	Maritime Transport Studies	Ship Geometry and Hydrostatics
	Marine Structural Engineering	Ship Resistance and CHD
	Marine Propulsion Systems	Elective Course
	Waves Loads and Sea-keeping	Elective Course
	Semester 3	**Semester 4**
Year 2	Master's Thesis	
	Design Project (Ship, Offshore, Yacht etc)	Elective Course
	Marine Engineering	Marine Hydrodynamics

Optional modules for electives
Matlab
Composite Mechanics
Finite Element Method - structures
Turbulence Modelling
Reliability Analysis of Marine Structures

Solent University – Southampton

The School of Engineering has a number of programmes related to NAME. However, Solent takes a slightly different approach in that it focuses on selected areas of specialties that directly link to the design and construction of maritime superyacht, yacht and power craft. The following qualifications are offered:

- Bachelor of Engineering (Honours) in Yacht and Power Craft Design (three years)
- Bachelor of Engineering (Honours) in Yacht Design and Production (three years)
- Master of Science in Superyacht Design (four years)

The literature review highlights that the BEngTech in Marine Engineering at NMU does not fully cover the academic foundation required for a NAME qualification in design and development. There is additional content and knowledge required. This will be analysed and addressed in this paper.

Research Methodology

The comparison of the NMU Bachelor Engineering Technology in Marine Engineering against the selected international institutions' NAME qualifications required a systematic evaluation of every subject/module that made up the core curriculum of the qualification. To comprehensively evaluate the data, a qualitative content analysis research methodology was used. Content analysis is the detailed and systematic analysis of the content of a body of material to identify patterns, themes or biases within that material (Leedy et al., 2014) and comprises replicable methods for making interpretations from observed communications to their context (Krippendorff, 1980). All module data (core content text) was imported into and analysed using the qualitative data analysis software, ATLAS.ti. The software highlights and automatically tracks these links and generates reports to view results accurately. To ensure validity, reliability and repeatability, the detailed text of each module from all three international institutions was carefully coded by evaluating every line of text, extracting the subject content keywords and descriptions, and allocating to a theme heading. Initially, a number of theme headings that were commonly related to the NAME field were outlined e.g., Naval Architecture, Mathematics and Principles, Ship Manoeuvring and Control, Resistance and Materials. If there was content not related to any current themes, a new theme was created and all related key words and content linked to the new theme. The themes that emerged from the international content were then evaluated against the NMU BEngTech core content to validate or highlight the gaps. The process followed the seven phases of qualitative data analysis (Marshall & Rossman, 2014). Focusing on the text from the marine modules from the international university programmes, we were able to arrange and reassemble the module text data systematically and establish patterns and networks that emerged from the text study.

Results

Analysis of NAME content covered by the three selected international universities

Once the core content details of the modules were analysed, a pattern emerged showing the content that should be covered in a high-quality marine qualification. These extracts were linked to general headings/themes covering the major sectors for a general (not specialised) NAME qualification. The analysis shows that any qualification aimed at developing the NAME framework in South Africa would need to consider the following content, separated into 18 themes:

1. Codes and Legal Regulations: all legal and regulatory codes and guidelines that an engineer needs to consider and be aware of.
2. Computer Design, Modelling and Software: content related to understanding, operating and producing results assisted by computers.

3. Design: general and specialised design theory and concept theory applied to designing systems, ships and vessels and general related items.
4. Economics, Management and Projects: all themes relating to economics, management and project management, including communication skills and requirements.
5. Electrical, Electronics and Automation: electrical power generation, electronics and automation to control and monitor the systems.
6. Ergonomics and Style: how vessels look and operate, considering comfort, style and seaworthiness
7. Finite Element Analysis (FEA): understanding of fundamental knowledge and techniques of FEA and developing tools to analyse engineering problems.
8. Hydrodynamics and Sea-keeping: the study of fluid dynamics and statistics associated with random processes and integration with a range of marine structures operating on or below the free water surface, for example, how structures interact with the water.
9. Marine Engineering: the principles, design and analysis of ship power plants, drivetrains and auxiliary systems found on board marine vehicles and structures.
10. Materials and Composites: the relationship between composition, microstructure and properties of materials, linked to a deeper understanding of their structural performance. This assessment of structural performance is also developed through more advanced stress and deflection analyses for more complex engineering components and systems used to manufacture the vessels.
11. Mathematics and Principles: laying the mathematical foundation for all engineering modules.
12. Naval Architecture: fundamental properties of floating bodies and insight into the design, construction, management and operation of marine vehicles and an awareness of an engineer's responsibility.
13. Offshore: engineering concepts and analytical techniques that are fundamental to design, operate and decommission offshore fixed, floating and seabed infrastructure in a safe, sustainable way. This includes learning about the different types of sites, platforms and monitoring /decommissioning requirements, an introduction to analytic and numeric methods for predicting the wind, wave and current loads on offshore structures, and the engineering design of different systems to ensure their safety and performance under these expected loads.
14. Renewable Energy and Environment: the atmospheric and gravitational processes present in earth-generated flows of wind and water. This area studies these resources and practical methods/technologies for extracting cost-effective electrical and other energy conversions. The main focus is on wind, wave and tidal energy devices including the use of turbines for low- and high-head hydroelectric schemes. Systems considered include the vital aspect of marine energy in the offshore environment including installation and system survivability.
15. Ship Manoeuvring and Control: fundamental concepts associated with the principles of manoeuvring and control theory, with a focus on vehicles operating on or below the air-water interface.
16. Ship Resistance and Propulsion:
    - Fundamentals of ship resistance to determine the resistance of a ship using traditional experimental and empirical methods, including modern computational methods to analyse the flow around a ship hull.
    - The components of the propulsion system of a ship, from the fuel tanks, through the machinery to the propeller. Systems engineering is introduced as a tool for design of general complex

systems with focus on marine machinery systems. Knowledge of basic hydrodynamic properties of the propeller together with propeller design principles.

17. Structures and Mechanics
    - Knowledge of ship structures and the analysis of their strength. Engineering beam theory and buckling analysis as applied to ship structures and their structural elements.
    - Fatigue design principles.
    - Structural principles and their application to marine-related problems. Fundamental understanding of the methods for the design and analysis of maritime structures and structural components.
    - Fundamentals of mechanics, statics, dynamics and materials.
    - Aspects of design relevant to the longitudinal and transverse strength of ships.
    - Production technology applicable to the shipbuilding industry from the perspective of the shipyard and its management, but also from a design for production viewpoint.
18. Thermofluids: core thermodynamics and fluid mechanics for engineering.

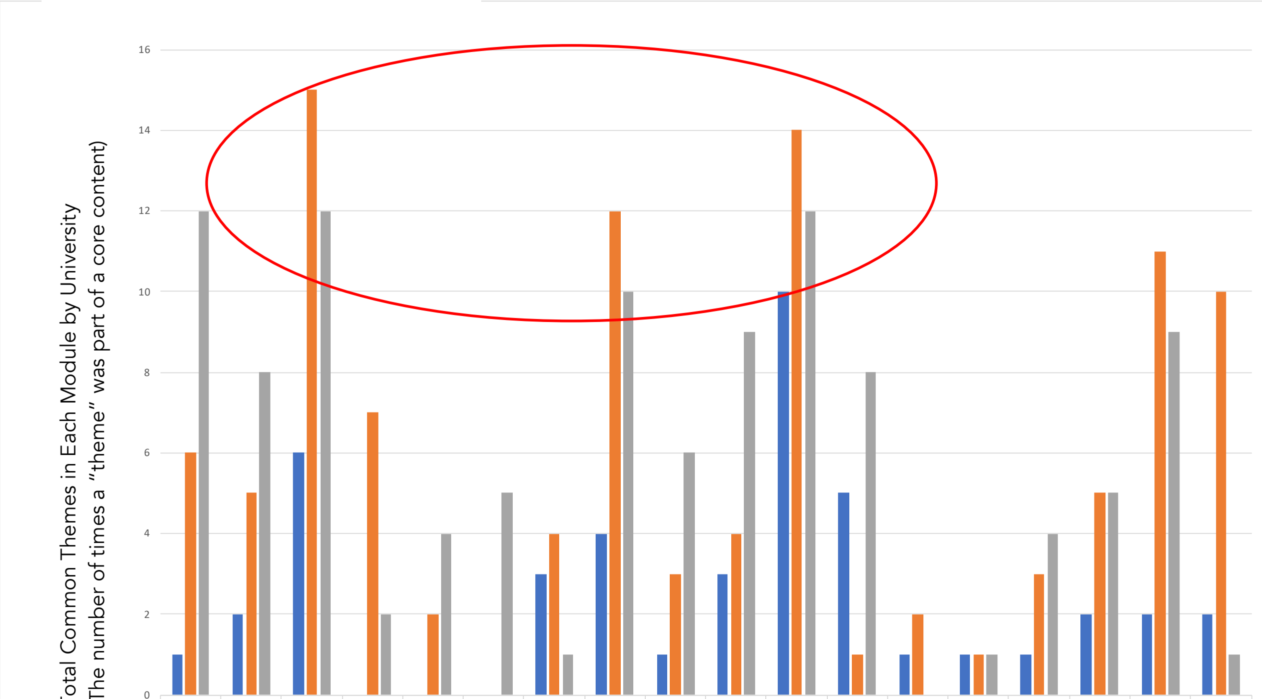
From the extensive ATLAS.ti text analysis, the graph shown in Figure 2 was developed. This shows the total common themes by comparing each university curriculum. For example, 'Design' and design-related core content, were featured 16 times over the 25 modules in the four-year MEng (Naval Architecture) at the University of Southampton. It was featured 12 times in the 27 modules at Solent university, also four years, but six times at Chalmers.

This graph shows that the most common topics/themes that have the most overlap of content are in the areas of design and mathematics, with mathematics showing the content most covered by all three universities. Hydrodynamics and sea-keeping and structures are also areas that are covered across the qualifications.

It was noteworthy that Chalmers University constantly had less common content compared to Solent's MSc and Southampton's MEng Ship Science/Naval Architecture four-year programmes. The reason for this is that Chalmers is a two-year postgraduate master's degree and requires a three-year engineering qualification as an entry into the programme. It is therefore expected that Chalmers would have less common content as there would be a significant portion of the content covered in the undergraduate qualifications that are not part of the Master's content, and therefore were not analysed as part of this research.

Solent and Southampton track against each other closely as they are both four-year qualifications. They accurately reflect the quantity of similar content covered relating to the concepts and themes that a good quality NAME qualification should cover, and therefore should be the focus of that qualification. Noting this, any qualification framework in South

Africa should focus on design, mathematics, hydrodynamics as well as sea-keeping and structures.



	CODES AND REGULATIONS LEGAL Gr=19	COMPUTOR DESIGN, MODELING AND SOFTWARE Gr=15	DESIGN Gr=33	ECONOMICS, MANAGEMENT AND PROJECTS Gr=9	ELECTRICAL, ELECTRONICS AND AUTOMATION Gr=6	ERGONOMICS AND STYLE Gr=5	FEA - FINITE ELEMENT ANALYSIS Gr=8	HYDRODYNAMICS AND SEAKEEPING Gr=26	MARINE ENGINEERING Gr=10	MATERIALS AND COMPOSITES Gr=16	MATHEMATICS AND PRINCIPLES Gr=36	NAVAL ARCHITECTURE Gr=14	OFF-SHORE Gr=3	RENEWABLE ENERGY AND ENVIRONMENTAL Gr=3	SHIP MANOEVERING AND CONTROL Gr=8	SHIP RESISTANCE AND PROPULSION Gr=12	STRUCTURES AND MECHANICS Gr=22	THERMOFLUIDS Gr=13
Chalmers University Gr=45	1	2	6	0	0	0	3	4	1	3	10	5	1	1	1	2	2	2
University of Southampton Gr=92	6	5	15	7	2	0	4	12	3	4	14	1	2	1	3	5	11	10
Solent University Gr=124	12	8	12	2	4	5	1	10	6	9	12	8	0	1	4	5	9	1

University

Figure 2: *Total common themes in each university*

The University of Southampton generally leads with more content over Solent owing to its being a science university. The focus of Southampton is the science of engineering, and therefore it approaches problem resolution from a 'first principles' position. Solent is an applied university, and therefore its approach is applied engineering. The understanding of first principles is taught, to ensure that students have a foundational knowledge of the formulae and concepts; however, the general approach is to provide the formulae to solve problems rather than develop the formulae from first principles. Solent takes applied teaching a step further and does not have a separate mathematics module, as is generally expected in an engineering programme. Solent teaches the specific mathematics skills in the modules and applies the mathematics in context (Jonathan Ridley, personal communication, July 14, 2020). Solent also has a focus on codes and regulations and materials, and specifically, composites. Solent's qualifications are further applied to the yachting and leisure craft industry. As a result, Solent focuses on the regulations for this sector as well as the material that the yachting industry uses, rather than the generalisation of marine materials. The next level of content that the programmes are built on are structures and mechanics.

All three institutions apply little focus to the renewable and environmental modules. However, this is a growing knowledge area that is gaining focus. All future programmes must integrate these modules into the programme to remain relevant to modern engineering.

Offshore engineering is only covered by Chalmers and Southampton. However, in a South African context, the offshore industry will continue growing as there is further exploration for oil and gas off the SA coast. Therefore, any South African qualification should incorporate offshore content. The requirement for offshore skills was again highlighted in a News24 article in February 2019 entitled 'What a major offshore gas find means for South Africa's energy future' (Mtshali, 2019).

Results analysis applied to Nelson Mandela University Marine Engineering programme

In late November 2017, the Faculty of Engineering, Built Environment and Information Technology at Nelson Mandela University in Gqeberha (formerly, Port Elizabeth) received approval from the South African Qualifications Authority (SAQA), the Higher Education Quality Framework (HEQF) and Council on Higher Education (CHE) to offer the Bachelor of Engineering Technology degree in Marine Engineering (Louie Swanepoel, personal communication, October 27, 2017).

From the outset, the goal of the Bachelor of Engineering Technology in Marine Engineering was to lay a solid foundation for naval architecture as there was no other institution in South Africa, or even in Africa, that offered a RINA-accredited qualification (or equivalent) in ship engineering, design and naval architecture. One exception was the University of Alexandria in Egypt, which has several NAME programmes from Bachelor up to PhD level (RINA, 2020).

Table 3 shows the framework of the current undergraduate Bachelor of Engineering Technology in Marine Engineering offered at the Nelson Mandela University. The core content of the undergraduate programme was evaluated against the 18 themes listed above in the results section. It was determined that an Honours and taught Master's programme should be developed to fully cover the required content and level to provide an academic foundation for future NAME managers.

	Semester 1	Semester 2
Year 1 – NQF 5	Mathematics IA	Mathematics IB
	Physics IA	Physics IB
	Engineering Drawing IA	Marine Engineering Knowledge I
	Professional Communication Language IA	Naval Architecture I
	Professional Communication Computers IA	Marine Law
	Semester 3	**Semester 4**
Year 2 – NQF 6	Mathematics II	Thermodynamics IIB
	Strength of Materials IIA	Strength of Materials IIB
	Statics and Dynamics IIA	Naval Architecture II
	Marine Engineering Knowledge II	Mechanical Design IIB
	Fluid Mechanics IIA	Marine Electrical Systems II
	Semester 5	**Semester 6**
Year 3 – NQF 7	Thermodynamics IIIA	Naval Architecture III
	Marine Electrical Systems III	Marine Engineering Knowledge III
	Marine Research and Project Management III	Marine Advanced Automation IIIB
	Marine Automation and Programming IIIA	Marine Engineering Capstone Project IIIB
	Mechanical Design III	

Table 3: *Bachelor of Engineering Technology in Marine Engineering NFQ 5, 6 and 7*

Nelson Mandela University Department of Marine Engineering Honours framework

To comprehensively address the gaps identified in the analysis of the undergraduate programme, an Honours and a Master's framework were developed to ensure that necessary NAME core content would be covered.

The framework illustrated in Table 3 was developed at NQF 8 level. This fourth year still did not fully address the NAME requirements, but it built progressively onto the foundation of the BEngTech. This level provided opportunity to introduce more complex marine engineering topics like hydrodynamics, that will still need a subsequent level to complete, Hydrodynamics II.

<table>
<tr><th rowspan="6">Year 4 – NQF 8</th><th>Semester 7</th><th>Semester 8</th></tr>
<tr><td>Applied Mathematics</td><td>Hydrodynamics</td></tr>
<tr><td>Ship Design and Economics</td><td rowspan="2">Research Project</td></tr>
<tr><td>Ship Structural Design and Production</td></tr>
<tr><td>Off-Shore Engineering I</td><td rowspan="2">Design Project</td></tr>
<tr><td>Marine Materials and Composites I</td></tr>
</table>

Table 4: *Proposed Fourth-year Honours for Nelson Mandela University Marine Engineering*

The fourth-year Honours in Marine Engineering at the Nelson Mandela University was submitted to the SAQA and the CHE for accreditation and registration, and was approved on 3 August 2021 (Julie Reddy, personal communication, November 18, 2021).

Nelson Mandela University Department of Marine Engineering Master's framework

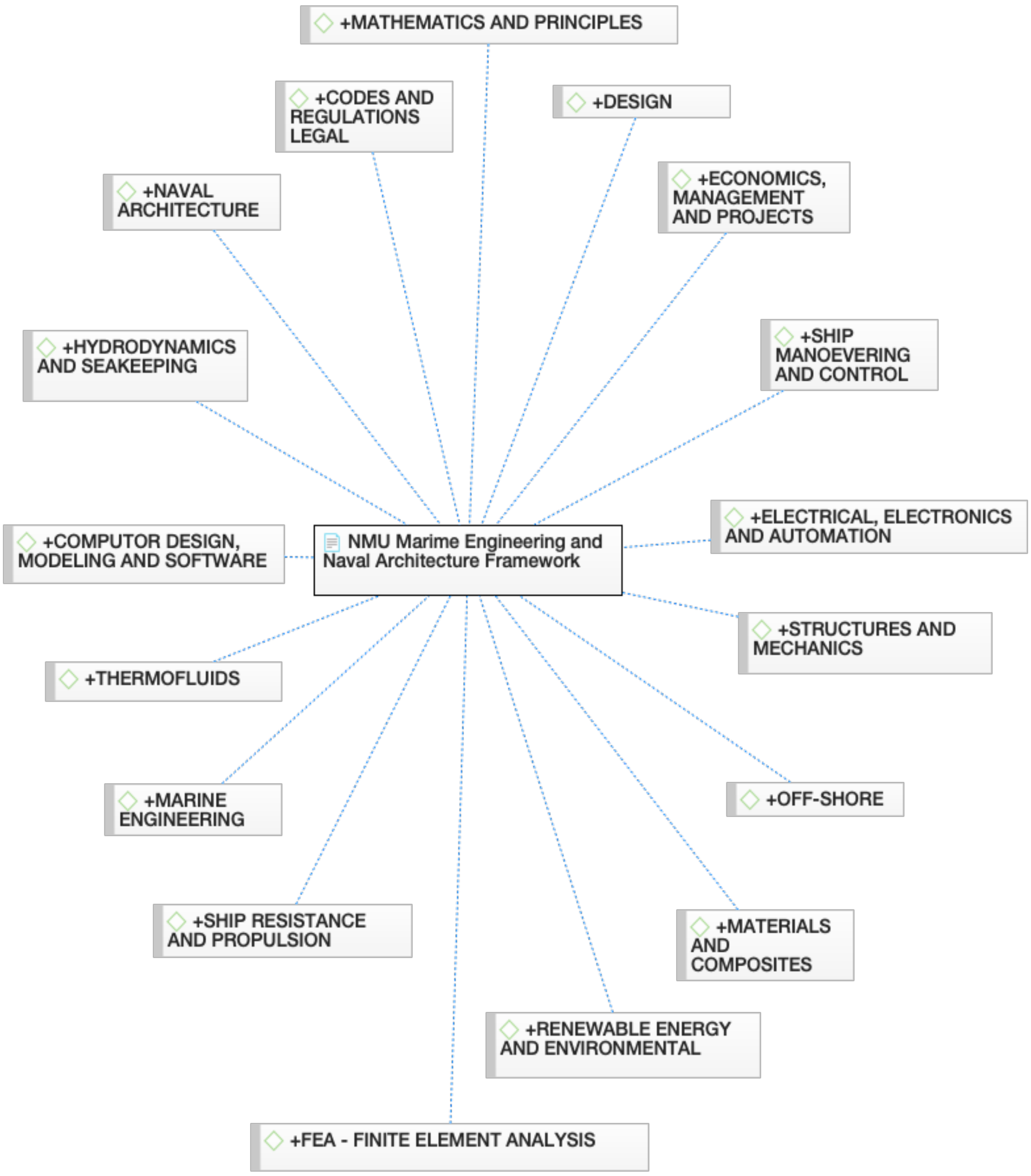
To present the full RINA-accredited qualification in South Africa, the Department of Marine Engineering has developed a Master's qualification framework to address the shortfall that was identified in this research after analysing the international qualifications. Table 5 outlines the modules that the NMU will require to meet full RINA accreditation. This framework still needs to be submitted to SAQA and CHE for approval in South Africa higher education.

<table>
<tr><th rowspan="6">Year 5 – NQF 9</th><th>Semester 9</th><th>Semester 10</th></tr>
<tr><td>Sea-keeping and Manoeuvring</td><td>Computational Analysis Techniques applied to CFD and FEA</td></tr>
<tr><td>Ship Resistance and Propulsion</td><td>Small Craft Performance</td></tr>
<tr><td>Marine Hydrodynamics II</td><td>Advanced Marine Engineering</td></tr>
<tr><td>Off-Shore Engineering II</td><td>Marine Structures</td></tr>
<tr><td>Renewable Energy and Environmental Flows</td><td>Dissertation Project</td></tr>
</table>

Table 5: *Proposed fifth year master's for Nelson Mandela University Marine Engineering*

A final evaluation of the full NMU framework was conducted. The network diagram (Figure 3) shows that, of the 18 themes listed in figure 2, the NMU Framework covers 17, with the only theme not covered being ergonomics and style. This is similar to Southampton's framework, which also does not cover this theme. It is worth noting that Solent University does cover this theme is this qualification specialises in luxury and superyachts. The NMU framework encompasses a general NAME qualification, with additional foci on offshore engineering as well as renewable and environmental energy. Therefore, the decision to exclude ergonomics and style was to make way for the offshore and renewable energy content. However, NMU should consider developing a short course that could focus on ergonomics and style and offer this to students and industry. This would create the opportunity for a guest lecturer to present the short course in South Africa specifically focusing on ergonomics and style (internal and external). This would be particularly beneficial to the luxury yacht and boat industry for all the yacht, catamaran and motorboats manufactured in South Africa.

Figure 3: *Network diagram of NMU Marine Engineering and Naval Architecture framework*



Conclusion

In this article, the academic requirements for an internationally recognised qualification for future engineering managers in NAME were evaluated. The results were used to curriculate an Honours and Master's degree in Marine Engineering for NMU in South Africa, which will need to be added to the current Bachelor of Engineering Technology Degree in Marine Engineering. The educational framework developed for NAME in SA is directly related to the national maritime economy and relevant to the industry needs. These graduates will be able to contribute towards growing the maritime industry in South Africa.

The diversity and current size of the maritime industry in South Africa requires that experts be academically prepared and relevant to the diverse requirements and needs of the industry. While there may be some students who are employed at their first-choice company, many graduates will apply for many different opportunities in the maritime industry, which might mean oil and gas, offshore engineering, ship maintenance or luxury yachts. The NMU framework developed in the article meets the requirement for this diverse academic preparation that will equip and prepare the graduates to enter any sector of the industry.

It is noted that the framework compared in ATLAS.ti did not highlight the practical design and research projects; however, these aspects are included in the individual modules. Research and practical projects are a requirement for ECSA accreditation and are therefore included in all aspects of the curriculum.

The NMU Framework covers 17 of the 18 NAME themes, with ergonomics and style the only theme not academically covered. NMU can use this module to create postgraduate short course opportunities with an international guest lecturer. This will be beneficial to those in the South African industry as the course is integral for internal and external styling.

The NMU NQF level 9 Master's Framework meets the required academic foundation for graduates to register with RINA. The NQF 9 level also enables the graduate to register with ECSA as a Professional Engineer in terms of the Washington Accord. NQF levels 7 and 8 meet the requirement for Professional Engineering Technologists in terms of the International Engineering Alliance Sydney Accord (ECSA, n.d.).

Graduates with the NMU Bachelor, Honours or the Master's qualifications will be well prepared academically to enter the maritime workplace and contribute meaningfully at these respective levels. With industry experience and mentoring, they will develop into the future engineering managers and leaders of the maritime industry in SA. In time, SA will replace the critical skills lost since the early 2000s, primarily due to the accessibility of an internationally recognised qualification in marine engineering available in South Africa.

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