

Designing a marine systems design specialization track at NTNU

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ABSTRACT

In this paper we describe and discuss the current and future MSc specialization programme in marine systems design at the Norwegian University for Science and Technology (NTNU). We follow the structure of a design process. First, we identify relevant stakeholders. That includes industry, society and the students themselves, and we discuss what are their key needs and requirements for a master level education. Further, we outline what can be considered a conceptual solution for the marine systems design specialization programme's structure and content. We apply two basic types of learning elements. First, a set of focused topic blocks covering central systems design models and methods to develop the required theoretical competence platform. Second, the students perform a series of creative, 'use case'-oriented collaborative development projects based on CDIO (Conceive, Design, Implement, Operate) principles. We discuss the "educational design solution" in terms of learning objectives vs. achieved results and evaluate the impact both from an academic and an industrial perspective.

KEY WORDS

Marine systems design; Education; Study programme

INTRODUCTION

"Everyone designs who devises courses of action aimed at changing existing situations into preferred ones" (Simon 1996). In this paper the "situation" refers to our marine technology study programme, unlike in most IMDC papers, where the design object is typically a ship.

Globally, there are only a few universities offering an integrated five-year MSc track in marine technology. Our marine technology programme at NTNU graduates around 120 MSc students each year. This reflects the importance and size of the maritime industries in Norway, traditionally being shipping and fisheries, shipbuilding, ship equipment systems, later including offshore oil & gas and aquaculture in the 70s, and more lately offshore energy, autonomous ocean space surveillance and now also deep-sea mining.

NTNU is also among the even fewer universities having a dedicated specialization in marine systems design (MSD). In our MSc programme, about 20-30 students each year have chosen this specialization, alongside those specializing in marine structures, hydrodynamics, cybernetics, or energy systems. The historical roots of the MSD programme date back to the late 60s, with the establishment of a separate department of *ship design*, and with Professor Stian Erichsen pioneering the development of *design* as a research and education field at NTNU beyond what was then considered a typical naval architecture and shipbuilding programme. Later, with the advent of the new ocean industries both in Norway and beyond, the specialization changed its name to *marine systems design*. This was reflecting both the shift of importance to "industry Norway" expanding from shipping to offshore oil and gas related design objects', but also the importance of a *systems* focus in developing everything from integrated multi-modal logistics to the installation and operation of subsea oil & gas fields, aquaculture, offshore wind farms, to name a few.

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As will be discussed in more detail later in this paper, we have a current string of both more general systems analysis courses as well as marine design methodology courses that is the backbone of the MSD specialization. However, we steadily see the need to review and re-design this track. There are several reasons for this. One is simply to critically evaluate the status quo at regular intervals as part of a continuous education quality process. Further, internal factors such as student exchange periods (80% of our student go abroad for at least one semester), changes in human resources and internal organization, and changing expectations from industry, all drive change and require adaptation. Finally, external developments such as the focus on sustainability and net zero emissions towards 2050, and developments in digitization and artificial intelligence, are additional instigators for change.

Asbjørnslett et. al. (2022) presented much of the concept ideas and some more details about the NTNU perspective on educating the next generation marine system design engineer. The NTNU future technology studies project was reviewed and discussed as to its consequences and implications for the organization and upgrades of the marine technology study and outline of the study plan. It was also explained how the trajectory of human expansion into the ocean represented by new and expanded ocean activities like marine aquaculture, deep-sea minerals, offshore wind energy generation, etc. in addition to the more conventional and well-established ocean activities like shipping, offshore oil & gas, fisheries, and others, may be seen as an accelerated demand for marine systems design architects and engineers. The CDIO (Conceive, Design, Implement, Operate) approach introduction in the study syllabus, the use of field studies to improve the understanding of operational matters, the introduction of sustainability and digitalization into the study plan, and finally, a short review and argumentation for the introduction of the marine system design (MSD) "diamond" as a realization and implementation tool of the needs-function-form mapping in engineering design, on different levels, meeting the diverse stakeholders' demand, were all addressed.

Thus, the overall objective of this paper is to *outline the goals, structure and content of a marine systems design MSc specialization track that meets anticipated needs and requirements for the next decade(s)*. Based on this, the important questions we want to address here and discuss at IMDC are as follows:

- Who are key stakeholders for such a programme, and what are their needs and requirements?
- How can we map these needs and requirements into specific learning objectives for the specialization programme in marine systems design?
- What should be the corresponding learning content, in terms of theory, models, processes, tools and skills?
- What should be the structure of the study programmes?
- How do we handle and include the interdisciplinary challenges of future study programmes?
- What should be the role of industry and industrially relevant design business cases in this education track?
- What is a good balance between a classical naval architecture approach and the exploration and implementation of new topic areas and technologies, such as artificial intelligence, digital twins, model-based systems engineering?

Needs and requirements

Before we start to define needs and requirements for a revised MSc education track, we must define *who* are actually our "customers". What immediately comes to mind for most technical universities is the industry and their needs since they are the main receivers of graduates which they subsequently turn into value-creating employees. This "what-the-industry-want" is also easily accepted by the students, since an education targeted towards their needs, make them attractive in the labour market after graduation. It is here important to keep in mind the tendency of industry to be short-sighted and very topical in their demands and expectations' setting. From experience, we know that study programmes are not that quickly to change and sometimes topics and expectations of industry can only be met by inter-departmental (institutes) set-ups, because they are multi-disciplined by nature and the universities and departments are not necessarily arranged such that cross-discipline challenges experienced by industry, can easily be handled by existing course programmes and syllabuses. Industry demands and expectations must, therefore, be carefully scrutinized and evaluated, and study programmes gradually adapted to these needs if at all possible. So, not all industry expectations can necessarily be met by universities.

Beyond the value-creating employee perspective, the students themselves are important stakeholders. A master level education is essential for the formation of an intellectual and competency platform for the individual that gives meaning, mastery and self-realisation throughout their life. The report "Worth knowing" (NOU 2000) points out that "higher education should not only provide society with competent professionals, but also aim for developing independent and insightful people." The first sets of Generation Z have arrived and already finished their MSc study at the universities. More student groups have or are about to finish their studies. As the first social generation to have grown up with access to the internet and portable digital technology from a young age, members of Generation Z, even if not necessarily digitally literate, have been dubbed "digital natives" (McKinsey 2023). Moreover, the negative effects of screen time are most pronounced in adolescents, as compared to younger children. Members of Generation Z tend to live more slowly than their predecessors when they were their age. This is

reflected in being more concerned than older generations with academic performance and job prospects and spend more time on electronic devices and less time reading books than before, with implications for their attention spans, vocabulary, academic performance, and future economic contributions.

For the society as such, it is desirable that we train master level engineers who can contribute constructively to the public debate with understanding, perspectives and opinions that stretch out over narrow commercial interests. This will be both a counterweight and a complementary voice in a public debate which is characterized to a greater extent by social scientists and economists than by engineers. Such a public debate will demand engineers who dare to challenge and question existing structures and to use their knowledge to point out errors and shortcomings in a world characterized by technology - including topics that may not always be in the industry's interest to raise. Most of the students we educate will, to a greater or lesser extent, work with research and development. Here, in addition to solving technology challenges in a short-term perspective, they must be trained to address more long-term, fundamental issues that often fall outside the industry's interest, but where a holistic understanding is important. The importance of this has increased by the need to curb greenhouse gas emissions. The solution is multifaceted, but technology does play a vital role - both in creating the problem in the first place, but also for developing solutions. And it should be said that industry representatives have told NTNU that we should listen to what they say - but we should not listen too carefully.

We are part of a knowledge society, where knowledge is perceived to have an intrinsic value beyond its usefulness from an industrial perspective. Knowledge is a crucial pillar in an enlightened, rational, and democratic society. The interaction between technology and society, and technology and humanity, is as such an important perspective which, both directly and indirectly, must be communicated as an important end goal for an education.

What is then the future role of the naval architect?

Previous IMDC contributions have addressed and seriously challenged the future role of the naval architect - to be strengthened and expanded upon as an integrator or manager of the ship design project - sometimes even administering the new building project development on behalf of the customer from idea to ship in operation. Thus, the naval architect becomes an integral part of the customer's business development process - as in current project-making activity (Ulstein & Brett et al. 2012, 2015). In addition, it has been argued that it is paramount that the naval architect retains his or her expertise and skills, and even continually improves them, in designing the better ship or marine object to meet all stakeholders' expectations.

Andrews (2018b) approaches the challenge by asking the question "is a naval architect an atypical designer - or just a hull engineer?" He continues: "It seems appropriate...to question whether the engineering discipline - that of naval architecture - which has to date dominated ship design practice, still remains best placed to continue in that role." In the conclusion, it is said that: "...despite the increasingly demanding safety (and decarbonization) regime in ship design, that emphasizes the naval architect's role as "the hull engineer", the naval architect's role remains that being the overall ship (solution) designer." In short, Andrews (2018a) put forward three main reasons for that assertion: a) "Everyone's problem is the naval architect's problem," b) "There is a need to have a whole ship perspective to ensure design balance is achieved from the initial synthesis and maintained through-out design development and through life", c) "Architecture is seen to be the key to both initial ship design synthesis and to achieving and maintaining design balance".

In addition to the appropriate academic qualifications a naval architect needs to also expand from wider engineering practice with a set of additional applied and social science expertise and skills such as finance, human resources, organization, marketing and communication and finally, project leadership and management skills, (Ulstein & Brett, 2015, 2018). Thus, more naval architects need to expand their multi-disciplinary expertise and skills to better support and be able to respond better to increasing industry demands. Again, it is suggested that "the ship designer of the future" must master equivalent expertise and knowledge within the fields of commercial, operational, and technical challenges related to a new building project realization. Thus, a new type of competent naval architect must be developed by academic education and training and put into practice situations different from the past.

Marine systems design - a managerial process

Over the years, it has become clearer to us that handling the whole process of a ship design project, with its apparent complexity, uncertainty, and ambiguity are more of a managerial mastery task rather than a classic naval architecture and marine engineering-based ship design and ship-hull engineering task. Another challenge is the conflict-oriented situation, which often arises in the ship design approach and how to turn it into something positive for the process and the parties involved. Conflict situations are generated within or among stakeholders in the ship design process as a manifestation of contesting differences in viewpoints, competence, and experiences. They occur when the views that are involved in the ship design discussions collide to produce cognitive turbulence, which can result in instable patterns of conflicting behaviour. Typically, three classes of conflict situation can arise in a ship design approach: i) tensions that may have no discernible cause, ii) disputes caused by

misreading and interpretations *and* minor provocations, and iii) conflicts represented as a manifestation of differences in opinions, experience, and expertise. Consistent with the systems viewpoint, it has been suggested that a conflict modelling cycle can contribute to the exploration of the undesirable behaviour patterns and inherent attitudes among the participants in the ship design process.

Under such a regime, we believe that traditional ship design approaches will gradually become an extended project management process to be offered owners rather than a given design package. Classic naval architecture and marine engineering skills and expertise will rather become an integral part of it. Hence, state-of-the-art naval architect education must gradually reflect these challenges.

New challenges – time for change

In line with RINA, it seems as if the traditional naval architecture and marine engineering basic bachelor and or master's degree educational disciplines and existing study programmes do not suffice as the basis for further enlightenment and proper handling of appearing multi-faceted, "wicked" problems. The wicked problem(s) being described by typically 10 propositions put forward by Rittel and Weber, (1973): "1. There is no definite formulation of a wicked problem. 2. Wicked problems have no stopping rule. 3. Solutions to wicked problems are not true or false, but good or bad. 4. There is no immediate and no ultimate test of a solution to a wicked problem. 5. Every solution to a wicked problem is a 'one-shot operation'; because there is no opportunity to learn by trial-and-error, every attempt counts significantly. 6. Wicked problems do not have enumerable set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated in the plan (business concept). 7. Every wicked problem is essentially unique. 8. Every wicked problem can be a symptom of another problem. 9. The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's solution. 10". The planner (naval architect) has no right to be wrong. Head and Alford (2015) propose some strategies for dealing with wicked problems – such as going beyond technical/rational thinking, collaborative working, new modes of leadership, and reforming the managerial infrastructure. These strategies can enable partial and provisional responses to problems, amounting to shared understanding about the nature and about ways of dealing with them, they conclude.

RINA (Andrews, 2018) suggests that such additional problem-solving expertise and skills training should take place after the formal degree-based education is finished. The authors of this article argue that such training is not only a question of future on-the-job training for a certain period but requires proper education in relevant non-technical subjects too.

It is, therefore, time to reconsider how we educate and train future naval architects. Future technology study programmes (Asbjørnslett et al., 2023) should expand their knowledge territories and or let other complementary trained expertise, team up with them each time and in such a way to create the necessary inter-disciplinary expertise and skills to advance the relationship between academic staff and students. Project-related work where students can achieve valuable collaborative experience, go beyond technical/rational thinking, take real leadership of their innovation projects, ensure that the different subjects of the marine technology study-programme is fully explored and utilized, seem to be in line with contemporary plans for the future of technology studies. Complementarity, openness and improved interpretive schemes for interfacing different subjects and study programme approaches and their corresponding project tasks and course work are most likely what we need. NTNU IMT is moving quickly in this direction. It will be interesting to see whether other academic marine design schools move into the direction of broadened and multi-disciplinary study programmes too.

THE CURRENT STUDY TRACK TO MEET NEW CHALLENGES

Programme structure

The integrated Master of Science programme extends over five academic years (10 semesters) and constitutes a course load of 300 ECTS credits. All 5-year master's programmes offer a combination of compulsory and elective courses. To graduate from a Master of Science programme a student must have completed all compulsory courses, as well as enough elective courses to achieve the total 300 ECTS credits required to complete the programme.

For a student that will graduate with a master's in marine technology, with a specialization in marine systems design, the study will comprise the following, see Table 1:

- There is a string of marine technology courses starting from the first semester, that is meant to cover all basic naval architecture topic areas, such as hydrostatics and stability, hydrodynamics, structures, cybernetics & power systems. This string is compulsory for all students. It converges towards the 6th semester with a capstone design project that will synthesize and integrate the different marine technology disciplines, providing hands-on training for the students to apply their knowledge in a realistic design setting.

- In parallel, the first three years will develop a sound foundation in mathematics (4x 7.5 ECTS), physics and chemistry, as well as covering basic engineering topics such as mechanics, fluid dynamics and thermodynamics.
- In the last part of the study, the students are obliged to dive deeper into selected marine technology topics, such as sea loads, advanced structural analysis, propulsion, etc.
- Additionally, a number of non-technical topics are compulsory, such as technology management and electives from economics, finance, or social sciences.

Table 1: The five year MSc programme in marine technology at NTNU. Yellow cells are common cross-specializations naval architecture courses, while the blue are courses specifically for the marine systems design specialization

Year	Sem	7.5 ECTS	7.5 ECTS	7.5 ECTS	7.5 ECTS
5	10	Master's Thesis			
	9	Complementary	MT elective	Simulation/Fleet design	Specialization Project
4	8	Experts in Team	MT elective	MT elective	Design methods II
	7	Complementary	MT elective	Other elective	Design methods I
3	6	MT elective	OR & Optimization	Machinery systems	MT6 Capstone design
	5	Mathematics 4N	Techn management	MT5 Marine dynamics	MT4 Propulsion&control
2	4	Statistics	Thermodynamics	Material Technology	MT3 Hydrodynamics
	3	Mathematics 3	Physics	Fluid Mechanics	MT2 Structures
1	2	Mathematics 2	Programming	Mechanics 2	Philosophy of science
	1	Mathematics 1	IT Introduction	Mechanics 1	MT1 Intro

The specialisation in Marine Systems Design starts off after the capstone design course. According to the learning goals, the specialization shall provide the students with knowledge and competence for the design and realization of complex, innovative marine systems, such as ships, marine transportation systems, offshore platforms, offshore logistics and systems for offshore energy production. After completing this specialisation, the candidates shall be able to:

- perform a technical analysis of relevant marine systems, such as stability and hydrostatics, resistance and propulsion, strength, reliability, and availability.
- analyse the economic, environmental, risk and safety-related performance of a vessel or fleet in a life cycle perspective.
- design and verify systems for operation in harsh marine environments, with a particular focus on Arctic conditions.
- use methods from operations research and risk analysis for optimization, simulation and decision support.
- apply a holistic perspective to the development and realization of marine systems, based on methods from design theory and systems engineering.

They should also develop skills that make them able to:

- develop holistic, complex innovative systems solutions both individually and as part of teams.
- make relevant ICT tools for computer aided design, technical analyses, optimization, simulation and risk and safety analysis.
- verify design solutions with respect to regulations and requirements from trade, customers, and society as such.
- efficiently present and communicate the final design solutions and corresponding documentation, both written and orally.

The overall programme

The new study programmes in marine systems design must be structured in such a way that not only "filtered" industry needs are catered for but also some of the needs of the incoming Generation Z students. Compared to previous generations, the alternative characteristics of Generation Z: live more slowly, more concerned with academic performance and job prospects,

more time spent on electronic devices and less time reading books, with implications for their attention spans, it is argued by the authors of this paper that in many ways, a perfect situation is now to make a new marine design course programme work based on the following synthesized assertions:

1. Traditional course time thieves, like making computer programmes work, and traditional library-oriented data-source searches can be replaced by more creative project 'use case'-oriented collaborative development work – idea creation, comparing different solution alternatives by performance indexed benchmarking and massive, big data web-based information solicitation – a real collaborative project expectation elucidation process.
2. Take a broader stand to a full project realization, get in charge with the project team and argue your project team's case and pursued project business proposition – a full practical project work and findings communication process – read less and do more innovation work – take leadership.
3. Use all subject disciplines related to commercial, operational, and technical matters, by engaging all the subject disciplines of a marine technology institute and thereby – make use of the knowledge infrastructure and network - apply the full CDIO (Conceive, Design, Implement, Operate) principles.
4. Prepare and document a real time series of decision-making related to the project development and ship design solution drawings, specification, and analyses – practical application of lessons learned to date and beyond.

CORE METHODOLOGY MODULES OF THE SPECIALIZATION

Still, “the proof lies in the pudding”. Given the needs and requirements developed so far, and the statements on the high-level learning objectives, what should be the specific content of the core specialization track? We have chosen to take a modular approach to this. At NTNU, the standard course is 7.5 ECTS⁴. We have chosen to break this up into 2.5 ECTS “virtual” modules, thus giving us 9 topical building blocks as a replacement for the three courses considered. The question then becomes: What should be those 9 modules?

We are still in the process of developing these modules. Our first draft contained the modules outlined in Figure 1. Each of these is supposed to provide one or a few tangible tools to the designer's toolbox, both from a theoretical and an application-oriented perspective. These modules will of course need to build on the other basic courses that the students have already covered, both generic topics (mathematics, mechanics, etc.), NAME topics and basic systems analysis (e.g. operations research, data analysis, statistics, etc.). In the following, we will briefly describe each of these and discuss the rationale for including them:

	Learning objectives	Main topics
1 Design theory & methodology	Theoretical foundations for engineering design in general, and marine systems design in particular	<ul style="list-style-type: none"> • Design strategies • Design methods • Design procedures & tools
2 Shipping logistics & economics	Know how to model maritime logistics systems (fleets, operations, infrastructure) and analyse KPIs related to economics, transport service levels	<ul style="list-style-type: none"> • Macroeconomics of shipping, shipping markets • Ship size & speed (microeconomics) • Ports and waterways, queues
3 Optimization methods for marine systems design	Modelling real life design problems as optimization problems for insight and decision support	<ul style="list-style-type: none"> • Vessel design problems • Fleet configuration and utilization • Transport problems using networks
4 Systems simulation and data analysis	Learn to capture real operations into simulation and data analysis models to derive system level performances	<ul style="list-style-type: none"> • Operation models from AIS MetOcean data analysis • Simulation model development and analysis • Visualization and animation
5 Designing digital twins and digital services	Develop digital services based on digital twin platforms according to engineering design principles	<ul style="list-style-type: none"> • The digital service design process • DT architectures and design patterns • Sensors and data channels/edge
6 Design for sustainability with focus on uncertainty and flexibility	Designing for LC sustainability, with focus on low and zero emission shipping solution	<ul style="list-style-type: none"> • Low emission regulatory context towards 2050 • Energy efficient ships, logistics, low emission fuels • Uncertainty and flexibility theory
7 Risk-based design	Learn basic risk analysis concepts, models and methods, and how they can be used as an integral part of complex marine systems design	<ul style="list-style-type: none"> • Basic risk models and methods • Risk-based design principles (safety equivalence)
8 Modular architectures, configuration-based design	Learn fundamental principles of modular architectures and product platforms, and their application in product and systems design	<ul style="list-style-type: none"> • Modularization, modular architectures • Product platform development • Configuration-based design, mass customization
9 Introduction to RAMS	Explore basic concepts of reliability, availability maintenance and safety (RAMS) applied to marine systems design and operations	<ul style="list-style-type: none"> • Basic RAMS concepts • Optimal inspection and maintenance policies • Fleet design for inspection and optimization

Figure 1: A preliminary outline of core theory and method modules as part of the systems design specialization

⁴ European Credits Transfer System

Design theory and methodology

This module will cover the theoretical foundations for engineering design in general, and marine systems design in particular. This includes different design models, the design processes at shipyards and ship designers, and provide a basis for understanding of design as a mapping from needs via functions to form. From before, the students have covered most topics related to marine systems analysis pertaining to hydrodynamics, structures, power systems, etc., and they have already a “hands-on” experience of a guided and relatively complete design process from their capstone project in the 6th semester.

The “function-to-form” principles in engineering design requires a fundamental logical shift for the students. Their previous engineering subjects typically has a form-to-function approach (“given this description, analyse the performance using this method algorithm”). They have already been exposed to the practical reality in the 6th semester capstone subject, which provides a good starting point for reflection and a more theoretical understanding of fundamental design principles. This includes the realization that there is not one “deductive” correct solution for real world design problems, motivating for the introduction of system architectures and corresponding conceptual choice theory. This is akin to “style” being a fundamental element of design according to Andrews (2018a), both as a mental and practical construct of design classes as archetypes that can be further developed and optimized by prototype refinement, (Coyne et al. 1990).

Shipping logistics & economics

A systems perspective on marine design requires a fundamental understanding of the operating context in which the ship will operate. The ship is typically part of a fleet, and the fleet a part of a logistics system. Further, we see the need for a deeper understanding of both the ship and fleet operations, as well as the operational context in terms of e.g. regulatory framework, economics & financing, fuel infrastructure, and technology development – and this from a lifecycle perspective.

This module should link relevant topics from the technical disciplines with topics from operations research and economics, with an emphasis on the strategic design decisions towards fleet renewal and retrofit under a high degree of uncertainty.

Optimization methods for marine systems design

Intrinsically, *design is about finding the best possible solutions* within a set of constraints. Thus, optimization is naturally a core topic for the marine systems design specialization. This includes reflections towards the challenges of capturing large, complex, multi-faceted problems, as real-world design problems typically are, into the relatively strict and formalized framework of mathematical optimization (Simon 1973, Ackoff 1979). Still, our experience is that the students gain considerable insight into a design problem by the modelling process itself, independently of the final optimal solution. This module is planned on the assumptions that all students have a basic course in operation research and optimization from before, so that the focus can be on application-oriented modelling of industry-relevant design problems.

Systems simulation and data analysis

We always design for operation. To understand, visualize and be able to analyse operations that are complex, dynamic, and typically stochastic, simulation and data analysis models become an important part of a designer’s toolbox as a means to derive system level performances.

Designing digital twins and digital services

Recent advancements in digitalization and the Internet of Things (IoT) have enabled various digital twin (DT) solutions, facilitating closer collaborations among ship designers, equipment manufacturers, and shipbuilders throughout the vessel's lifecycle. An important aim of DT solutions is to offer value-added services by based on real-time data streams from onboard sensors. For instance, one such service could involve monitoring the vessel's inventory from its inception to decommissioning, actively providing docking services for maintenance, upgrades, and retrofits as needed. Another example includes the establishment of online shore-based operation centres, capable of delivering specialized expertise and economies of scale through the simultaneous management of multiple vessels. These examples illustrate how digital twins become an import outcome from a systems design process, alongside the delivery of the physical vessel. Furthermore, these DT-based value-added services should be *designed* based on the same underlying principles and using a similar methodology as for the ship design itself (Erikstad 2019b).

Design for sustainability with focus on uncertainty and flexibility

We always design for the future, and the future is intrinsically uncertain. Still, we do not have the luxury of waiting for these uncertainties to be uncovered. Design decisions must be made today, increasingly for the long horizon to meet sustainability goals following the 2050 zero emission target defined by IMO. At NTNU, we have an ongoing process towards defining and developing what should be the curriculum related to sustainability, both for the engineering education as such, as well as for the marine technology programme. We believe this topic should be combined with teaching theory, models and methods for designing for uncertainty, flexibility and changeability, such as real options, stochastic programming, epoch-era analysis, scenario development, combined with lifecycle analysis methods.

Risk-based design

Understanding fundamental concepts of risk is a necessary element in all systems-oriented programmes. Many students will take elective courses covering this topic in depth, predominantly from other perspectives than design. A basic module here should cover fundamental risk analysis concepts, models, and methods, and how they can be used as an integral part of complex marine systems design process. It is already central to core topics in naval architecture, e.g. probabilistic damage stability, (Papanikolaou 2012), and it will be increasingly important for developing new and innovative solutions for which there is a limited existing regulatory framework, say, new zero emission fuels, new energy-saving technologies, etc. Here, principles of “equivalent-risk” and “equivalent-safety” are needed for validating design solutions.

Introduction to RAMS

Covers basic concepts of reliability, availability, maintenance, and safety (RAMS) applied to marine systems design and operations. RAMS concepts are important for the operation of the system as such, but also for understanding and modelling important service operations (say, service vessels/fleet for wind farm inspection and maintenance).

Modular architectures, configuration-based design

This module covers fundamental principles of modular architectures and product platforms, and their application in product and systems design, (Erikstad 2019a).

Alternative modules

The nine modules proposed here were the first attempt to define a specialization track for marine systems design. With each module covering 2.5 ECTS, this corresponds to three normal courses, which is our current planning constraint. There will be good arguments for including other topics in this track, though this will have the consequence that one of these nine will have to be removed. Some of the alternatives considered are:

- Project-making and business development, focusing on how shipping and maritime projects are initiated and matured from both technical, commercial/financial and operational perspectives. This includes stakeholder’s perspectives, requirements elucidation, and analysis of markets and competitors using tools like Accelerated Business Development (ABD), (Ulstein & Brett, 2015).
- Strategic business models for the design firm. In the DREAMS⁵ project, NTNU and Ulstein have investigated the relation between strategic business models, the organisation of the design firm, the structure and content of alternative design processes, and the technical and commercial outcome of the process. It remains an open question to us whether this should be a part of a systems design specialization curriculum.
- Model-Based Systems Engineering (MBSE). This is an approach to systems development that has strong historical roots, as well as having received renewed attention lately. It puts emphasis on the explicit modelling of all central aspects of the system using formal, standardized models, and thus have a relevance to the students beyond systems design. MBSE could be a separate module in our 9-module collection, or it could be integrated as a common modelling framework in most of the other modules.
- Artificial Intelligence in design. At present, with AI application beyond “classical machine learning” is still relatively immature, this would basically be raising relevant discussions and exploring opportunities towards using

⁵ Design Re-Engineering and Automation for Marine Systems

AI in design. Though with the present pace of development in this area, it is likely that more substantial models, methods, skills, and applications will have reached a level of readiness to be an unavoidable part of the curriculum.

This list could have been longer. A key point is that we live in an uncertain dynamic world, thus we should design our study programme so that we can continuously adapt – and to the extent possible open up for a certain degree of choice for each student. Over time, it is expected that this list of complementary study modules will be expanded upon to for example meet special contemporary topical needs of the industry and political trends. Other existing modules might be frozen for some years if demand and student interests do not prevail and later on to be revised and revitalized if need be.

From subject theory to project making - Capstone design course

NTNU IMT decided in fall 2023 to adjust and enhance their 3rd level 6th semester TMR4256 Design of Marine Systems Course (previously PMS) into a capstone project that became compulsory for all specializations. The capstone project being a unique opportunity to carry out independent group work to devise an innovative solution for a real-world problem. Figure 2 depicts the international development and search for a modernization approach to existing and traditional training of engineers, particularly at MSc level. Table 1 showed how the Capstone initiative is positioned in the middle of the 10-semester long MSc-course structure of NTNU. In this way, it is thought that students after 5 semesters of basic theoretical training of engineering subjects like maths and physics and others, will need and experience a challenging course in the 6th semester where they will have to develop their innovative skills, handle commercial, operational and technical aspects related to a real problem-solving project.

An important change was that this course was made compulsory for all specializations – so that, e.g., a student who wants to study hydrodynamics should understand the setting for supporting the hull form and propeller design as part of an integrated process.

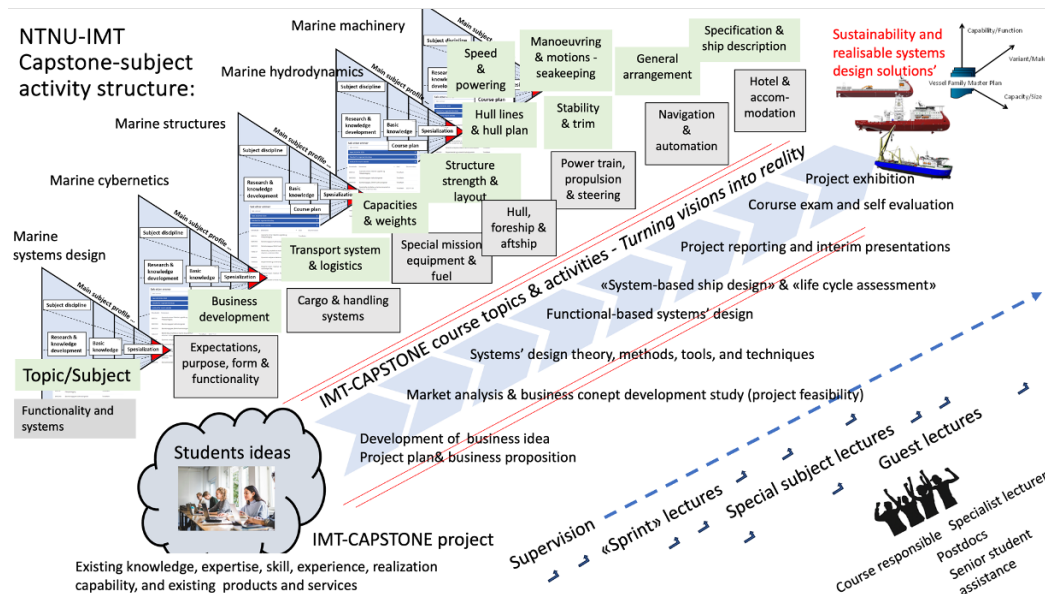


Figure 2: The outline of the new capstone design course

The idea is that students with their 6th semester start background and with additional core lectures, external guest contributions and many "sprint" training sessions can make the students develop an idea almost into a "sellable" and "producible" marine system design solution.

All the traditional naval architecture and marine engineering disciplines are there and applied by the students. In addition, they must also expand their horizon in the early part of the course project work in being introduced, for the first time, with market, business, commercial, and operational matters that influence their project problem solving process. A new important feature of the Capstone initiative is that academic staff (subject specialists) from other main subject disciplines are directly involved in the course execution by particularly running the ad hoc "sprint" training sessions on subject matters arising as the progress of student work takes place and project problems arise – "problem solving at your fingertips". A comprehensive course project

plan is needed and a tight control of course time-plan is executed. Continual facilitation of project work and supervision of student students are practiced.

Interaction with industry is important and is encouraged. Industry representatives are, therefore, involved by web, telephone or physical presence. A lot of emphasis is placed on presentation of ongoing and final work and the course finish off with a two-day oral exam and a two-week exhibition of project work done at the end of the semester.

Almost midway through the Capstone effort, it is still too early to summarize the experiences so far. We, therefore, promise to return to IMDC at a later stage and report on more thought through and well documented experiences.

CONCLUSIONS

In this paper we have outlined a revised plan for a specialization track in marine systems design at NTNU. This is indeed a complex design process, starting with defining the needs of multiple stakeholders, such as students, industry, and society at large, and ending up with, though somewhat fragmented, propositions for what should be part of a marine systems design master-level specialization. We have further described our revised Capstone design course that serves as the introduction to a holistic systems design thinking.

We live in a time where new areas are being opened for exploration, energy production and extraction, where typically deep water, long supply lines, and challenging climatic conditions require new expertise and technology. Energy shortages and a focus on the environment pave the way for profitable exploitation of wind power far offshore. Global warming demands significant reductions in emissions to the air from maritime transport, where a vision of zero emissions from the industry itself sets high expectations for technology that has not yet been developed. Our northern areas are becoming more accessible for marine activities, with associated challenges for vessel technology, logistics, risk, and environment, and where commercial exploitation of a trans-Arctic route is increasingly seen as a real possibility. Aquaculture is moved out into exposed waters. All this paints a picture of an industry where the most important constant factor is change. And the pace of change seems to be accelerating. The future for which we are educating our engineers appears, however, unpredictable, unclear, and complex. We, therefore, see the need to understand multidisciplinary and complex issues, while important areas of knowledge continue to be developed, accompanied by a need for bringing fragmented expertise within narrow areas closer together. This creates significant challenges in terms of what knowledge and skills we should convey so that our students are as well-prepared as possible for a 40-year plus career after completing their education.

CONTRIBUTION STATEMENT

Stein Ove Erikstad: Conceptualization; writing – original draft, review and editing. **Per Olaf Brett:** Conceptualization; writing – original draft. **Benjamin Lagemann:** Writing - review and editing.

REFERENCES

- Ackoff, R. L. (1979). "The Future of Operational Research is Past." *Journal of the Operational Research Society* 30
- Adi, A., & Stoeckle, T. (2022). "Public relations as responsible persuasion: Activism and social change." In *The Routledge Companion to Public Relations* (1st edition, pp. 302–314). Routledge.
- Andrews, D. J. (2003). "Marine Design - Requirement Elucidation rather than Requirement Engineering." *International Marine Design Conference (IMDC)*.
- Andrews, D. J. (2018a). "Choosing the Style of a New Design - The Key Ship Design Decision." *International Journal Maritime Engineering*, 160(Part A1). <https://doi.org/10.3940/rina.ijme.2018.a1.457>
- Andrews, D. (2018b). "Is a naval architect an atypical designer – or just a hull engineer?," *International Marine Design Conference*, Helsinki.
- Asbjørnslett, B. E., Brett, P. O., Lagemann, B., & Erikstad, S. O. (2022). "Educating the Next Generation Marine Systems Design Engineer – The NTNU Perspective". *14th International Marine Design Conference*, Vancouver, CA

- Brett, P. O., Carneiro, G., Horgen, R., Konovessis, D., Oestvik, I., & Tellkamp, J. (2006). "LOGBASED: Logistics-Based Ship Design". *International Marine Design Conference (IMDC)*.
- Coyne, R. D., Rosenman, M. A., Radford, A. D., Balachandran, M., & Gero, J. S. (1990). "Knowledge-Based Design Systems". Addison-Wesley.
- Erikstad, Stein Ove (2019a), "Design for Modularity: Volume 1: Optimisation of Ship Design and Operation for Life Cycle", Chapter in book: "A Holistic Approach to Ship Design", ed. Apostolos Papanikolaou, pp 329-356, Springer Verlag, ISBN 978-3-030-02809-1
- Erikstad, S. O. (2019b). "Designing Ship Digital Services". In V. Bertram (Ed.), *COMPIT'19 - 18th Conference on Computer and IT Applications in the Maritime Industries*. Tullamore, Ireland
- McKinsey (2023). "What is Gen Z?" Web-based article, <https://www.mckinsey.com/featured-insights/mckinsey-explainers/what-is-gen-z>, dated March 20, 2023, accessed April 22, 2024
- NOU (2000), "Freedom and responsibility – on higher education and research in Norway", *NOU* 2000:14
- Papanikolaou, A. (2012), "Risk-based Design", *Springer Verlag*
- Head, B. W., & Alford, J. (2015). "Wicked Problems: Implications for Public Policy and Management". *Administration & Society*, 47(6), 711-739. <https://doi.org/10.1177/0095399713481601>
- Horst, W. J. R., & Webber, M. M. (1973). "Dilemmas in a General Theory of Planning". *Policy Sciences*, 4(2), 155-169. <http://www.jstor.org/stable/4531523>
- Simon, H. A. (1973). "The Structure of Ill-structured Problems." *Artificial Intelligence* 4: pp. 181-200.
- Simon, Herbert A. (1988). "The Science of Design: Creating the Artificial". In: *Design Issues* 4.1/2, pp. 67–82. issn: 07479360, 15314790. doi: 10.2307/1511391. url: <http://www.jstor.org/stable/1511391>.
- Simon, H. A (1996). "The Sciences of the Artificial". 3 ed. Cambridge, Massachusetts: MIT Press. <https://doi.org/10.7551/mitpress/12107.001.0001>.
- Ulstein, T., Brett, P. O. (2012). "Critical Systems Thinking in Ship Design Approaches." In *IMDC 2012: 11th International Marine Design Conference*, 1:365–83. Glasgow, Scotland.
- Ulstein, T., Brett, P. O. (2015). "What Is a Better Ship? - It All Depends." In *IMDC 2015: Proceedings of the 12th International Marine Design Conference*, 1:49–69. Tokyo, Japan: International Marine Design Conference.