

Educating for an unknown future: How to prepare students of ship design for the propulsion of tomorrow

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ABSTRACT

It is very likely that the students that we educate today will work with what we currently refer to as modern propulsion or alternative fuels in their career. As educators, the goal is to best prepare our students for their working life. This article looks into what a naval architecture student would need to know about these modern propulsion systems and fuels when they graduate. In this article, two types of knowledge are defined; adaptive knowledge, knowledge that spans multiple areas, and routine knowledge, that addresses a specific case. By identifying what competencies fall under the adaptive knowledge and which fall under routine knowledge, it is possible to advice on changes that should be made to the curriculum in order to best prepare students for the future.

KEY WORDS

Design education; green propulsion; green shipping; marine engineering

INTRODUCTION

Last year, in 2023, the IMO published the common ambition of its member states to bring the greenhouse gas (GHG) emissions close to zero. Additionally, they made a commitment to use more alternative, zero and near zero GHG fuels by 2030 (IMO, 2023). These goals, together with the general trend towards cleaner and greener fuels and propulsion methods means that the students we educate today will need to work with these alternative fuels and propulsion systems in their career. However, as we are still at the beginning of the green revolution in shipping there are many different types of fuel and corresponding propulsion systems to choose from. Unfortunately, we cannot simply address them all in detail.

Education has always had to deal with adapting to innovations made in the industry. Especially in the last decades, technology and tools used in industries are changing rapidly, making educational institutions play catch-up. There is a field of tension between teaching students traditional skills and adding new skills. This is influenced by the wishes of the industry, but also by the skillset of the lecturers and the available time to set up a curriculum surrounding these new technologies.

In this article, we look at how we can best prepare students for the unknown future, allowing them to excel regardless of how a ship's propulsion system will look in the future. We start of with an analysis of the current curriculum for the marine engineering. From there, we define the competencies that a student who graduates with a bachelor degree has. Next, we make the transition to identifying what competencies students should have in the future. This is based on three parts; the first is an analysis of a project performed by our third year students who were tasked with designing a Crew Transfer Vessel (CTV) powered by fuel cells, without them receiving specific training in this area. Additionally, a literature review is performed to find if a trend can be found there. Finally, the industry is asked for their input to see what competencies recent graduates lack. Together, this leads to an overview of what changes should be made to better prepare our students for the future. The article ends with an advice on where the focus should lie.

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In this article the focus lies on modern propulsion systems such as batteries and fuel cells and different (low flash point) fuels. Other methods to reduce GHG emissions on ships such as scrubbers and wind assisted sailing also exist. However, the use of these types of systems is assumed to not be as disruptive for the industry and therefore the curriculum. This means that they are out of scope.

CURRICULUM MAPPING

Currently, the curriculum at NHL Stenden mostly focusses on ships powered by conventional propulsion. In the first year, students are introduced to the main drivers and auxiliary systems. They learn about the most important values of the propulsion systems and make some basic calculations to determine the type and size of engine a ship requires. In the second year, as part of a project, students are asked to make a more detailed design of the engine room. They determine the required power to propel the ship, calculate the amount of additional power that is required and make technical drawings of the engine room such as a detailed design of the engine room and a one line diagram. In the third year students are tasked to design a more complex ship design which requires a better understanding of the required power on board.

To identify the skill that students now have when they leave their study program a method known as curriculum mapping is used. Generally, it is used to identify how generic skills, such as literacy, numeracy and interpersonal skills of students are evaluated, however, it also works for technical skills. Curriculum mapping is used to identify in which subject specific competencies are taught. For example, it can be used to identify where students learn to present their work orally, or where they learn to write a comprehensive report (Sumsion & Goodfellow, 2004). For this article, the method was inverted. Using the study guide of the NHL Stenden University of Applied Sciences as well as input from the lecturers for the different subjects and projects the current competencies within the bachelor curriculum related to the propulsion of ships is investigated.

Defining main educational themes

The mapping of the competencies leads to a long list of different skills related to the propulsion of the ship. In many cases the competencies could be directly derived from the learning outcomes of the different subjects, leading to well defined competencies. The competencies are then grouped together under overarching themes. By identifying the different themes, it is easier to define where changes to the curriculum are required and what elements can remain the same.

The themes are identified conceptually, as is a common approach in this type of research (Male et al., 2011). For this research six themes have been defined; technical theory, design; knowledge of systems and components; operations and economics; safety and fit for 2050. Within these themes, the competencies are identified. Below, each of the six themes are explained further, explaining which current competencies would fall under the relevant theme. The full list of the competencies belonging to the six themes can be found in Table 1. These competencies are used in the end of this article to identify what changes need to be made to the curriculum and what can remain the same.

Technical theory

Technical theory is a very broad theme than encompasses the general knowledge students should have to understand the working principles of the propulsion systems. This includes a general understanding of basic thermodynamic principles but also electrical engineering. The competencies in this theme form the basis on which students build with the other themes.

Design

The theme design covers the competencies related to the design of the engine room. This means that students are able to select the required machinery based on a set of requirements, place it in the allocated space and identify how their choices might influence the rest of the design. As this study only looks at the design of the engine room. Design strategies, although a key part of education of a naval architect, are left out of the scope of this research.

Knowledge of systems and components

This theme covers the understanding of different components that make up the propulsion system. In a traditional system, this would include the diesel engine, (shaft) generators, gearbox etc. Additionally, it includes, but might not be limited to, auxiliary systems and fuel systems. In addition to understanding the different propulsion types, this theme also covers the ability to connect ship types with common or favourable propulsion types.

Operations and economics

It is not enough for a naval architect to be able to design an engine room, they should also understand the effects the chosen propulsion has on the operational profile or building cost of the ship. This theme covers the effect that the choice of propulsion type will have on the operation of the ship, as well as the influence on building cost and operational cost.

Safety

Safety is always a key aspect in any operation, but is also a very broad term. For this article, safety is everything that has to do with safe operation of the ship, with regards to the propulsion system. A main competency in this area is the understanding of the dangers of different propulsion and fuel types. This also includes a basic understanding of the rules governing the design of the engine room and knowing how to apply them.

Fit for 2050

The final theme already looks towards the future. The current curriculum already has an aspect that looks into elements of modern propulsion. Covered in this theme are calculations regarding the emissions of a ship, knowledge of the EEDI, EEOI and EEXI and benefits of electrification on board of ship. However, the competencies within this theme are still fractured and not very well defined.

Table 1 Summary of the themes and corresponding competencies

Theme	Included competencies
Technical theory	<ul style="list-style-type: none"> - The student can apply the basis laws of thermodynamics (e.g., first and second law, ideal gas law etc.) - The student can apply basic electric principles (e.g., Kirchhoff, AC, DC, Lorentz force etc.)
Design	<ul style="list-style-type: none"> - The student can translate functional requirements to system solutions which are subsequently integrated into a ship design that meets the requirements of the client. - The student can select required machinery based on system requirements. - The student can perform a matching procedure to determine the required propellor and main driver characteristics. - The student is capable of placing the selected propulsion system and auxiliary systems into the general plan of the ship. - The student understands the logic behind the general plan of different types of cargo ships. - The student can compare different types of conventional propulsion systems with regards to performance, efficiency, manoeuvrability, comfort, design and cost.
Knowledge of systems and components	<ul style="list-style-type: none"> - The student can explain the components and processes that are part of the following propulsion systems: <ul style="list-style-type: none"> o A conventional internal combustion engine o A gas turbine o A blue fuel system - The student knows the capabilities of the following propulsion systems <ul style="list-style-type: none"> o A conventional internal combustion engine o A gas turbine o A blue fuel system - The student knows the auxiliary systems of a conventional propulsion system.
Operations and economics	<ul style="list-style-type: none"> - The student is aware of the different operational profile of conventional propulsion systems - The student can determine the operational cost of conventional propulsion systems
Safety	<ul style="list-style-type: none"> - The student knows and is conscious of the technical, human and organisational dangers and risk of different propulsion systems
Fit for 2050	<ul style="list-style-type: none"> - The student knows the different types of ship emissions and the influence of the environment. - The student can determine the environmental impact of a specific design. - The student knows the advantages and disadvantages of different modern propulsion types.

Comparison with other study programs

While a detailed analysis of other study programs has not been done at this time, a cursory comparison is made to see if there are large differences. Within the Netherlands, two other universities offer a bachelor's degree in naval architecture; the Delft

University of Technology and the Rotterdam University of Applied Sciences. The study programs are not the same, Delft has a more theoretical focus, and in Rotterdam they specifically mention marine engineering as separate subjects instead of being integrated into projects as is the case at NHL Stenden (Delft University of Technology, 2023; Hogeschool Rotterdam, 2023). However, based on the short study guide descriptions and discussions with lecturers from the other schools it can be concluded that many of these competencies overlap.

Adaptive expertise

Adaptive expertise is a term first introduced by Hatano and Inagaki (Hatano & Inagaki, 1984). They stipulate that in learning one can have two types of expertise; routine expertise and adaptive expertise. Routine expertise means a person is highly skilled at a specific task, but lack the flexibility to use the skills and knowledge related to this tasks to new problems. Adaptive expertise on the other hand means that creativity and flexibility are used to solve a problem. This also means that the “standard” procedures for solving a problem are not always followed. To allow for students to thrive not only in the current state of technology but also in the future, they should gain adaptive expertise. However, educational institutes struggle with how to help students develop the creativity and flexibility to become an adaptive expert when needed, without forgoing the need for standardised routine expertise (McKenna et al., 2006). An efficient study program prepares students to have both areas of expertise (Pierrakos et al., 2016).

COMPETENCIES IN PRACTICE: DESIGN OF A FUEL CELL POWERED CTV

In the second semester of their third year, the marine technology students at NHL Stenden are tasked with the full design of a vessel for a specific client. They will run through the entire design process, from identifying the clients wishes to the drawing of the general plan. Last year (2022/2023) the students were tasked with designing a crew tender vessel that was powered by fuel cells. They did not receive any specific training or lectures on the detailed workings of the fuel cells, they had to find the relevant information for themselves. This project therefore provides a good insight into what further information the students would require to fully understand how to design a ship with this type of propulsion.

The final report of the project shows that the students are capable of performing the calculations that determine the required power that needs to be installed on the ship. This is, of course, no different when designing a ship with conventional propulsion. They also calculate the amount of energy they can get out of a m³ of hydrogen, giving them a reasonable assumption in the amount of hydrogen they would need to take. This, once again, is no different from designing for HFO or MDO. In the next step the students select a fuel cell, as they have been taught.

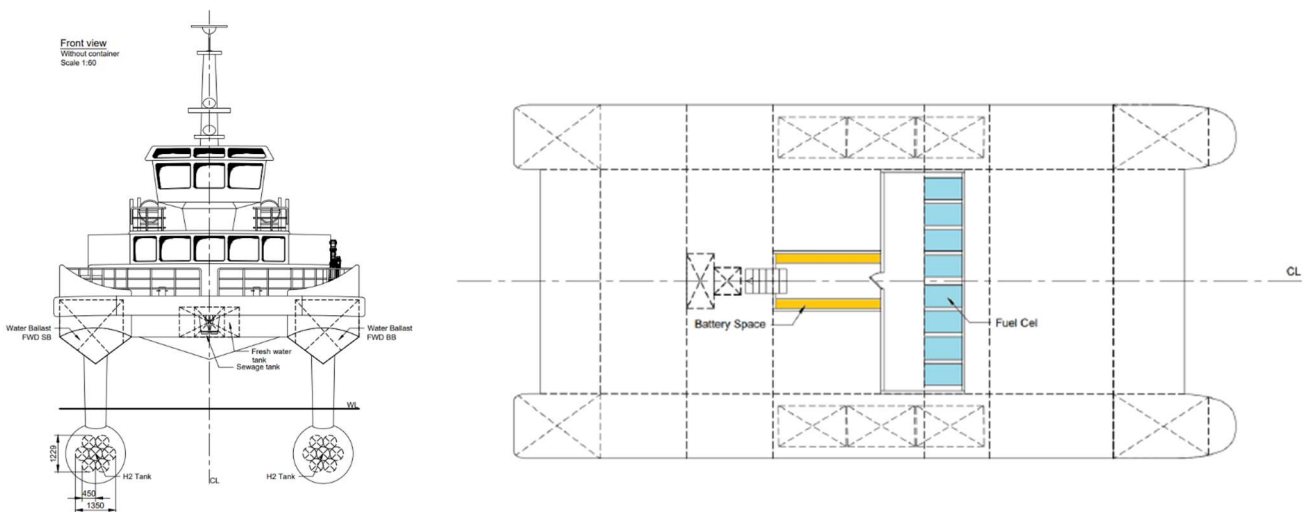


Figure 1 - general plan of the CTV designed by the third year students

The steps the students take up to here show that they have the competencies that one would expect them to have given the list presented in Table 1. However, after this, we see what happens when students try to apply routine expertise as adaptive expertise. It becomes clear that the students have not understood the different equipment that is required for a fuel cell system to operate. The choice they made in the design and the general arrangement show that they do not know enough about the set-up of a system that uses fuel cells. Additionally, the report shows that they have a limited understanding how a fuel cell system generates energy and how this energy is used to power the ship. One example of this is the battery pack. Although the report mentions the fact that a battery pack of 45 batteries is required and it is also drawn into the general arrangement of the ship (see

Figure 1), it is never explained how much power can be stored in these batteries. The confusion seems to stem from how a system with a fuel cell works. Basically, they have designed a system that gets its power from the fuel cell, and provides this to an electrical engine and the propellor directly, as can be seen in Figure 2. This shows that they have a very good understanding of how a propulsion system with a diesel engine works, but that they failed to make the translation towards a fuel cell system. Figure 3 gives a very basic representation of the main components of a fuel cell system.

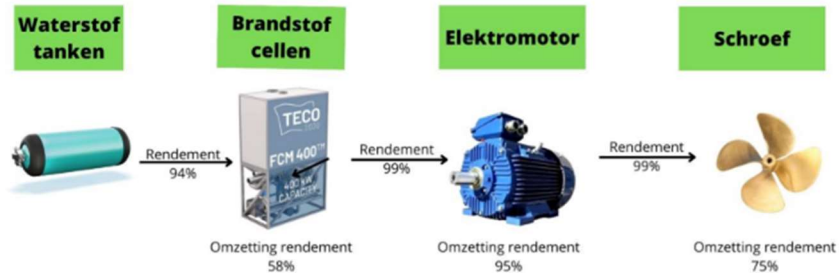


Figure 2 - Basic setup of a fuel cell system according to the students, showing that they designed it as they would a diesel direct system and misunderstood the fundamental differences between these systems.

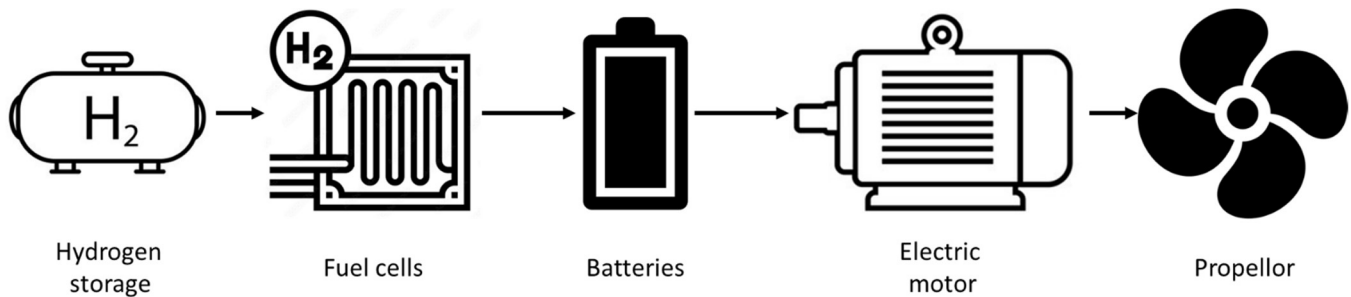


Figure 3 Very basic overview of the main components of a propulsion system with fuel cells

The analysis of this project shows that the competency regarding the matching procedure; *the student can perform a matching procedure to determine the required propellor and main driver characteristics*; can be classified as adaptive expertise. Regardless of the requirements of the propulsion system, the students can perform the required calculations. The students also show that they can change from conventional fuel types to different types of fuel to calculate the consumption and thus the size of the tanks. The students also made a reasonable estimation of the production cost of the system, based on basic figures they had found. However, for a functioning design, the theme of Knowledge of systems and components should be expanded with knowledge of the fuel cell and its corresponding systems. Likely, the same argument can be made for a system that runs on batteries.

It would be beneficial for the students to not only learn about the different systems that a modern propulsion system consists of, but also work with them in a project. By applying the knowledge they have gained in practice it cements. Additionally, they might run into situations not covered by the theory, leading them to use what they have learned creatively, making the step towards adaptive knowledge.

REQUIREMENTS ACCORDING TO LITERATURE

In literature, the terms green propulsion, automation and digitalisation are often used together when it comes to the future of the shipping industry (Skillsea, 2022). As we are still at the beginning of the transition to other types of propulsion, much of the literature focusses on the possibilities and capabilities of different types of batteries and fuel cells and the systems that manage them. To the authors knowledge, no research has been published on what naval architecture students should know.

There are however, articles that look into very specific calculations or estimations that can be done to determine specific details about, for example, determining the power demand or determining the degradation of batteries in a system. In these articles machine learning and AI is used to perform the calculations or the analysis. A bachelor student of naval architecture is not required to understand the machine learning and AI that is used, but might, at some point be working with the resulting programs, tools, or calculation methods. This means that some understanding of the working principles of machine learning and AI might be required or beneficial.

Existing training and documentation in modern propulsion systems

Although there is seemingly no standard or advice in what naval architects should know about modern propulsion, there is a wide variety of introductory courses, books and other documentation available that cover different types of modern propulsion. In general, everything seems to follow the same set-up. It starts with an introduction on the main engineering principles of the technology that is discussed. From there the operating characteristics are introduced and finally the link is made to the system operating in a maritime context (Baldi et al., 2022; MAN Energy Solutions, 2019; Maritime Hydrogen Safety (MarHySafe) Joint Development Project, 2021; Netherlands Maritime Technology, 2024; Stoiber & Valøen, 2016)

This makes sense. Before being able to grasp the benefits and abilities of a propulsion type, one should have a basic understanding of how this works. The main difference in this case will be the electro-chemical propulsion, as it is substantially different from the current propulsion systems. Both the chemistry required to grasp the working principles of these types of propulsion systems and the electrical engineering required to understand how the power is distributed throughout the ship are not currently part of the standard curriculum.

Adjusting requirements for seafarers

The training and education of the seafarers that work on the ships is much more regulated than that of the designers. The IMO is looking to make large changes to the International Convention of Standards of Training, Certification and Watchkeeping for Seafarers (STCW). In a large review of the current STCW code it was decided that a committee should look into how the changes in propulsion should be anticipated (IMO Subcommittee on Human Element Training and Watchkeeping, 2024).

A large European project, Skillsea, looked into the skills that seafarers should have now and should have in the future (Oksavik et al., 2020; Zec et al., 2020). They mainly identify a skill gap in digital skills, such as understanding the complex digital architecture of modern systems, and green skills, which focusses on energy efficient and environmentally friendly ship operations.

In the results of this project, it is suggested that additional specialisation can be offered, without (currently) making changes to the STCW. They suggest, among others, the following technical skills (Oksavik et al., 2020):

- Knowledge of logistic and optimisation methods in terms of the operation of ship and machinery
- Operation of complex hybrid and zero-emission machineries
- Measurement, calculation and documentation of emissions
- In-depth knowledge of the complex systems on board
- Advanced skills in analytics and use of data in optimisation of the fleet

There is an overlap between the observation made regarding the student project and the skills that are suggested here. The Skillsea project finds that the knowledge and understanding of the modern systems on board is lacking for seafarers, as we also found during the student project. The measurement and calculation of emissions is already covered in the curriculum and mentioned under the theme Fit for 2050 in Table 1.

The optimisation methods have not come up yet. For the seafarers, this mostly focusses on the operation, for example by sailing at ideal speeds, or having the propulsion system function at peak efficiency. At the moment, there is not a lot of focus on the operational profile of the ship, as a diesel engine does not offer a lot of flexibility in operational modes. However, an electrical system has much more adaptability and flexibility, making use case calculations more important (Klein Woud & Stapersma, 2008).

THE WISH OF THE INDUSTRY

Finally, we look at the wishes of the industry. As ships powered by modern propulsion systems are already operating and with more in the order books, companies that work with these systems are looking for personnel that has knowledge of these systems. To determine what companies require, informal interviews have been held. During these interviews the competencies of the students were discussed, to see if the list of competencies is complete, and more importantly, if they feel that knowledge should be added.

One of the main findings is that companies that design and install modern electro-chemical propulsion systems in house find it difficult to find recent graduates that have the required knowledge and interest to work at their company. In general, these companies state that the lack of knowledge with regards to electrical engineering is lacking. They do not generally expect student to be completely familiar with different types of modern propulsion systems but having a stronger basis in theory would help them be better prepared to work with these systems. Many of the companies provide in house training, either on the job or as a course for their new employees to make them more familiar with modern propulsion systems. Interestingly one company stated that they were also hiring engineers from ships who have a specialisation as an Electro Technical Officer, because they

are currently the best qualified to understand how the systems work. Companies have also branched out, hiring mechanical or electrical engineers who have no direct knowledge of ships, training them in that area, as they cannot find employees who have both knowledge of electrical engineering and ships.

HOW TO BEST PREPARE OUR STUDENTS

With the analysis completed, it is time to look at the competencies defined at the start of this article. This is the current starting point for bachelor students, but from the analysis, several changes can be proposed. The summary of the findings can be found in Table 2.

Table 2 Summary of the findings per defined theme and suggested changes to the competencies within the theme

Theme	Type of expertise	Summary and suggested changes
Technical theory	Adaptive expertise	<p>Talking with industry shows that the interest and knowledge with regards to electrical engineering is lacking. While it is listed as a competency, the students' knowledge in this department is generally not sufficient to work with more electrified systems.</p> <p>Suggested change: A broader focus on the theory of electrical engineering and chemistry to help students better understand how electrochemical propulsion works.</p>
Design	Adaptive expertise	<p>The analysis of the design of the CTV shows that most of the competencies in this theme are adaptive knowledge that translates very well to other types of propulsion.</p> <p>Suggested change: Adapt the final competency: <i>The student can compare different types of conventional propulsion systems with regards to performance, efficiency, manoeuvrability, comfort, design and cost</i> to also include modern propulsion systems.</p>
Knowledge of systems and components	Routine expertise	<p>From the analysis it has become clear that this theme requires some changes. While other types of fuel do not seem to be a problem for the students, as the design process remains the same, the systems that are not based around an internal combustion engine are more difficult. Therefore, these should be added to the list for both of the competencies listed under this theme. At this point, this seems to be fuel cells and batteries, however, this could be completely different in the future.</p> <p>Suggested change: knowledge of a system working with fuel cells and or batteries should be added to both competencies.</p>
Operations and economics	Adaptive knowledge	<p>The operational profile of a system with a modern propulsion system can be very different from that of a system with a conventional propulsion system. However, with the additional knowledge provided in the previous two theme, the skills and methods taught in this theme should translate well enough for students to work with modern systems as well.</p> <p>Suggested change: The competencies should be adapted to include modern propulsion systems, however, this does not necessarily change the content of this theme.</p>
Safety	Adaptive and routine knowledge	<p>Safety has not been a significant area within this article. Every different power generation configuration has different safety risks. However, the process of identifying and handling these risks remains the same. Some additional attention could be paid to specific risks of other types of propulsion and fuel, but a change to the competency is not required.</p> <p>Suggested change: When focussing on the working principles of modern propulsion systems, additional attention should be paid to additional risks that are present when a ship is equipped with different fuel and/or propulsion systems.</p>

Fit for 2050	Adaptive knowledge	There are not many changes required to this theme. The effects of the emissions and the influence of shipping on the environment will remain a factor. The fact that we are teaching students about low and no carbon fuels doesn't mean that learning about emissions is suddenly obsolete.
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CONCLUSIONS

Table 2 shows that the competencies in most of the themes can be classified as adaptive knowledge. The competencies that require the most attention are the once under the theme knowledge of systems and components. This knowledge very much counts as routine knowledge, meaning that each type of new propulsion needs to be addressed separately. In addition to the specific knowledge regarding the working principles of the new propulsion types and the required auxiliary systems, the connection between the themes *operations and economics* and *safety* might need additional attention. However, the competencies here does not necessarily change, it is mainly using the competencies from the theme *knowledge of systems and components* in a different way.

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