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DEVELOPMENT AND LESSONS LEARNED OF NEW MODULAR SHIP DESIGN ACTIVITES FOR GRADUATE EDUCATION DURING COVID

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ABSTRACT

This paper describes two new modular ship design activities for graduate education at Delft University of Technology that have been developed during COVID. First, a new 2-hour hybrid format (in-person and virtual participation) game was designed to teach students modular design for offshore support vessels (OSVs). Second, an 8-week MSc-level ship design project was redeveloped to cover the design of a small fleet of modular OSVs for offshore wind. The paper discusses the drivers behind these new design educational activities, the details of the activities themselves, and concludes with lessons learned focused on improving graduate education for masters students studying ship design.

KEY WORDS

Ship design education; activity-based teaching and learning; COVID impacts; modular design; offshore support vessels (OSVs)

INTRODUCTION

This paper describes two new developments that have been implemented to an obligatory MSc course on advanced ship design techniques at Delft University of Technology. These developments have been brought about due to three separate causes: 1) changing market needs, 2) COVID and virtual learning, and 3) the desire to introduce gamification and active teaching and learning into ship design education. These three very different drivers meant that new design activities had to be developed, including new case studies, and new teaching methods incorporating both gamification and virtual learning. First, a smaller case study will discuss the introduction of a new hybrid format (in-person and virtual participation) game designed to teach students modular design for offshore support vessels (OSVs). Second, after implementing lessons learned from the first case study, a full course design project for the fall of 2021 was redeveloped to cover the design of a small fleet of modular offshore service vessels (OSVs) for offshore wind.

Both developments were supported heavily by PhD researchers and MSc students working on either an independent research assignment or their MSc thesis. In this sense, both the development of these activities and the execution of them during the course were learning opportunities for the researchers and MSc students.

Changing market needs

The maritime energy transition, specifically the growth of the offshore wind market and industry push towards developing service vessels to support the energy transition, especially in the North Sea, have created a need to have design exercises related to this problem in maritime education. There are over 15 distinct vessel types involved in the lifecycle of an offshore wind farm covering: pre-construction, construction and installation, operations and maintenance, and decommissioning (Marine Scotland 2014). To date, many of these vessels have been optimized for offshore oil and gas or deep sea mining exploration, which creates an opportunity for the maritime industry to develop new solutions for Offshore Service Vessels (OSVs) targeted specifically to offshore wind.

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These OSVs are unique because of the dynamic environment in which they have to sail. They operate on both short term contracts or long charters and thus have to be adaptable to market fluctuations such as oil price variations or charter rates. They have to sail in various weather conditions which require a very good seakeeping capability increasing the design challenges and complexity. Modularity has been proposed as a potential for reducing costs and lead time of these vessels. Due to the large number of OSVs needed in the near and long term, modularity provides an opportunity for reduced design time, reduced build and assembly work and allows yards to build multiple vessels at the same time by increasing yard capacity. Also, modularity allows for creativity in the early design phases by creating flexibility to produce multiple feasible designs which can later be configured even after the construction stage by upgrading or switching to other specific types of modules (Tvedt 2012).

The Netherlands maritime industry has shown great interest in these problems, and has supported numerous MSc thesis projects in this direction. Since 2020, the lead author has supervised over 8 completed and on-going MSc theses in this area with support from over 5 industry partners covering different aspects of the problem from understanding market uncertainty and early stage design challenges (van Lynden 2021; Zwaginga 2020; Zwaginga, et al 2021), seakeeping (Bronkhorst 2021; Bronkhorst, et al 2022), accessibility issues of far offshore wind turbines (Brans 2021; Brans, et al 2021), and modularity approaches for developing product families for OSVs (Kao 2021). On-going work is focused on improving the environmental sustainability of the OSVs themselves. These reasons made clear the choice to develop a teaching module around the design of modular OSVs for offshore wind.

COVID and virtual learning

In 2020 COVID brought about abrupt changes for teaching and education of ship design. Collette, et al (2022) discuss nicely the challenges universities faced and some of the approaches various universities took to maintain quality education. At TU Delft specifically, most of the lectures immediately went virtual and as the pandemic progressed TU Delft cycled between moderate in-person teaching and fully remote. Maintaining contact with the students and facilitating collaborating working environments was challenging. As COVID continued to influence the following academic years in uncertain ways, new approaches to teaching and learning were needed. At TU Delft there were some opportunities for limited in-person gatherings for students and teachers. To maintain fairness between students between those joining in-person and those unable or unwilling to join in person, a hybrid approach was pursued where collaboration was facilitated between those joining physically and those online. This required a modification in the delivery of the education material and design project set-up, since previously it had been heavily dependent on in-person group collaboration.

Gamification and active teaching and learning

By definition, active teaching and learning is an educational approach meant to help students assimilate information better by involving students in various course activities such as discussions, problem solving, case studies, role plays, games, and other creative tasks. Unlike traditional teaching, this method stimulates the student more and offers a greater degree of responsibility during the lecture. Active teaching and learning also requires additional preparation from the professor’s side as their guidance during the activity itself is a crucial part of the whole process. Usually activities last from a few minutes up to a whole lecture, or stretched across several sessions based on its complexity. Some of the stated benefits include:

- Students will increase their knowledge content and develop critical and creative thinking as well as problem-solving abilities (Anderson, et al 2006).
- It improves students’ enthusiasm towards the learning process (Thaman, et al 2013)
- Enhanced problem-solving skills, communication, interpersonal skills and group work (Kember and Leung 2005)

This is especially helpful to the engineering field where learning by doing practical activities can help deepen the knowledge of the learners or ease the understanding of relatively hard concepts. The goal for the authors was to develop the most suitable activity which can best fit teaching the concept of modularity for OSVs for offshore wind. For this application, the principles and methods could be much better understood by being taught in a more interactive manner to maintain focus on the design specific learning objectives.

One of the primary challenges of developing and implementing a group activity during COVID was the need to include both virtual and in-person collaboration. In-person activities have the advantage that people get to interact with each other, improving communication, teamwork, confidence, and creating a better work environment. Also, 1-on-1 interaction between the student and the teacher might prove to be more efficient as the teacher can more easily provide help, be it as guidance during the activity or for any technical issues which might arise with the work material. The drawbacks of an in-person activity is that they might have applicability limitations, materials can be damaged or hard to transport, and it might not arise interest if the activity is not unique enough. Digital activities, on the other hand can be done either in class or online, depending on the Universities’ facilities and halls availability (Lupoae 2020).

These drivers led the development of two new MSc-level hybrid format modular ship design activities that focused on OSVs for offshore wind. The activities were introduced into the MSc design course, Design of Complex Specials, offered by lead author Assistant Professor Austin Kana.

Background of Design of Complex Specials

Design of Complex Specials is an 8-week obligatory MSc course in Marine Technology at TU Delft. The course is offered in the first quarter of the study program, and aims to introduce marine design students into advanced marine design techniques. The course is roughly split between a survey of advanced marine design approaches and tools, such as systems engineering, set-based design, concurrent design, optimization, and current TU Delft ship design research. The other half of the course involves the integrated design of a complex vessel. From 2017 until 2020 the design project was a military submarine, as described in Kana and Rotteveel (2018). Due to the reasons above, in 2021, the design project was changed to a fleet of modular OSVs for offshore wind. As an obligatory course, the students inherently have various discipline related interests (such as hydrodynamics, structures, marine engineering, or ship design), and were also multi-cultural due to the numerous international students in the study program. The varied student backgrounds and interests influenced some of the decisions on how the design project and teams were set up, as described below.

ACTIVITY 1: A 2-HOUR HYBRID MODULAR SHIP DESIGN AVTIVITY[5]

The first activity was developed during the summer of 2020 by MSc student and co-author, Laurentiu Lupoae, during an independent research assignment under the supervision of Austin Kana. As part of the assignment, a literature review was conducted on modularity, OSVs, and active teaching and learning techniques. From this review, it was decided to opt for the conception of a dynamic Excel tool which follows a specification game principle in which students will act as designers tasked with applying modularity on a family of products. The project required groups of 4-5 students to plan a preliminary module arrangement for a group of vessels based on limitations set in an Excel tool, predefined according to modular principles.

The activity was scheduled to run during the fall semester in the Design of Complex Specials course. The activity was set to last between 2 to 4 hours, including time for an initial introductory presentation by the teacher and assessment of the output data from the designated tool. Given COVID, the activity had to be available for both in class and remote usage. This was another advantage of using Excel as the basis for the tool, as all students had access to Excel on their personal computers, even off campus.

The students were presented up front with the learning goals of the activity aimed to encompass the general approach of modular design. These learning objectives focused on the appropriate uses of modularity, the general principles of modularity, what types of modules there are, choices for holistic approaches to modularity, the modular design stages, and other practicalities involving the design and production stages.

Activity description

For this activity, students were assigned to teams of 4-5 people representing a design company specialized in modular design. The students were asked to develop a family of OSVs which need to have the capability to accomplish various types of missions. The students were provided an activity Reader containing a description of the game, background of the different OSVs and required capabilities, and a tutorial of the Excel tool prior to the game, however the Excel tool itself was not available until the game itself. For the remainder of the time (about 2 hours) the teams had to complete the assignment and present the results. Within the 2 hours available for the activity, the students aimed to:

1. Create a feasible module arrangement by designing a family ships between the given limits and with all the required capabilities
2. Beat the baseline individual ship designs by obtaining better cost, weight, production and design time than the baseline models
3. Win the contract against future competitors (their classmates)

The three different OSVs (not specifically for offshore wind) included:

1. A subsea operations vessel
2. A platforms and rig supply vessel
3. A rig and platform installation vessel

[5] Much of this section has been adapted from Lupoae (2020).

For this activity, it was assumed that the hull structure, propulsion type and power plant of the OSV were fixed. Therefore, the project was to select modules based on mission specifications and create a feasible preliminary model. The data for the hull characteristics and common modules was provided in the Excel tool. The students were restricted to a certain number of modules and by parameters such as total weight, deadweight, and volume. In summary, in order to successfully complete the assignment, the students had to:

1. Analyze all the modules and identify them based on the requirements
2. Select modules based on the interaction between them
3. Select the number of modules
4. Compare the output parameters to the baseline designs
5. Discuss and present the results

In class/Online Participation

The students were split between in-person and virtual students. The teams were set in advance based on the availability of the students to attend in person. Each team had at least 1 team member join virtually, thus it was a forced hybrid model. This was done to ensure as much fairness between the teams, as a fully in-person team may have a different approach or advantages than a fully virtual team. This forced hybrid approach also helped indirectly with introducing multi-disciplinary and multi-cultural student backgrounds into a single team since the only deciding factor on team formation was availability to join in person. The rest of the team formation was random. Virtual meeting rooms were set up using the course Brightspace page, but teams were also free to set up their own virtual meeting space instead (e.g. Zoom, Teams, Skype, etc.).

Excel tool breakdown

The tool was made in Excel which contained several worksheets: Available Modules, Ship 1-3, and Output Parameters.

Available Modules

This worksheet provided an extended overview of all the available modules which can be used in the current design. The data in this sheet is divided in 2 categories: Physical attributes, and Cost & Specifications. Four types of available modules were provided, including:

1. Propulsion, such as: forward tunnel thruster, and engine room
2. Work modules, such as: foldable crane, and shark jaw and towing pins
3. Functional tanks, such as: fresh water and diesel
4. Accommodation, such as: state cabin and galley

In total, over 40 individual modules were provided in the Excel sheet for the students to select and distribute between their vessels. Each module is also provided with volume, mass, cost per unit, production time, and design time. For the 2 hour activity, the available modules were assumed fixed, and students were not allowed to add or modify them, due to time considerations. This constraint was relaxed for the 8-week design project described below.

Ship 1, Ship 2, Ship 3

For each individual ship, the team had to define modules according to the specified mission requirements. Each sheet was identical and allowed for module customization according to the designers' choices. This worksheet included the hull parameters of the ship, a table containing the common modules between the ships, and a dynamic table containing the available modules for selection (Figure 1). A total of 85 modules for each ship were available for selection, including the identical modules. After choosing the desired modules and the numbers, the Tool automatically generated charts for mass, cost, volume, and time for a better understanding of the implications of the user's choices.

23								
24	Common items	Type	Number	Volume[m3]	Mass[t]	Total group cost[$]	Total production time[hrs]	Additional detail design time[hrs]
25	Forward tunnel thruster	Propulsion	2	608,05	74,00	212.500,00	320,00	357,60
26	Azimuth pulling propeller	Propulsion	2	1.403,60	112,00	637.500,00	400,00	460,80
27	Engine room	Propulsion	1	1.222,00	278,00	1.935.000,00	504,00	226,80
28	Side water ballast tank	Functional tanks	4	242,80	248,80	173.521,65	115,28	452,90
29	Bottom water ballast tank	Functional tanks	1	94,40	96,70	71.433,27	55,26	59,43
30			10					
31								
32	Variable modules	Type	Number	Volume[m3]	Total mass per module pack[t]	Total group cost[$]	Total Production time[hrs]	Additional detail design time[hrs]
60	Base oil	Functional tanks	-	-	-	-	-	-
73			-					

Figure 1: Screenshot of parts of Ship 1, Ship 2, Ship 3 worksheet

Output Parameters

In the last sheet, an overview of each individual ship was provided for key performance indicators in order to assess the performance between each ship and between the various design teams (Figure 2). In order to make a comparison between modular and point based design, the alternative individual design parameters have been calculated as a baseline. The users' role was to provide a better modular solution. With that, they had to assess the design criteria of overcapacity and number of components as a measure of performance of their modular solution.

Parameters \ Ship	Ship 1	Ship 2	Ship 3
Overcapacity	-	-	-
Number of components ratio	0,15	0,13	0,14
Weight[t]	809,50	809,50	809,50
Cost[$]	3.029.954,93	3.029.954,93	3.029.954,93
Cost/Weight ratio [$/t]	3.743,00	3.743,00	3.743,00
Occupied Hull Volume[m3]	3.570,85	3.570,85	3.570,85
Max Deadweight[t]	345,50	345,50	345,50
Total detail design time[hrs]	1.557,53	1.557,53	1.557,53
Total production time[hrs]	1.394,54	1.394,54	1.394,54

Ship 1-baseline		Ship 2-baseline		Ship 3-baseline	
Variable Modules no.	65	Variable Modules no.	77	Variable Modules no.	71
Total weight[t]	5.273,17	Total weight[t]	4.693,41	Total weight[t]	5.207,69
Deadweight[t]	3.209,40	Deadweight[t]	3.877,30	Deadweight[t]	2.774,10
Volume[m3]	7.718,65	Volume[m3]	8.877,35	Volume[m3]	7.744,65
Total cost[$]	8.647.381,01	Total cost[$]	8.690.582,00	Total cost[$]	8.715.739,61
Production time[hrs]	5.434,02	Production time[hrs]	5.427,10	Production time[hrs]	5.146,86
Detail design time[hrs]	4.924,50	Detail design time[hrs]	5.508,90	Detail design time[hrs	5.161,34

Figure 2: Screenshot of Output Parameters worksheet

According to mass production principles and to incentivize modularity, the higher the number ordered for a product, the lower the cost. Thus, the Excel tool calculated a discounted price, a reduced production time, and detail design time for each individual module based on the acquisition of a certain number of modules of the same type. These savings were done according to the following assumptions:

Table 1: Assumed modularity savings in cost, design time, and production time

Total number of modules in fleet	Cost	Design Time	Production time
3-6	-10%	-10%	-10%
6-9	-20%	-20%	-20%
9-12			-30%

In addition, the output parameters also included specific ship metrics related to:

- **Overcapacity ratio**: the division between the number of work modules used for a specific mission for the current design and the number of work modules used for a specific mission in the baseline design.
- **Number of components ratio**: the division between number of components (variable and common) used for the current design and number of components used in the baseline design.
- **Weight**: the cumulative weight of all modules used (including the common modules)
- **Cost:** the cumulative cost for each individual ship based on the used modules.
- **Cost/Weight ratio:** the common parameter used in the industry to assess the costs per ton of module
- **Occupied hull volume:** volume occupied by all modules.
- **Max Deadweight:** the cumulative weight consisting of: cargo, fuel, fresh water and ballast water and provisions. People and provisions onboard were neglected.
- **Total production time**: the cumulative number of production hours for module production and installation for each individual ship.
- **Design time**: the total design hours. The amount of additional detail design needed to for each individual ship.

Lessons Learned

The following are the lessons learned from the activity:

1. **Virtual participation does not match in-person participation**. Those who participated virtually expressed less satisfaction with the activity. This may have been due to technical difficulties. The other reason may have been due to the fact that only 1 or 2 joined virtually and thus 3-4 were in-person. This may have made it difficult for the virtual members to participate as openly as the in-person student. Also, during the final discussion at the end, it was harder to include the remote students as well as the in-person students.
2. **Some students claimed the activity was too much of a matching activity than a ship design activity.** Once they figured out the goals and how the tool worked, some students claimed they focused simply on optimizing the metrics to winning the game as opposed to thinking critically about the ship design considerations about their actual design

choices. Thus, care must be taken in the development stage to try to avoid this during the execution of the game to ensure focus remains on the ship design thinking and learning.

3. **Due to assumptions made in the Excel tool, the trade-offs were not as clear as hoped**. The developers had hoped for clear trade-offs between costs and performance of the ships, thus facilitating a nice discussion at the end as to why certain teams favored certain design approaches and choices. However, at the end there was one clear winning team across all metrics, which was good for the team, but poor for the discussion on trade-offs.
4. **The development as part of MSc individual research project was clear added value.** This was clear added value to both the MSc student himself, as he was able to actually lead in executing the game, but also for the students in the game as well. They were able to see the opportunities available to them in future potential independent research projects, and the impact they may have.

Overall this activity was deemed a success and was thus introduced as part of the broader ship design project in the course.

ACTIVITY 2: AN 8-WEEK MODULAR SHIP DESIGN PROJECT

For the 2021/2022 academic year, the course Design of Complex Specials was redesigned primarily by the new design project. Since 2016/2017, the design project had been a military submarine (Kana and Rotteveel 2018), and due to the reasons discussed above, the project was changed to a modular fleet of OSVs for offshore wind. From a course perspective, this provided several advantages. First, by removing the submarine project, additional lecture hours became available to cover a broader survey of advanced marine design techniques, as less hours were needed to cover the technical specifics of submarines. Second, the design project became more relevant for the maritime energy transition, and was thus potentially more interesting to a broader range of students.

Background of Design Project

The design project involved students designing a small modular fleet (of either 2 or 3 vessels) in teams of 6 students over 8 weeks. Students were provided introductory lectures on offshore wind, OSVs for offshore wind, and design approaches on systems engineering, and modularity early in the course. At the start of the project the students were provided a unsorted list of requirements, functions, and systems for their OSV family. This list included requirements that were both tightly constrained in some areas, and allowed design flexibility in others. To understand details of some of these requirements, functions, and systems some independent research from the student teams was required. This was done to simulate part of the wicked nature of early stage complex ship design. Wherever tradeoffs were required, it was up to the students to decide and justify the decisions. The students were expected to use knowledge gained from the lectures to sort this list, and come up with a suitable approach to allocate them to their small fleet. The project was split into two phases, each lasting about 4 weeks. The two phases included a midterm report and final design.

A Midterm Report

The first half of the project was primarily focused on sorting the requirements, functions, and systems, and making initial decisions on how to allocate functionality and systems between the ships, using techniques learned in the lectures. It was expected that all 6 students contribute to this effort. There were four elements in this phase of the project:

1. *Breakdown structures*: The teams were expected to analyze and develop breakdowns structures for the requirements, functions, and systems, and explain their reasoning.
2. *Use of a design tool*: Students were to perform an initial modularity analysis using the Modular Function Deployment tool (Erixon 1998; Smit 2019) and the Modularity Game Excel Tool described above (Lupoae 2020) to help support their tradeoff analysis and initial modularity decisions. The students were asked to explain all their rationale and decisions.
3. *Status update on your design progress*. The following portions were expected to be in progress: primary tradeoff analysis, initial systems allocation to ships, and a project planning. The decision on 2 ships or 3 ships was expected in the midterm report.
4. *Report and Feedback session*. The teams had a strict 8 page limit for which to report the items above, and the report was formally assessed as part of their grade (about 20% of their final grade). A rough allocation of 26 hours of work per student was estimated for this phase. Students also had the opportunity for a 20 minute review session with the instructor to review the work in the midterm report and ask any questions.

The Final Design

The second phase was focused on the actual design of the ships themselves. For this, the teams were required to form sub-teams within their team for each ship. For example, if they chose to design 3 ships, they would split into 3 sub-teams of 2 people, where each pair of students focuses on one specific ship. Likewise, if they chose to design 2 ships, they would have 2 sub-teams of 3 students each focusing on a specific ship. In the final report, the teams explicitly listed which team members designed which ship, as the individual design of each ship was assessed separately, helping differentiate individual from team performance.

As ship design is integrative and multi-disciplinary, this team requirement helped ensure each student focuses on an entire ship design (as opposed to only one discipline). Thus, for the purposes of this assignment the students were not allowed to break their team into functional groups, where for example, one team member does the stability for all the ships, and another does the marine engineering, etc. For this portion of the design project, the students were provided an Excel and Rhino-based design tool specifically designed for this project, which is described in more detail below. Final ship designs were assessed on the following criteria:

- Weight and sizing estimation
- Stability
- Arrangement and layout of systems
- Resistance and propulsion, marine engineering
- Overall quality of design

In addition, the modularity of the designs was assessed as part of the family. The following criteria was used:

- Modularity (e.g. modularity KPIs, how well did they incorporate modularity into their fleet/ family?)
- Module consistency across fleet (e.g. how consistent is the sizing and placement of modules across the fleet?)
- Overall quality of fleet/ family (e.g. KPIs evaluation, overall effectiveness)

Each aspect was assessed equality, helping ensure the students contribute roughly equal effort to all aspects, as opposed to over emphasizing one aspect at the expense of the others. This final design was worth about 50% of the final course grade, and students were estimated to each spend about 68 hours on this phase.

Modular OSV Design Tool

The students were provided a design tool to support the actual development and generation of their designs. This tool is based off of the same framework as the previous submarine (and earlier surface naval ship) design tool as described in Kana and Rotteveel (2018). The set-up of the tool is with Excel and Rhino and shown in Figure 3. The interface between Excel and Rhino was done via a python script. The objectives of the tool are the same as previous versions in facilitating weight balancing, layout creation, and visualization of concept designs to help enable fast manual iterations between design iterations. Kana and Rotteveel (2018) outline the requirements for the design tool, the rationale behind the high level architecture of the tool, and the reasons behind it to keep the focus on graduate education. This set up of the tool also made the transition to remote work easy due to COVID regulations as students were able to either remote access into TU Delft software or were able to execute them locally on their personal computers.

In addition, the block and object definitions, reference plane definitions, and use of secondary objects remains the same as the submarine tool. For the submarine, reference planes and equations were used to define the hull shape, while the OSV had a predefined hull shape where the students' determined the length, beam, and depth.

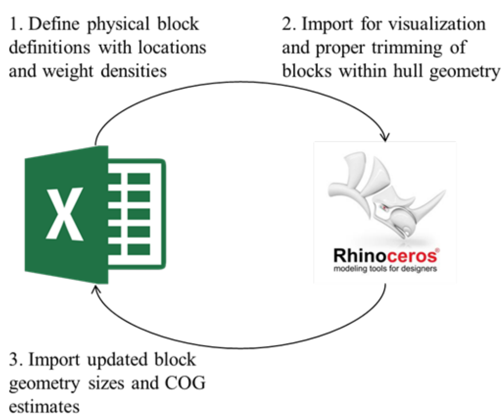

Figure 3: Steps and software platforms for OSV design tool.

In addition to the required updated estimates on weight and systems sizing, the primary differences between the two tool variants was the definition of the hull form, and resistance calculations. A baseline monohull hull form was provided for the students in Excel. This hull form was more long and slender than the expected final designs for service vessels, and thus the teams were forced for modify the primary dimensions for their designs. In the submarine tool variant, the baseline design seemed to be too close to final converged design solutions, and thus limited design creativity and learning opportunities. By providing a baseline hull that is a bit further away from the expected final designs, the students were forced to critically evaluate their design dimensions more closely, as it pertains to their specific ships. In addition, hull forms for OSVs do not typically fit into the classical hull forms of the Holtrop and Mennen resistance estimation approach, and typically operate in DP mode for a large portion of their service life. For a rough resistance estimation we proposed the students to use Equation (1). This is an oversimplification as it only accounts for frictional resistance. Some teams noticed that the estimated resistance was low and added an estimation of the wave making resistance:

$$R_T = 0.5*\rho*V^2*C_f*(1+k)*S \quad (1)$$

Where ρ is the density, V is the ship speed, S is calculated via the Rhino model, and C_f is the frictional resistance coefficient calculated by the ITTC-1957 method. The *(1+k)* form factor could be estimated via Table 2.

Table 2: Form factor estimation

C_B	$1+k$
<0.7	1.10 – 1.15
0.7-0.8	1.15 – 1.20
>0.8	1.20 – 1.30

Final Designs

In the course there were nine design teams, with four teams choosing to design two vessels, and five teams opting for three vessels. This was a nice even split. Given the freedom to allocate functions to different vessels, there were nine different types of OSVs designed across the teams, including:

- Cable operations and laying vessel
- Sub-sea operations vessel
- Research and diving support
- Geotechnical and research vessel
- Multi-purpose vessel
- Construction and installation support
- Service operations vessel
- Support and transport vessel
- Maintenance sand inspection vessel

Figure 4 provides two final design variants of a cable laying vessel and a sub-sea operations vessel from two different teams.

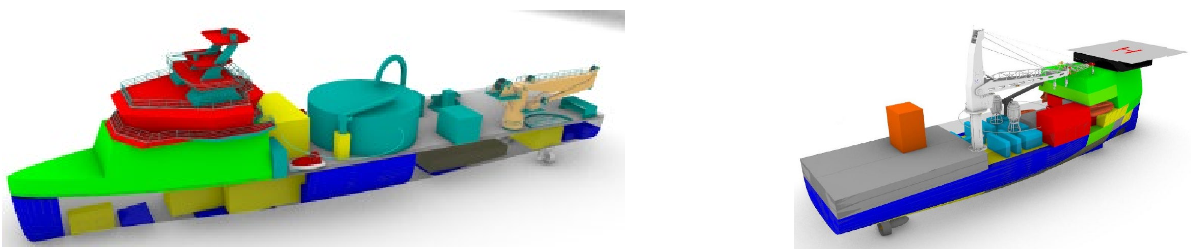

Figure 4: Example cable laying vessel (L) and sub-sea operations vessel (R) developed by two different teams

LESSONS LEARNED AND DISCUSSION

The following are lessons learned from the design project:

- **Keep tooling simple, for reduced annual maintenance.** Each year, estimates need to be updated, and possible software updates require the Rhino-Excel tool to be examined each year. Keeping the education tools simple helps reduce this work load from a course preparation standpoint.
- **Various design education support tools and documentation can lead to confusion in a short course if not organized well.** For the course there were multiple Excel tools, readers, manuals, and a Rhino tool. To help clarify which tool or document to use when, we had to develop the flowchart in **Figure 5** for the students. This added a layer of complexity and time for the students. In future iterations of the course we will work to simplify the delivery of the design assignment materials.

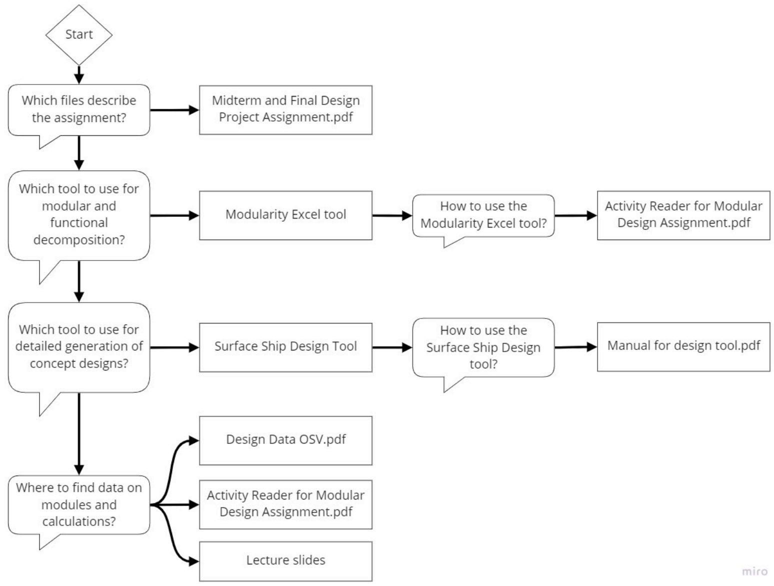

Figure 5: Flowchart provided to students to help organize all design assignment materials.

- **The two phase project schedule (first problem breakdown, then execute design) seems to work well**. This set up forces students to take the necessary time early in the project to critically think about their early design decisions, in a structured manner. This hopefully prevents the "run off and design" situation where design solutions are created without critically thinking about the problem they are designed to solve.
- **The hours distribution throughout the course could be improved.** Students noted that the course was very back loaded with expected hours, which conflicted with the students' other course load (exam preparation, etc.). As a design project, this is hard to mitigate, but in future years, we aim to move the midterm report earlier by one week (to week 3), which would allow 5 weeks to execute the design (instead of 4). To facilitate this, we aim to assign the teams prior to the course starting to allow them to start work immediately on the project as a team.
- **Suggest multi-disciplinary, multi-cultural team formation.** Modern ship design is inherently multi-disciplinary working in multi-cultural teams. Where possible, student design teams should be set up to reflect this.
- **Formal scientific education testing and evaluation would help improve whether these design assignment changes actually improve learning and knowledge retention of the students**. The current assessment of these activities has been done informally via the lessons learned described above; however, developing a formal scientific method to test these new design methods in terms of student growth and knowledge retention would add clear value.

CONCLUSIONS

The development of two new modular ship design activities for graduate education at Delft University of Technology that were developed during COVID proved to be a valuable contribution to the course "Design of Complex Specials". The three drivers behind these activities (changing market needs, COVID and virtual learning, and gamification and virtual learning), all provided a direction for selecting activities related to hybrid team design projects related to the design of a fleet of modular OSVs for offshore wind.

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