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The Effectiveness of Project-Based Learning Compared to Conventional Methods in Teaching Applied Mathematics for Ship Stability and Center of Mass Calculation

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Abstract

Mathematics constitutes a vital foundation in maritime education, serving as an essential tool for ensuring safety, operational efficiency, and sustainability in the shipping industry. Its applications extend to critical areas such as route optimization, cost reduction, and environmental protection. Nevertheless, applied mathematics is often perceived as one of the most challenging subjects for nautical students, largely because of the difficulty in linking abstract concepts to practical, real-world maritime problems. This learning gap highlights the need for pedagogical strategies that can transform theoretical knowledge into tangible applications relevant to the maritime field. Project-Based Learning (PBL) has emerged as an effective instructional approach to address these challenges by promoting active learning, enhancing problem-solving abilities, and fostering both creativity and critical thinking. In maritime education, PBL can be particularly impactful in teaching complex topics such as ship stability, where mathematical principles play a central role. Ship stability, especially in relation to intact conditions, is crucial in vessel design and operation, as it determines a ship's capacity to resist external forces and recover equilibrium. A key mathematical component of this process is the calculation of a vessel's center of mass, which integrates mass distribution across structural components and loading conditions. By constructing ship models and applying coordinate-based methods, students can connect theoretical mathematics with practical stability analysis. This experiential approach not only deepens conceptual understanding but also equips future maritime professionals with the analytical competencies essential for safe and efficient operations in the global shipping environment.

Introduction

Mathematics plays a fundamental role in maritime training programs, as emphasized in the Standards of Training, Certification, and Watchkeeping (STCW) within the IMO Model Course 7.01 for Masters and Chief Mates (Qi, 2022). Its significance in maritime education is particularly evident in ensuring both safety and economic efficiency in the shipping industry. By utilizing mathematical modeling to process and analyze data, it becomes possible to optimize shipping routes, leading to reduced transportation costs per ton compared to conventional routes. This optimization not only enhances economic efficiency but also contributes to environmental sustainability by minimizing air pollution and mitigating climate change (Yang et al., 2022; Chen et al., 2023; Awewomom et al., 2024; Mir et al., 2022).

Applied mathematics is often considered one of the most challenging subjects to comprehend, particularly for nautical students, who frequently struggle to connect mathematical concepts with their real-world applications (Vroutsis et al., 2022; Vettriselvan et al., 2025). To overcome

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this difficulty, students must first develop a thorough understanding of practical problems before identifying the most effective solutions (Gholami et al., 2023; Hmelo-Silver, 2004; Van Merrienboer, 2013; Rahmah & Lubis, 2024; Wardat et al., 2023). Project-Based Learning (PBL) has been recognized as an effective pedagogical approach that enables students to transform abstract mathematical concepts into concrete applications. This method fosters scientific knowledge and enhances creativity by engaging students in hands-on problem-solving experiences (Rasul et al., 2018; Shieh & Chang, 2014; Demirhan & Sahin, 2021; Kumar & Acharya, 2025).

To address these challenges, PBL combined with technological integration offers an opportunity to maximize students' cognitive potential (Rizal et al., 2019; Shpeizer, 2019; Jin & Bridges, 2014). This instructional approach is expected to enhance the teaching of applied mathematics by promoting collaboration, critical thinking, and conceptual discussions among students (Rézio et al., 2022; (Wangid et al., 2021).

In the maritime industry, ship stability is a critical aspect that ensures a vessel's ability to resist capsizing when subjected to external forces and to restore its equilibrium once those forces are removed (Davis, 2019; Hanzu-Pazara et al., 2016; Belenky et al., 2019). Intact stability, in particular, refers to a vessel's stability when it remains undamaged and structurally sound. This property is one of the most crucial technical considerations in ship design, as excessive rolling motions can compromise stability and increase the risk of capsizing (Wang, 2023; Okello, 2025; Vassalos et al., 2022).

While various factors influence a ship's stability, one key application of applied mathematics in the maritime sector is the calculation of a vessel's center of mass. Determining the center of mass requires integrating mass distributions from different geometries and dimensions. During the design phase, individual weights are analyzed to predict both the light ship mass and maximum load scenarios. These calculations account for structural components such as the hull, superstructure, accommodations, machinery, and potential load conditions, ensuring optimal stability and safety (Melnyk et al., 2024).

To enhance the comprehension of nautical students in applied mathematics courses, a project-based learning approach is implemented to facilitate the calculation of a ship's center of mass, a fundamental aspect in determining ship stability. As part of this learning process, students construct a ship model using styrofoam, designed to represent a container vessel capable of accommodating 48 containers. The container arrangement follows a structured configuration of 3 rows forward, 4 layers vertically, and 4 columns sideways.

In the initial unloaded state, the center of mass of the ship model is positioned at its geometric midpoint. This central point is then mapped onto a Cartesian coordinate system (x, y, z) for analytical purposes. Within this system, movement along the x-axis is defined as positive towards the right and negative towards the left, while the y-axis increases upwards and decreases downwards. Similarly, the z-axis extends forward in the positive direction and moves backward in the negative direction. This coordinate-based approach allows for a systematic analysis of mass distribution and its impact on ship stability.

Problem Statement

Based on the background of the study, the research problem can be formulated as Does the implementation of Project-Based Learning (PBL) in Applied Mathematics to determine the center of mass demonstrate greater effectiveness compared to traditional theoretical classroom-based instruction?

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Research Objectives

Based on the problem formulation, the objective of this study is:

To evaluate the effectiveness of Project-Based Learning (PBL) in Applied Mathematics compared to traditional theoretical classroom instruction.

Research Outcome

Aims to achieve several key outcomes. Academically, the study seeks to compare the effectiveness of Project-Based Learning (PBL) with traditional theoretical instruction in applied mathematics, specifically within the context of maritime education. The research will contribute to the development of an instructional framework that integrates PBL and hands-on modeling, enhancing students' comprehension of mathematical concepts related to ship stability. Additionally, the study aims to collect empirical data on student performance, engagement, and understanding when applying mathematical principles to practical maritime scenarios.

The research will produce valuable educational resources, including a comprehensive PBL module for teaching applied mathematics, detailed guidelines for constructing a styrofoam ship model for educational use, and assessment tools designed to evaluate students' grasp of the center of mass concept. These materials will provide opportunities for experiential learning in the classroom.

Furthermore, the findings will be disseminated through academic publications in peer-reviewed journals related to maritime education and engineering, as well as at national and international conferences. The practical implications of this research include recommendations for incorporating PBL into maritime curricula to improve problem-solving abilities and conceptual understanding. The insights gained will also provide valuable guidance for educators and policymakers seeking to adopt innovative teaching strategies that bridge the gap between theoretical knowledge and its application in real-world maritime contexts.

Methods

Research Approach

The present study was conducted through a dual-method approach designed to capture both the measurable and interpretative dimensions of students' learning processes. This integration of quantitative and qualitative inquiry allowed the research to move beyond mere numerical assessment, situating statistical outcomes within a broader context of lived educational experience. The quantitative component involved the systematic collection of data derived from students' completed center of mass calculations an integral part of their applied mathematics coursework. These calculations not only reflected their mastery of computational and analytical reasoning but also represented an applied manifestation of theoretical knowledge. As Creswell and Creswell (2018) note, such quantitative designs provide the structural rigor necessary to evaluate learning performance objectively, while at the same time laying the groundwork for comparative analysis across participants. By subjecting the collected data to statistical interpretation, the study sought to identify discernible patterns of achievement, variability, and conceptual understanding that could be empirically substantiated.

Complementing this, the qualitative dimension of the study was intentionally structured to uncover the human and experiential aspects that often remain invisible within numerical data. This was achieved through a set of carefully designed questionnaires that invited students to articulate their perceptions, challenges, and reflections regarding their learning experiences both in conventional classroom settings and under the framework of Project-Based Learning

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(PBL). Such a design recognized that learning is not a mechanical act, but rather a dynamic interaction between cognition, context, and personal meaning-making. In the spirit of Bell (2014), qualitative insights added interpretative depth to the findings, providing the narrative texture necessary to understand why certain patterns emerged in the quantitative phase. The decision to employ a mixed-methods framework, as proposed by Johnson and Onwuegbuzie (2004), was thus grounded in the conviction that the complexity of educational phenomena requires multiple lenses of observation. Through this integrative approach, the study sought to construct a holistic understanding of students' cognitive competencies and affective responses to differing pedagogical models.

Population and Sample

The study focused on a clearly defined population first-semester students enrolled in the Nautical Science program whose learning context provided a coherent and unified environment for analysis. Given that the total number of students was relatively limited and easily accessible, the research adopted a total sampling technique, thereby including every member of the cohort as part of the sample (Etikan et al., 2016). This decision was not merely logistical but also epistemological, grounded in the understanding that when the population is sufficiently small, total inclusion eliminates the arbitrariness and potential distortion introduced by random selection. As Creswell and Creswell (2018) emphasize, such comprehensive inclusion enhances the internal validity of the data and ensures that the findings faithfully reflect the collective characteristics of the target group.

By encompassing the entire cohort, the study minimized individual differences that might otherwise confound the interpretation of learning performance. This approach allowed the analysis to capture the general tendencies and shared experiences that define the learning culture within the program, rather than isolating fragmented patterns. Moreover, the decision to use total sampling reinforced the relational dimension of the inquiry, since all participants engaged in the same academic environment, instructional strategies, and assessment systems. The data obtained therefore represented a collective academic and perceptual profile, offering an authentic depiction of the cohort's engagement with applied mathematics both under traditional instruction and through the PBL framework. In this sense, the sampling choice was instrumental in preserving the ecological validity of the research context, situating its findings within the real and shared conditions of the learning community.

Data Collection

The data collection procedures were meticulously organized to ensure both methodological precision and pedagogical authenticity. The process began with students engaging in a structured simulation of ship-loading scenarios, where they performed calculations to determine the center of mass of a scaled model vessel. During this phase, students were encouraged to integrate theoretical mathematical formulas with empirical observations, thereby exercising analytical judgment and procedural accuracy. Each experiment was carefully documented, with students recording their step-by-step processes, observations, and interpretations. These records culminated in the creation of detailed laboratory reports, which served not only as repositories of raw data but also as reflective artifacts of the students' evolving understanding of mathematical concepts in applied maritime contexts.

After completing their calculations and analyses, the students compiled their findings into structured reports, which were subsequently reviewed and evaluated as part of the data corpus for this research. These reports contained procedural narratives, numerical results, and interpretative conclusions, providing a comprehensive picture of both process and outcome. As

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a final step, students presented their work through oral and written presentations, transforming technical data into communicable academic discourse. This sequence of activities was designed not merely as an evaluative exercise but as an experiential learning process, reinforcing theoretical mastery while cultivating communication, reasoning, and collaborative competencies. In aligning with the applied nature of the Nautical Science curriculum, this process embodied the pedagogical ideal of bridging theory and practice an essential tenet of effective STEM education.

In addition to the experimental component, data were also gathered from structured questionnaires that explored students' perceptions of the two instructional modalities: conventional classroom-based applied mathematics learning and the project-based approach. These responses were analyzed using inferential statistics, specifically through a mean square comparison test, to examine whether significant differences existed between the two learning methods. The test was conducted through SPSS software, following standard statistical procedures. Before running the main analysis, a series of prerequisite tests were performed to ensure data validity. These included the Shapiro–Wilk and Kolmogorov–Smirnov tests for normality, Levene's and Bartlett's tests for homogeneity of variance, and checks for scale level and independence of observations. Only after these assumptions were confirmed did the mean square comparison test proceed, ensuring that the interpretations drawn were methodologically sound and statistically reliable.

Ultimately, the methodological rigor of this process reflected the study's commitment to both empirical integrity and pedagogical depth. Each layer of data quantitative performance metrics, qualitative reflections, and experimental documentation contributed to a textured and multifaceted understanding of how students learned and reasoned through mathematical problems in real-world maritime contexts. By designing the research in this way, the study did not merely measure learning outcomes but also illuminated the cognitive and affective pathways through which understanding was constructed, interpreted, and transformed within the framework of applied mathematics education.

Results and Discussion

Build Ship Models

In the implementation of the Project-Based Learning (PBL) approach, a scaled ship model was specifically designed to serve as the central instructional tool and experiential learning medium. The model had precise dimensions of 51 cm in length, 20 cm in height, and 20 cm in width, reflecting proportional scaling principles used in naval architecture. To facilitate structured analysis, the ship's length was divided into three equal sections of 17 cm each, allowing for longitudinal segmentation suitable for calculating weight distribution and center of mass. Its width was divided into four equal sections of 5 cm, and its height was similarly divided into four equal segments of 5 cm, enabling volumetric compartmentalization and systematic arrangement of simulated cargo loads.

The structural design allowed the model to accommodate a total of 48 scaled containers, each measuring 17 cm × 5 cm × 5 cm. These container dimensions were deliberately aligned with the sectional divisions of the ship's length, width, and height, ensuring spatial compatibility and realistic loading patterns. This arrangement enabled students to simulate cargo placement scenarios in multiple configurations, thereby enhancing their understanding of balance, stability, and load distribution within a vessel. Such activities not only fostered practical problem-solving skills but also encouraged the integration of applied mathematics concepts into real-world maritime operations.

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The ship model was fabricated from styrofoam, chosen for its lightweight nature, ease of cutting and shaping, and cost-effectiveness, while still offering sufficient structural rigidity for repeated handling and repositioning of cargo units during classroom exercises. The material's workability allowed for precise dimensioning and rapid prototyping, making it suitable for iterative design adjustments throughout the learning process. By engaging directly with this tangible, scaled representation of a vessel, students were provided with opportunities to bridge theoretical knowledge and practical application in a controlled learning environment. This design approach aligns with the principles of experiential learning outlined by (Thomas, 2000), wherein hands-on projects are used as vehicles for deepening conceptual understanding, fostering critical thinking, and developing industry-relevant competencies.

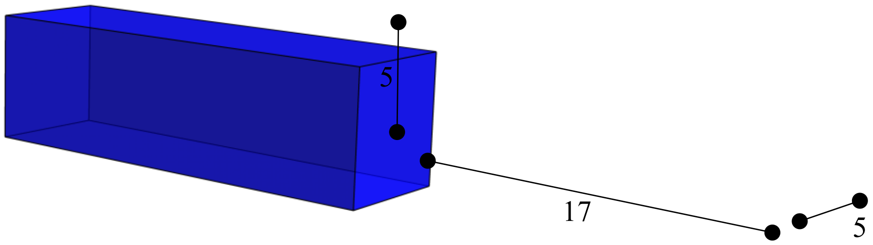

Figure 1. Container size

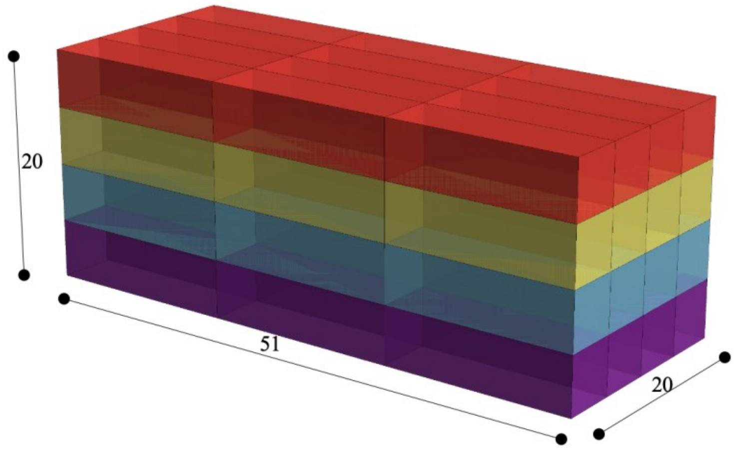

Figure 2. Design of Container Ships

Determine the centre of Mass

In calculating the center of mass for the ship model, each cargo unit was assumed to be homogeneous, meaning that its mass was uniformly distributed throughout its volume. This assumption is widely used in engineering mechanics because it simplifies the process of determining the centroid of a body by aligning it with its geometric center (Beer et al., 2015). Given the container's dimensions of 17 cm × 5 cm × 5 cm, its center of mass can be calculated by halving each dimension, resulting in coordinates positioned 8.5 cm from either end along its length, and 2.5 cm from each side along both its width and height. By treating each container's center of mass as a single representative point, the analysis of the ship's overall center of mass becomes a matter of applying the weighted average formula for discrete bodies, where each container's mass and position are factored into the computation (Hibbeler, 2016).

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This approach offers two primary advantages in a Project-Based Learning (PBL) context. First, it reduces computational complexity, allowing students to focus on the conceptual understanding of balance and stability without the need for advanced mass distribution models. Second, it mirrors real-world cargo loading calculations in maritime operations, where the assumption of uniform density is often employed for standard containerized loads, provided that weight distribution does not significantly deviate from the average (Stopford, 2008). By using this method, students are able to model various loading configurations, calculate the resulting center of mass, and assess the impact on vessel stability, thus directly applying theoretical mechanics principles to practical maritime engineering scenarios.

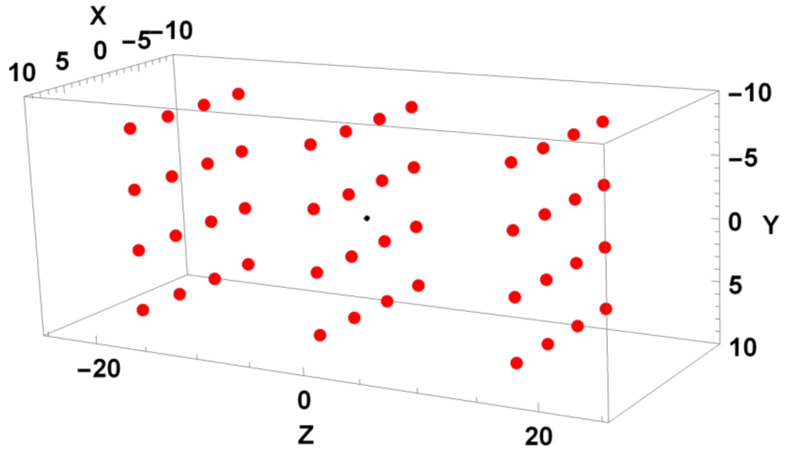

Figure 3. Cntainer Center of Mass in Cartesius Coordinate

Table 1. Centre of Mass each Containe

Bay 3 (Back)		Bay 2 (Middle)		Bay 1 (Front)	
Container Number	**Coordinate Centre of Mass**	**Container Number**	**Coordinate Centre of Mass**	**Container Number**	**Coordinate Centre of Mass**
Container 01	(-7.5, -7.5, -17)	Container 17	(-7.5, -7.5, 0)	Container 33	(-7.5, -7.5, 17)
Container 02	(-2.5, -7.5, -17)	Container 18	(-2.5, -7.5, 0)	Container 34	(-2.5, -7.5, 17)
Container 03	(2.5, -7.5, -17)	Container 19	(2.5, -7.5, 0)	Container 35	(2.5, -7.5, 17)
Container 04	(7.5, -7.5, -17)	Container 20	(7.5, -7.5, 0)	Container 36	(7.5, -7.5, 17)
Container 05	(-7.5, -2.5, -17)	Container 21	(-7.5, -2.5, 0)	Container 37	(-7.5, -2.5, 17)
Container 06	(-2.5, -2.5, -17)	Container 22	(-2.5, -2.5, 0)	Container 38	(-2.5, -2.5, 17)
Container 07	(2.5, -2.5, -17)	Container 23	(2.5, -2.5, 0)	Container 39	(2.5, -2.5, 17)
Container 08	(7.5, -2.5, -17)	Container 24	(7.5, -2.5, 0)	Container 40	(7.5, -2.5, 17)
Container 09	(-7.5, 2.5, -17)	Container 25	(-7.5, 2.5, 0)	Container 41	(-7.5, 2.5, 17)
Container 10	(-2.5, 2.5, -17)	Container 26	(-2.5, 2.5, 0)	Container 42	(-2.5, 2.5, 17)
Container 11	(2.5, 2.5, -17)	Container 27	(2.5, 2.5, 0)	Container 43	(2.5, 2.5, 17)
Container 12	(7.5, 2.5, -17)	Container 28	(7.5, 2.5, 0)	Container 44	(7.5, 2.5, 17)
Container 13	(-7.5, 7.5, -17)	Container 29	(-7.5, 7.5, 0)	Container 45	(-7.5, 7.5, 17)
Container 14	(-2.5, 7.5, -17)	Container 30	(-2.5, 7.5, 0)	Container 46	(-2.5, 7.5, 17)
Container 15	(2.5, 7.5, -17)	Container 31	(2.5, 7.5, 0)	Container 47	(2.5, 7.5, 17)
Container 16	(7.5, 7.5, -17)	Container 32	(7.5, 7.5, 0)	Container 48	(7.5, 7.5, 17)

Stowage of containers on a ship

Container stowage on ships is a strategic process aimed at optimizing cargo space utilization while ensuring vessel stability and navigational safety. The arrangement follows the principle of balanced weight distribution, whereby heavier containers are placed at the bottom and closer to the vessel's centerline, while lighter containers are positioned on top or toward the outer

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sides. This practice minimizes the vessel's rolling moment and reduces the risk of cargo shifting during rough seas.

The stowage is guided by a detailed stowage plan that organizes containers by rows (positions across the ship's width), bays (positions along the ship's length), and tiers (vertical levels). Rows are numbered outward from the centerline, with even numbers on the port side and odd numbers on the starboard side. Bays are numbered sequentially from the bow to the stern, with odd numbers typically allocated to 20-foot containers and even numbers to 40-foot containers. Tiers are numbered upward from the vessel's bottom, starting at "00" or "02" for containers in the hold, and increasing by two for each additional level on deck. This standardized coding system ensures precise container location tracking and facilitates efficient loading and unloading at multiple ports.

Proper container placement not only prevents accidents but also improves operational efficiency by reducing handling time and costs during port operations. Additionally, adherence to the International Maritime Organization (IMO) guidelines and the International Convention for Safe Containers (CSC) ensures compliance with global maritime safety standards.

The sequence of container stowage on ships generally begins with the lowest tier and progresses upward, while simultaneously considering bay and row positions according to the stowage plan. The process starts with the bottom tier, usually coded as "00" or "02" for containers in the hold, ensuring that heavier containers are placed at the lowest levels to maintain a low center of gravity and enhance vessel stability (Code, 2011). Once the base tier is fully loaded, subsequent tiers are filled in an ascending order until reaching the maximum allowable deck height.

Following tier arrangement, containers are positioned within specific bays, which are numbered sequentially from the bow to the stern. Odd-numbered bays are typically assigned to 20-foot containers, while even-numbered bays accommodate 40-foot containers (Branch, 2007). The stowage plan ensures that containers destined for earlier discharge ports are placed on top or in easily accessible positions to reduce rehandling. Finally, rows numbered outward from the vessel's centerline, with even numbers to port and odd numbers to starboard are arranged so that heavier containers are placed closer to the centerline to minimize rolling moments and maintain transverse stability (Stopford, 2009). This tier–bay–row sequence, when combined with careful consideration of cargo type, destination, and weight distribution, ensures safe and efficient maritime container transport.

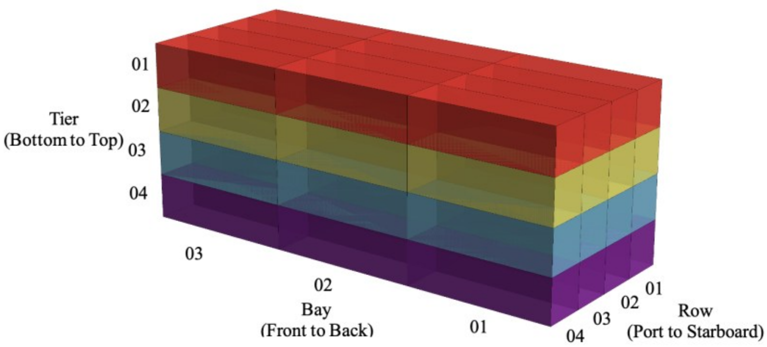

Figure 4. Stowage of containers on a container ship

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Table 2. Stowage of containers on a container ship

Container Number	Container stowage (Tier, Bay, Row)	Container Number	Container stowage (Tier, Bay, Row)	Container Number	Container stowage (Tier, Bay, Row)
Container 01	(01, 03, 01)	Container 17	(01, 02, 01)	Container 33	(01, 01, 01)
Container 02	(01, 03, 02)	Container 18	(01, 02, 02)	Container 34	(01, 01, 02)
Container 03	(01, 03, 03)	Container 19	(01, 02, 03)	Container 35	(01, 01, 03)
Container 04	(01, 03, 04)	Container 20	(01, 02, 04)	Container 36	(01, 01, 04)
Container 05	(02, 03, 01)	Container 21	(02, 02, 01)	Container 37	(02, 01, 01)
Container 06	(02, 03, 02)	Container 22	(02, 02, 02)	Container 38	(02, 01, 02)
Container 07	(02, 03, 03)	Container 23	(02, 02, 03)	Container 39	(02, 01, 03)
Container 08	(02, 03, 04)	Container 24	(02, 02, 04)	Container 40	(02, 01, 04)
Container 09	(03, 03, 01)	Container 25	(03, 02, 01)	Container 41	(03, 01, 01)
Container 10	(03, 03, 02)	Container 26	(03, 02, 02)	Container 42	(03, 01, 02)
Container 11	(03, 03, 03)	Container 27	(03, 02, 03)	Container 43	(03, 01, 03)
Container 12	(03, 03, 04)	Container 28	(03, 02, 04)	Container 44	(03, 01, 04)
Container 13	(04, 03, 01)	Container 29	(04, 02, 01)	Container 45	(04, 01, 01)
Container 14	(04, 03, 02)	Container 30	(04, 02, 02)	Container 46	(04, 01, 02)
Container 15	(04, 03, 03)	Container 31	(04, 02, 03)	Container 47	(04, 01, 03)
Container 16	(04, 03, 04)	Container 32	(04, 02, 04)	Container 47	(04, 01, 04)

Calculations of the Center of Mass of a Ship

The center of mass of a ship, modeled as a rigid body in three-dimensional space, can be determined by calculating the sum of the mass moments of each elemental mass with respect to a chosen coordinate system and dividing it by the total mass. For a set of nnn discrete particles or mass elements with position vectors $r_i = (x_i, y_i, z_i)$ corresponding masses m_i the coordinates of the center of mass along each axis can be expressed using the sigma notation as.

$$x_c = \frac{\sum_{i=1}^{n} m_i x_i}{\sum_{i=1}^{n} m_i}\ ;\ y_c = \frac{\sum_{i=1}^{n} m_i y_i}{\sum_{i=1}^{n} m_i}\ ;\ z_c = \frac{\sum_{i=1}^{n} m_i z_i}{\sum_{i=1}^{n} m_i}$$

In practical naval architecture applications, it is crucial to define the coordinate system and to account for contributions from cargo, structure, and fuel, as variations in the mass distribution directly affect the vessel's stability, trim, and overall hydrodynamic performance (Fossen, 2011; Rawson & Tupper, 2001).

If the *x*-coordinate value of the ship's center of mass is negative, it indicates that the equilibrium position is located toward the port side (left). Conversely, if the *x*-coordinate value is positive, the equilibrium position is located toward the starboard side (right). For the *y*-coordinate, a negative value signifies that the center of mass tends to be located lower in the vertical axis (bottom), while a positive value indicates a tendency toward an upper vertical position (up). Regarding the *z*-coordinate, a negative value represents a center of mass position shifted toward the aft section (back), whereas a positive value signifies a shift toward the forward section (front) of the vessel. This interpretation is consistent with standard naval architecture coordinate conventions used in stability and trim assessments (Rawson & Tupper, 2001).

Table 3. Report on the Calculation of the Ship's Center of Mass
Project-Based Learning – Applied Mathematics Course Nautical Studies A – Group I

Number	Type of Cargo	x_i	y_i	z_i	Weight	x_i x m_i	y_i x m_i	z_i x m_i
01	Rice	-7,5	-7,5	-17	319	-2392,5	-2392,5	-5423
02	Rice	-2,5	-7,5	-17	316	-790	-2370	-5372

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03	Rice	2,5	-7,5	-17	311	777,5	-2332,5	-5287
04	Rice	7,5	-7,5	-17	315	2362,5	-2362,5	-5355
05	Rice	-7,5	-2,5	-17	298	-2235	-745	-5066
06	Rice	-2,5	-2,5	-17	292	-730	-730	-4964
07	Rice	2,5	-2,5	-17	295	737,5	-737,5	-5015
08	Rice	7,5	-2,5	-17	305	2287,5	-762,5	-5185
09	Rice	-7,5	2,5	-17	296	-2220	740	-5032
10	Rice	-2,5	2,5	-17	303	-757,5	757,5	-5151
11	Rice	2,5	2,5	-17	298	745	745	-5066
12	Rice	7,5	2,5	-17	291	2182,5	727,5	-4947
13	Rice	-7,5	7,5	-17	300	-2250	2250	-5100
14	Rice	-2,5	7,5	-17	302	-755	2265	-5134
15	Rice	2,5	7,5	-17	296	740	2220	-5032
16	Rice	7,5	7,5	-17	313	2347,5	2347,5	-5321
17	Peanuts	-7,5	-7,5	0	238	-1785	-1785	0
18	Peanuts	-2,5	-7,5	0	234	-585	-1755	0
19	Peanuts	2,5	-7,5	0	237	592,5	-1777,5	0
20	Peanuts	7,5	-7,5	0	233	1747,5	-1747,5	0
21	Peanuts	-7,5	-2,5	0	224	-1680	-560	0
22	Peanuts	-2,5	-2,5	0	226	-565	-565	0
23	Peanuts	2,5	-2,5	0	227	567,5	-567,5	0
24	Peanuts	7,5	-2,5	0	232	1740	-580	0
25	Black Rice	-7,5	2,5	0	262	-1965	655	0
26	Black Rice	-2,5	2,5	0	264	-660	660	0
27	Black Rice	2,5	2,5	0	266	665	665	0
28	Black Rice	7,5	2,5	0	257	1927,5	642,5	0
29	Black Rice	-7,5	7,5	0	259	-1942,5	1942,5	0
30	Black Rice	-2,5	7,5	0	264	-660	1980	0
31	Black Rice	2,5	7,5	0	268	670	2010	0
32	Black Rice	7,5	7,5	0	263	1972,5	1972,5	0
33	Brown Rice	-7,5	-7,5	17	305	-2287,5	-2287,5	5185
34	Brown Rice	-2,5	-7,5	17	303	-757,5	-2272,5	5151
35	Brown Rice	2,5	-7,5	17	304	760	-2280	5168
36	Beans	7,5	-7,5	17	300	2250	-2250	5100
37	Beans	-7,5	-2,5	17	292	-2190	-730	4964
38	Beans	-2,5	-2,5	17	299	-747,5	-747,5	5083
39	Corn	2,5	-2,5	17	281	702,5	-702,5	4777
40	Corn	7,5	-2,5	17	284	2130	-710	4828
41	Corn	-7,5	2,5	17	281	-2107,5	702,5	4777
42	Corn	-2,5	2,5	17	281	-702,5	702,5	4777
43	Corn	2,5	2,5	17	283	707,5	707,5	4811
44	Corn	7,5	2,5	17	278	2085	695	4726

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45	Corn	-7,5	7,5	17	280	-2100	2100	4760
46	Corn	-2,5	7,5	17	278	-695	2085	4726
47	Corn	2,5	7,5	17	265	662,5	1987,5	4505
48	Corn	7,5	7,5	17	262	1965	1965	4454
Total					13380	-235	-225	-4658
center of mass						- 0,017	- 0,017	- 0,348

Based on the calculated coordinates of the ship's center of mass, the value (−0.017,−0.017,−0.348) indicates that the equilibrium position is slightly shifted toward the port side (negative x-axis) and marginally lower along the vertical axis (negative y-axis) compared to the vessel's geometric center. Furthermore, the notably negative z-coordinate suggests a more significant displacement toward the aft section of the ship. This spatial distribution implies that the ship's mass is asymmetrically distributed, with a minor lateral and vertical deviation, yet a considerable longitudinal shift toward the stern, which may influence the vessel's trim and overall stability.

The following summary presents the calculated data of the ship's center of mass obtained from 18 student groups of the Nautical Science Study Program in the first semester. These data represent the outcomes of practical exercises designed to enhance students' understanding of mass distribution analysis and its implications for vessel stability. By evaluating the positional shifts of the center of mass in three-dimensional coordinates, each group demonstrated the ability to apply theoretical concepts to a simulated ship model, thereby reinforcing their competencies in maritime stability assessment.

Table 4. Summary Report Ship Center Of Mass Calculations From 18 Groups Of Nautical Science Student

Groups	**Amount of Cargoes**	$\sum_{i=1}^{n} x_i m_i$	$\sum_{i=1}^{n} y_i m_i$	$\sum_{i=1}^{n} z_i m_i$	$\bar{x}$	$\bar{y}$	$\bar{z}$
NA I	13380	-235,00	-225,00	-4658,00	-0,018	-0,017	-0,348
NA II	13409	142,50	6082,50	-153,00	0,011	0,454	-0,011
NA III	13992	-40,00	540,00	6171,00	-0,003	0,039	0,441
NA IV	12940	1640,00	890,00	816,00	0,127	0,069	0,063
NA V	13772	205,00	-770,00	3672,00	0,015	-0,056	0,267
NA VI	13238	730,00	175,00	-5032,00	0,055	0,013	-0,380
NB I	13205	-367,50	567,50	-4471,00	-0,028	0,043	-0,339
NB II	13013	557,50	-852,50	2329,00	0,043	-0,066	0,179
NB III	13029	872,50	-3002,50	-6392,00	0,067	-0,230	-0,491
NB IV	13027	772,50	-642,50	-680,00	0,059	-0,049	-0,052
NB V	13110	425,00	-3355,00	-4964,00	0,032	-0,256	-0,379
NB VI	13093	242,50	-3297,50	-5474,00	0,019	-0,252	-0,418
NC I	13130	210,00	-115,00	1122,00	0,016	-0,009	0,085
NC II	13065	1477,50	-1177,50	969,00	0,113	-0,090	0,074
NC III	12977	-1687,50	-577,50	1190,00	-0,130	-0,045	0,092
NC IV	13100	-1265,00	-410,00	-255,00	-0,097	-0,031	-0,019
NC V	13106	-1080,00	-485,00	-1768,00	-0,082	-0,037	-0,135
NC VI	13043	-652,50	567,50	-357,00	-0,050	0,044	-0,027

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Table 5. Summary Report Ship Stability According Center Of Mass Calculations From 18 Groups Of Nautical Science Student

Groups	$\bar{x}$	$\bar{y}$	$\bar{z}$	Row position	Tier position	Bay position
NA I	-0,018	-0,017	-0,348	Port side (Left)	Lower (Bottom)	Aft (Back)
NA II	0,011	0,454	-0,011	Starboard side (Right)	Upper (Up)	Aft (Back)
NA III	-0,003	0,039	0,441	Port side (Left)	Upper (Up)	Forward (Front)
NA IV	0,127	0,069	0,063	Starboard side (Right)	Upper (Up)	Forward (Front)
NA V	0,015	-0,056	0,267	Starboard side (Right)	Lower (Bottom)	Forward (Front)
NA VI	0,055	0,013	-0,380	Starboard side (Right)	Upper (Up)	Aft (Back)
NB I	-0,028	0,043	-0,339	Port side (Left)	Upper (Up)	Aft (Back)
NB II	0,043	-0,066	0,179	Starboard side (Right)	Lower (Bottom)	Forward (Front)
NB III	0,067	-0,230	-0,491	Starboard side (Right)	Lower (Bottom)	Aft (Back)
NB IV	0,059	-0,049	-0,052	Starboard side (Right)	Lower (Bottom)	Aft (Back)
NB V	0,032	-0,256	-0,379	Starboard side (Right)	Lower (Bottom)	Aft (Back)
NB VI	0,019	-0,252	-0,418	Starboard side (Right)	Lower (Bottom)	Aft (Back)
NC I	0,016	-0,009	0,085	Starboard side (Right)	Lower (Bottom)	Forward (Front)
NC II	0,113	-0,090	0,074	Starboard side (Right)	Lower (Bottom)	Forward (Front)
NC III	-0,130	-0,045	0,092	Port side (Left)	Lower (Bottom)	Forward (Front)
NC IV	-0,097	-0,031	-0,019	Port side (Left)	Lower (Bottom)	Aft (Back)
NC V	-0,082	-0,037	-0,135	Port side (Left)	Lower (Bottom)	Aft (Back)
NC VI	-0,050	0,044	-0,027	Port side (Left)	Upper (Up)	Aft (Back)

Maintaining the stability of a ship critically depends on the precise positioning of its center of mass. The center of mass represents the average location of the vessel's total weight, and its position directly influences the ship's equilibrium during navigation. To ensure optimal stability, the center of mass must remain within defined limits along all three axes. Along the x-axis, which governs lateral or port-to-starboard balance, the center of mass should be maintained within the range of $-0.1 \leq x \leq 0.1$. Similarly, for vertical stability, the y-axis must remain within $-0.1 \leq y \leq 0.1$, ensuring balance from the bottom (keel) to the top (superstructure) of the ship. Along the z-axis, which affects fore-and-aft equilibrium, the center of mass should stay within $-0.1 \leq z \leq 0.1$, controlling stability between the bow and stern.

Deviations beyond these boundaries increase the risk of tilting, rolling, or pitching, which can lead to uneven weight distribution, reduced hydrodynamic performance, and in extreme cases, capsizing. The careful management of the center of mass is therefore essential not only for operational efficiency but also for the safety of the crew, cargo, and vessel structure. Proper load distribution, continuous monitoring, and adherence to these limits are fundamental practices in naval architecture and marine engineering, ensuring that the ship maintains balance and navigates safely under a wide range of operational conditions.

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Based on the evaluation of the center-of-mass (COM) positions against the defined stability limits (−0.1 ≤ x ≤ 0.1, −0.1 ≤ y ≤ 0.1, and −0.1 ≤ z ≤ 0.1), three overall risk categories were established. Low risk indicates that the COM values for all axes remain within the specified range, representing a balanced and stable condition. Moderate risk occurs when one axis exceeds the threshold, signaling a potential imbalance in that particular direction. High risk is assigned when two or more axes fall outside the limits, significantly increasing the likelihood of instability.

Table 6. Risk Category According Center of Mass Calculations

Groups	***x***	***y***	***z***	**Risk Category**	**Notes**
NA I	-0.018	-0.017	-0.348	Moderate	*z* is outside the limit.
NA II	0.011	0.454	-0.011	Moderate	*y* is outside the limit.
NA III	-0.003	0.039	0.441	Moderate	*z* is outside the limit.
NA IV	0.127	0.069	0.063	Moderate	*x* is outside the limit.
NA V	0.015	-0.056	0.267	Moderate	*z* is outside the limit.
NA VI	0.055	0.013	-0.380	Moderate	*z* is outside the limit.
NB I	-0.028	0.043	-0.339	Moderate	*z* is outside the limit.
NB II	0.043	-0.066	0.179	Moderate	*z* is outside the limit.
NB III	0.067	-0.230	-0.491	High	*y* and *z* are outside the limits.
NB IV	0.059	-0.049	-0.052	Low	All axes within limits.
NB V	0.032	-0.256	-0.379	High	*y* and *z* are outside the limits.
NB VI	0.019	-0.252	-0.418	High	*y* and *z* are outside the limits.
NC I	0.016	-0.009	0.085	Low	All axes within limits.
NC II	0.113	-0.090	0.074	Moderate	*x* is outside the limit.
NC III	-0.130	-0.045	0.092	Moderate	*x* is outside the limit.
NC IV	-0.097	-0.031	-0.019	Low	All axes within limits.
NC V	-0.082	-0.037	-0.135	Moderate	*z* is outside the limit.
NC VI	-0.050	0.044	-0.027	Low	All axes within limits.

Summary of Ship Stability Risk

Out of the 18 measured COM points:

Low Risk: 4 points (NB IV, NC I, NC IV, NC VI)

Moderate Risk: 11 points (NA I, NA II, NA III, NA IV, NA V, NA VI, NB I, NB II, NC II, NC III, NC V)

High Risk: 3 points (NB III, NB V, NB VI)

The majority of cases fall into the Moderate Risk category, indicating that most COM deviations involve a single axis. However, the presence of High Risk points where two or more axes exceed the limits signals the need for immediate attention to prevent potential stability hazards.

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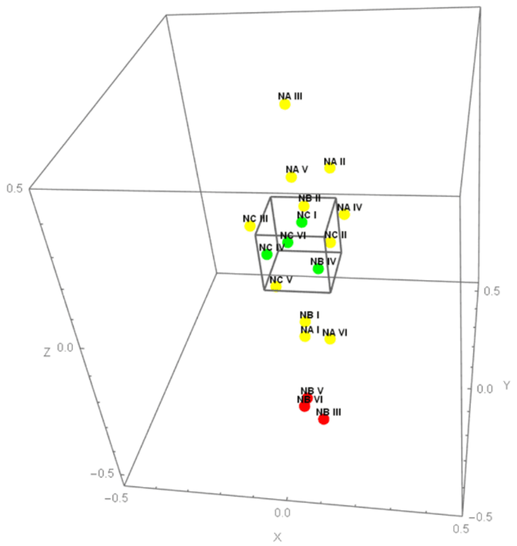

Figure 5. Position of Center Of Mass

Factors causing the center of mass to be off-center in a ship

Improper Cargo Planning

Improper cargo planning is one of the most common causes of imbalance in a vessel's center of mass (CoM). In many operational cases, the cargo manifest is arranged solely according to the order of loading and unloading or the type of cargo, without adequate consideration for optimal weight distribution (Branch, 2007; Stopford, 2008). This can occur when there is no preliminary calculation of trim and stability before the vessel departs. Furthermore, even when a stowage plan is prepared by a qualified cargo planner, deviations from the plan whether due to operational haste, lack of coordination, or oversight can undermine vessel stability. The result is a concentration of cargo at one end or side of the ship, shifting the CoM significantly away from its safe operational limits. Such a shift increases the risk of excessive list, trim, or in severe cases, capsizing, especially when compounded by adverse sea conditions.

Inaccurate Cargo Weight Data

Another significant factor contributing to CoM deviation is inaccurate cargo weight data. In certain instances, the documented weight in the cargo manifest is lighter than the actual cargo mass, leading to erroneous stability calculations. This problem is particularly pronounced in cases involving liquid cargo, where the free surface effect can cause internal mass shifts that alter the vessel's balance (IMO, 2016). Similarly, containers that exceed their declared gross weight commonly referred to as overweight containers pose a severe stability risk (Marine Insight, 2023). When these inaccuracies are not detected before departure, the initial stability and trim calculations become flawed, leading to uneven weight distribution and unexpected CoM displacement during the voyage.

Asymmetrical Loading and Unloading Operations

Asymmetrical loading and unloading operations also contribute to instability in vessel CoM. This occurs when cargo is loaded or discharged from only one side of the vessel without corresponding counterbalancing actions. In some cases, operational limitations such as insufficient port equipment or specific port demands force a deviation from the planned loading sequence (Hetherington et al., 2006). Furthermore, conducting loading operations in adverse weather conditions can cause the vessel to heel temporarily, which may result in cargo shifting

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before securing procedures are completed. If such imbalances occur during partial loading or unloading phases, the CoM can shift suddenly, leading to potentially hazardous operating conditions. In extreme cases, this instability may require immediate corrective action, such as ballasting or redistributing cargo, to restore the vessel to a safe operating state.

Student Perceptions Aplied Mathematical Learning

To comprehensively examine students' perceptions of conventional versus project-based learning (PBL) methods in applied mathematics, a structured questionnaire was employed. The instrument consisted of fifty items, evenly divided between twenty-five statements addressing conventional teaching methods and twenty-five statements evaluating PBL experiences. The conventional learning section was organized into five distinct domains. Firstly, mathematics instruction was reported as largely one-directional, dominated by lecture delivery, which limited opportunities for student participation, critical thinking, and meaningful classroom discussions. This instructional style often resulted in student passivity and reduced engagement with the learning process. Secondly, students frequently relied on rote memorization of formulas rather than developing a conceptual understanding of mathematical principles. Opportunities to relate mathematics to real-life scenarios or to independently explore problem-solving strategies were rarely provided, limiting practical application skills. Thirdly, learning activities were perceived as monotonous and insufficiently varied, creating a sense of boredom, reduced motivation, and restricted creative expression. Fourthly, instructors emphasized obtaining correct answers quickly over encouraging thoughtful reasoning, collaboration, or cooperative learning among students, which diminished opportunities for developing higher-order cognitive skills. Finally, assessments were predominantly test-based, lacking integration of authentic, real-world projects, which left students with minimal autonomy or control over their learning process, thereby constraining self-directed learning and intrinsic motivation.

In contrast, the PBL questionnaire focused on five complementary categories highlighting the benefits of project-based approaches. Firstly, students indicated that PBL fostered increased engagement, self-confidence, creativity, and a sense of challenge, promoting active participation in the learning process. Secondly, project-based tasks were reported to enhance conceptual understanding and retention, particularly when projects were connected to real-world applications, thereby stimulating critical thinking and problem-solving abilities. Thirdly, PBL encouraged frequent discussion, collaboration, and continuous feedback from both instructors and peers, creating a dynamic learning environment that supported social and cognitive development. Fourthly, students expressed a greater sense of independence and responsibility, as they were actively involved in the design, planning, and execution of projects, which facilitated the development of self-regulated learning skills. Lastly, participants perceived PBL as enjoyable and meaningful, offering a holistic platform to demonstrate knowledge and competencies while instructors assumed the role of facilitators, guiding rather than directing learning. Overall, the contrast between conventional and PBL methods highlighted the potential of project-based approaches to cultivate critical thinking, creativity, engagement, and autonomy in mathematics learning, offering insights for pedagogical enhancement in higher education contexts.

The collected data from the student perception questionnaires will be analyzed using a comparison of means to determine whether there is a statistically significant difference between perceptions of conventional and project-based learning (PBL) methods in applied mathematics. Before conducting parametric tests, it is essential to perform assumption tests to ensure validity (Field, 2018; Gravetter & Wallnau, 2017). The prerequisite tests include normality, homogeneity of variance, and independence of observations. Normality, often tested using the

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Shapiro-Wilk or Kolmogorov-Smirnov test, ensures that the data distribution approximates a normal curve (Field, 2018). Homogeneity of variance, assessed via Levene's test, verifies whether the variances of the two groups are equal, which is critical for the validity of t-tests (Gravetter & Wallnau, 2017). Independence ensures that each observation is unaffected by others (Creswell & Creswell, 2018).

If these assumptions are met, an independent samples t-test (or paired samples t-test for repeated measures) can be conducted to compare group means (Field, 2018). Descriptive statistics, t-values, p-values, and effect sizes (e.g., Cohen's d) will be reported to interpret the magnitude and significance of differences (Gravetter & Wallnau, 2017). However, if the assumptions are violated, non-parametric tests are recommended because they do not require normal distribution or equal variances. For independent groups, the Mann–Whitney U test is appropriate, whereas the Wilcoxon signed-rank test is used for paired data (Pallant, 2020). In non-parametric analyses, median values, rank sums, test statistics, p-values, and effect sizes (e.g., r) will be reported (Field, 2018; Pallant, 2020). Overall, conducting assumption checks and selecting the appropriate test ensures that the comparison of student perceptions between conventional and PBL methods is both statistically valid and meaningful.

The following items constitute the questionnaire designed to assess students' perceptions and experiences in Applied Mathematics. Each statement aims to capture various dimensions of learning, including engagement, confidence, critical thinking, creativity, problem-solving, and real-world application. Respondents are requested to indicate their level of agreement with each statement using a Likert scale, typically ranging from "strongly disagree" to "strongly agree." This structured approach allows for a systematic evaluation of the effectiveness of applied mathematics instruction and provides empirical data for further statistical analysis.

Table 7. Student Perceptions toward Conventional and Project-Based Learning (PjBL) in Mathematics

No	Statement
1	The lecturer explains the material more than students actively ask questions.
2	I feel that mathematics learning is one-way, from the lecturer to the students.
3	I understand mathematics topics through direct explanations from the lecturer.
4	Often, I only listen without being asked to think critically.
5	I am accustomed to doing exercises from the textbook during learning.
6	Learning assessment is based solely on tests or exams.
7	I feel passive during mathematics lessons.
8	The lecturer emphasizes correct answers more than the thinking process.
9	I rarely discuss with classmates during lessons.
10	Mathematics lessons feel monotonous and boring.
11	Class time is mostly filled with the lecturer's lectures.
12	I feel insufficiently challenged in mathematics learning.
13	Conventional learning makes me memorize formulas but not understand concepts.
14	I feel that grades are more important than conceptual understanding.
15	Conventional learning makes me less creative.
16	I tend to memorize rather than understand the material.
17	I do not get the opportunity to relate mathematics to real-life situations.
18	I get bored quickly when the lecturer continuously explains.
19	I am not accustomed to working in groups in class.
20	Mathematics learning often makes me anxious or fearful.
21	I feel the lecturer rarely gives real projects or assignments.

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22	I am not given the freedom to find solutions on my own.
23	I only copy and complete practice problems without much thinking.
24	Learning emphasizes speed in answering questions.
25	I feel I have little control over how I learn mathematics.
26	Project-Based Learning (PjBL) makes me more active in learning.
27	Project-based learning increases my self-confidence.
28	Mathematics projects help me think critically and creatively.
29	PjBL challenges me more in solving problems.
30	I feel more creative when participating in project-based learning.
31	PjBL makes me more prepared to face real-world problems.
32	I learn mathematics through projects related to real-life situations.
33	I understand mathematical concepts better when working on projects.
34	I am more interested in learning mathematics through real projects.
35	I can connect mathematical concepts to everyday life.
36	I find it easier to remember concepts learned through projects.
37	I often discuss and collaborate with classmates while learning.
38	I receive feedback from lecturers and peers when working on projects.
39	I frequently use various learning resources when working on projects.
40	I learn to manage time and teamwork during PjBL activities.
41	The lecturer gives me the opportunity to find solutions independently.
42	I am involved in designing learning projects.
43	I feel more responsible for my own learning process.
44	I become more independent in learning mathematics.
45	I feel emotionally and intellectually engaged in projects.
46	I find learning more enjoyable and not boring.
47	I feel satisfied when successfully completing mathematics projects.
48	Assessment in PjBL reflects my abilities comprehensively.
49	I feel learning time is more meaningful with PjBL.
50	The lecturer acts as a facilitator, not the sole source of knowledge.

Conventional Learning Approach

Mathematics learning is predominantly one-directional and lecture-based, which makes me passive and rarely engaged in critical thinking or discussion.(Statement no 1-6)

I tend to memorize formulas rather than understand concepts, with limited opportunities to relate mathematics to real-life situations or independently solve problems.(Statement no 7-12)

Learning activities are monotonous and lack variation, which leads me to feel unchallenged and less creative. (Statement 13-16)

The lecturer emphasizes correct answers and speed in problem-solving more than the thinking process or collaboration among students. (Statement No 17- 22)

Assessment is primarily based on tests without the inclusion of real projects, making me feel that I have little control over my own learning process.(Statement No 23-25)

Project-Based Learning (PjBL) Approach

Project-based learning makes me more active, confident, creative, and challenged in studying mathematics. (Statement No 26-31)

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I better understand and retain mathematical concepts because the projects I complete are related to real-life contexts and encourage critical thinking. .(Statement No 32-36)

I frequently engage in discussions, collaboration, and receive feedback from both lecturers and peers while working on projects. .(Statement No 37-40)

I feel more independent and responsible for my learning process, being actively involved in designing and completing projects. (Statement No 41-45)

Project-based learning feels enjoyable and meaningful, reflecting my overall abilities with the lecturer acting as a facilitator. (Statement No 46-50)

Table 8. The following is a summary of the questionnaire results on students' perceptions regarding applied mathematics Learning

Conventional Learning Approach (x)						(PBL) Approach (y)						
y_1	y_2	y_3	y_4	y_5	y	y_1	y_2	y_3	y_4	y_5	y	y-x
29	24	15	23	14	105	22	21	16	21	20	100	-5
20	12	8	16	10	66	30	24	14	22	23	113	47
19	15	10	11	9	64	21	19	14	15	17	86	22
15	14	11	14	9	63	29	24	18	23	23	117	54
23	21	14	22	9	89	21	21	12	23	21	98	9
29	30	19	27	15	120	28	24	20	24	22	118	-2
15	16	9	17	5	62	30	24	20	25	25	124	62
21	20	17	21	9	88	30	25	20	25	25	125	37
20	9	10	20	11	70	30	24	20	25	25	124	54
20	21	16	17	12	86	21	19	16	17	12	85	-1
27	30	18	24	15	114	30	25	20	25	25	125	11
16	7	10	20	12	65	30	24	20	25	25	124	59
13	9	10	7	9	48	30	25	20	25	24	124	76
14	14	20	17	9	74	24	25	20	25	25	119	45
17	14	9	11	5	56	27	20	18	21	21	107	51
17	19	9	17	11	73	23	20	16	19	22	100	27
24	24	10	14	12	84	27	17	17	18	14	93	9
22	26	14	19	10	91	16	16	13	13	14	72	-19
17	13	11	14	7	62	13	12	18	17	12	72	10
24	24	16	24	12	100	28	23	19	23	25	118	18
25	25	17	24	12	103	21	20	16	19	23	99	-4
11	13	9	14	6	53	24	14	16	20	20	94	41
17	11	6	15	6	55	30	21	17	21	22	111	56
16	14	8	12	6	56	16	18	13	18	17	82	26
28	26	17	26	12	109	30	23	20	19	25	117	8
17	14	9	11	5	56	27	20	18	21	21	107	51
21	22	10	17	9	79	21	19	13	17	15	85	6
20	20	12	20	7	79	29	21	17	22	20	109	30
18	21	12	19	7	77	19	12	13	12	13	69	-8
21	19	13	18	10	81	23	17	14	18	17	89	8
21	18	10	17	9	75	24	20	18	22	18	102	27
18	20	12	16	8	74	23	21	15	20	21	100	26
22	20	12	20	8	82	25	20	16	19	20	100	18
20	21	12	18	9	80	23	19	18	19	18	97	17

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20	17	10	20	9	76	27	19	15	20	22	103	27
22	20	10	19	9	80	23	22	16	20	19	100	20
21	17	12	17	9	76	27	22	18	19	21	107	31
20	20	11	19	8	78	24	19	18	22	20	103	25
22	20	10	19	9	80	24	21	17	22	21	105	25
18	19	13	15	10	75	23	22	18	21	22	106	31
20	18	14	19	8	79	23	21	15	19	20	98	19
19	20	13	15	11	78	24	20	17	22	22	105	27
18	20	10	15	10	73	25	19	15	21	20	100	27
22	20	10	18	10	80	25	20	16	22	22	105	25
20	18	11	20	11	80	24	22	17	20	20	103	23
18	21	12	17	8	76	25	21	15	20	21	102	26
22	19	12	16	10	79	27	19	15	21	21	103	24
18	16	11	15	8	68	23	20	18	19	22	102	34
21	17	12	17	9	76	27	22	18	22	21	110	34
21	19	10	17	10	77	26	21	18	20	18	103	26
20	21	14	20	8	83	26	20	15	19	19	99	16
21	20	12	16	8	77	25	22	16	20	20	103	26
18	18	10	19	10	75	24	20	17	21	22	104	29
19	16	13	18	9	75	24	22	17	22	18	103	28
18	18	13	19	9	77	25	20	15	20	21	101	24
22	18	10	20	10	80	27	22	16	20	19	104	24
20	17	10	20	11	78	26	20	18	19	20	103	25
18	19	13	19	9	78	24	19	17	22	20	102	24
19	20	10	20	9	78	26	20	16	19	20	101	23
20	17	14	19	11	81	23	20	15	20	22	100	19
21	19	11	16	10	77	25	21	18	20	20	104	27

"Statistical test to examine the level of students' learning perception."

Null Hypothesis (H_0)

There is no significant difference in students' perceptions between Applied Mathematical conventional learning approach and Applied Mathematical Project Based Learning (PBL) approach approach.

H_0 : μ Conventional Learning approach = μ Project Based Learning approach

Alternative Hypothesis (H_1)

There is significant difference in students' perceptions between Applied Mathematical conventional learning approach and Applied Mathematical Project Based Learning (PBL) approach.

H_1 : μ Conventional Learning approach ≠ μ Project Based Learning approach

Table 9. Tests of Normality

	Kolmogorov-Smirnov			**Shapiro-Wilk**		
Variable	**Statistic**	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
YX	.155	61	< .001	.959	61	.039

Test of Normality (y - x)

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The results of the normality tests, namely Kolmogorov–Smirnov (K-S) and Shapiro–Wilk (S-W), both yielded significance values ($p < 0.05$). These findings indicate that the data deviate from a normal distribution. Consequently, the normality assumption required for conducting a Paired Sample T-Test is not satisfied, and thus, the use of non-parametric alternatives such as the Wilcoxon Signed-Rank Test is recommended.

Table 10. Ranks

Y - X	**N**	**Mean Rank**	**Sum of Ranks**
Negative Ranks	6[a]	5.83	35.00
Positive Ranks	55[b]	33.75	1856.00
Ties	0[c]	—	—
Total	**61**	—	—

Rank of (y - x)

Table 4. Test Statistics

Test	**Y - X**
Z	-6.542[b]
Asymp. Sig. (2-tailed)	< .001

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks

Wilcoxon Signed-Rank (y-x)

Based on the results of the Wilcoxon Signed-Rank Test, the analysis yielded a value of Z = -6.542 with a significance level of Asymp. Sig. (2-tailed) < 0.001. Since the significance value is smaller than $\alpha = 0.05$, it can be concluded that the null hypothesis (H_0) is rejected. Thus, there is a significant difference between the scores before the treatment (X) and after the treatment (Y).

Furthermore, the *Ranks* table indicates that 55 respondents showed an increase in scores ($Y > X$), while only 6 respondents experienced a decrease in scores ($Y < X$), and none showed the same scores ($Y = X$). This finding suggests that the majority of respondents experienced an improvement in their scores after the treatment.

Therefore, it can be concluded that the applied treatment produced a significant improvement in Y scores compared to X scores, indicating that the treatment had a positive effect on the respondent.

At the heart of this study lies an effort to humanize the learning of technical concepts that are often taught as mechanical and detached. The experience of engaging students in project-based learning through the construction and analysis of ship models has revealed that mathematics, when embodied in material practice, becomes less about formulaic accuracy and more about interpretive understanding. Students were not simply computing coordinates of mass; they were, in a deeper sense, negotiating balance, precision, and consequence. This subtle shift from performing calculation to performing meaning is what renders the findings of this study significant. It invites us to reconsider what "understanding" truly entails in maritime education not the memorization of equations, but the capacity to reason with the physical world. This redefinition of learning echoes the transformative dimension of Project-Based Learning (PBL) described by Zhong et al. (2023), who assert that when learners construct knowledge through

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authentic problems, the process cultivates an epistemic agency that cannot emerge from lecture-based instruction alone.

This notion of epistemic agency becomes palpable in the learning process observed in this study. The ship-model project transformed an abstract mathematical topic into an encounter with reality one that required precision, cooperation, and judgment. The learners' gestures, their weighing of containers, the recalculation of center of mass, and their collective adjustments to balance all pointed to a dynamic, lived cognition. It was not merely a shift in pedagogy but a reorganization of thought: students began to see mathematics as something enacted, not recited. Such embodiment of cognition finds support in the meta-analytic evidence from Lavado-Anguera et al. (2023), who found that the strength of PBL's impact stems less from its structure and more from its authenticity the degree to which learners confront the same uncertainties professionals face. In our study, those uncertainties were tangible: misplacing one container or miscalculating its mass immediately altered the equilibrium of the model. Learning, therefore, became visceral, self-correcting, and alive.

What is particularly revealing is how this learning process aligns with broader conversations in maritime education about the necessity of authentic experience. Dewan et al. (2023) observed that both immersive and non-immersive simulators enhance conceptual depth not because of technological novelty, but because they allow learners to feel the system they study to observe cause and effect in real time. Our use of a simple physical model achieved precisely that: a tactile, low-cost environment where abstraction met embodiment. In this sense, the findings resonate with the argument of Karahalil et al. (2024), who contend that effective simulation-based learning depends less on fidelity and more on structure on whether students are guided through cycles of reflection, feedback, and recalibration. That structure was consciously built into our study, as learners repeatedly measured, recalculated, and reasoned through each modification of their model. In those moments of iterative engagement, the classroom ceased to be a place of instruction and became a laboratory of discovery.

The coherence of these processes also explains the depth of engagement and creativity manifested by the participants. Creativity, in this context, is not ornamental but cognitive an act of synthesis that connects quantitative reasoning with spatial and practical intuition. The meta-analysis published in STEME Journal (2025) provides strong empirical support for this observation, noting a large effect size of PBL on creativity when learners work within complex, authentic constraints. Our findings reflect this very condition: students were not given freedom in a vacuum but were asked to solve an engineering problem bounded by realism to make decisions that would preserve balance while optimizing stowage. Their creative reasoning emerged not from abstract brainstorming but from disciplined improvisation, from negotiating between mathematical precision and pragmatic constraint. As Rehman (2024) suggests, such "structured creativity" is the hallmark of professional competence a cognitive rhythm that integrates analysis, intuition, and adaptability.

Yet, the results also remind us that learning is a fragile ecology. The variation among groups particularly those that still displayed "High Risk" CoM outcomes reveals that even within a successful PBL framework, not all learning experiences are equal. Some groups thrived in collaborative reasoning; others reduced the project to a sequence of tasks, missing the conceptual essence of equilibrium. This heterogeneity mirrors what Johnson et al. (2024) identify as the "implementation paradox" of PBL: while it is inherently student-centered, its success still hinges on the instructor's invisible architecture the scaffolding, the feedback, the culture of reflection that sustains inquiry. Without these, PBL can degenerate into procedural busyness. Our data subtly bear this out. Where facilitation was strong, conceptual

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breakthroughs occurred; where facilitation faltered, engagement became mechanical. This realization underscores that the strength of PBL lies not in the project itself, but in the quality of dialogue it sustains between learner and task.

That dialogue is also ethical in nature, particularly in a discipline like maritime engineering where precision can mean the difference between stability and disaster. The students' errors in weight distribution often caused by mismeasurement or misplaced assumptions mirror the real-world vulnerabilities that the maritime industry confronts. As the IMO (2024) technical report indicates, inaccurate cargo weight data remain one of the most common precursors of vessel instability. The educational implications are profound: by reproducing these errors safely in a learning environment, students internalize the significance of accuracy, not as an academic ideal but as a professional imperative. This is where experiential pedagogy transcends cognition it begins to cultivate character. The project thus becomes not only a medium for understanding center of mass but also a moral rehearsal for responsible practice.

While these findings align closely with contemporary evidence, their interpretation must remain tempered by critical humility. As Erdem (2022) and Zhong et al. (2023) both caution, PBL's immediate benefits may not directly translate into long-term retention or transfer. The temporal boundaries of our study confined to a single course module prevent any confident claim about durability of learning. However, this limitation is generative rather than constraining. It invites continuity. As Phanphichit (2025) suggests, sustained learning in technical disciplines emerges through a sequenced combination of modeling, simulation, and reflection. Extending this design longitudinally could reveal how conceptual understanding matures into professional intuition over time an inquiry that future research should pursue.

What ultimately surfaces from this discussion is a portrait of learning that is profoundly human: iterative, imperfect, reflective, and transformative. The convergence between our empirical observations and the current literature suggests that PBL, when genuinely enacted, reshapes not only how students learn but who they become as learners. It transforms knowledge from a commodity transmitted by experts into a practice shared among apprentices of reality. In the physical balance of a miniature ship, students discovered the moral and intellectual balance that defines their future profession precision tempered by judgment, calculation guided by reflection, and collaboration grounded in responsibility. Such is the enduring value of project-based learning: it teaches not only how to measure, but how to mean.

Conclusion

This study demonstrates that Project-Based Learning (PBL), particularly through scaled ship model projects, provides authentic opportunities for integrating theory with practice in maritime education. The findings indicate that this approach enhances conceptual understanding of ship stability, mass distribution, and the center of mass, while simultaneously fostering essential problem-solving skills. Moreover, the identification of high-risk cases emphasizes the critical importance of accurate weight data, balanced loading, and careful cargo planning to ensure maritime safety.

In addition, students reported that PBL was more engaging and motivating than conventional methods. By encouraging active participation rather than rote memorization, PBL promotes confidence, creativity, and critical thinking in applied mathematics. These competencies are crucial for professional readiness, as they enable students to apply abstract concepts to real-world maritime operations effectively.

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Recommendations

Based on these findings, maritime institutions are encouraged to adopt PBL more systematically within their curricula. Scaled ship model projects and authentic operational simulations should be prioritized, as they provide valuable insights into maritime safety and efficiency (Hmelo-Silver, 2004; Stopford, 2008; Thomas, 2000). Institutional support in the form of adequate facilities, simulation tools, and collaboration with industry partners is also essential to ensure the effective implementation of PBL (S. Bell, 2010).

Future research is recommended to explore the application of PBL across different levels of student competence and diverse maritime contexts. Such studies will strengthen the evidence base, ensure adaptability to varying educational settings, and confirm the sustainability of PBL as a pedagogical strategy capable of preparing students for the complexities of maritime professions.

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