Undergraduate courses for enhancing design ability in naval architecture

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ABSTRACT: *Contemporary lectures in undergraduate engineering courses typically focus on teaching major technical knowledge-based theories in a limited time. Therefore, most lectures do not allow the students to gain understanding of how the theories are applied, especially in Naval Architecture and Ocean Engineering departments. Shipyards require students to acquire practical ship design skills in undergraduate courses. To meet this requirement, two lectures are organized by the authors; namely, “Planning Procedure of Naval Architecture & Ocean Engineering” (PNAOE) and “Innovative Ship Design” (ISD). The concept of project-based and collaborative learning is applied in these two lectures. In the PNAOE lecture, sophomores receive instruction in the designing and building of model ships, and the students’ work is evaluated in a model ship contest. This curriculum enables students to understand the concepts of ship design and production. In the ISD lecture, seniors learn how to develop their creative ideas about ship design and communicate with members of group. They are encouraged to cooperate with others and understand the ship design process. In the capstone design course, students receive guidance to facilitate understanding of how the knowledge from their sophomore or junior classes, such as fluid mechanics, statics, and dynamics, can be applied to practical ship design. Students are also encouraged to compete in the ship design contest organized by the Society of Naval Architects of Korea. Moreover, the effectiveness of project-based and collaborative learning for enhancing interest in the shipbuilding Industry and understanding the ship design process is demonstrated by citing the PNAOE and ISD lectures as examples.*

KEY WORDS: Capstone design; Naval architecture; Design ability; Project-based learning; Collaborative learning.

INTRODUCTION

The conventional undergraduate engineering curriculum is based on classroom lectures and mainly focused on teaching theories and technical knowledge. However, this curriculum does not enable students to develop design abilities they need to keep up with the rapid progress in engineering. Especially in the field of naval architecture, the huge scale of ships and offshore structures, which are the main products of naval architecture, make it difficult for students to understand the relationship between theory and engineering design. Therefore, two courses were organized by the authors specifically for undergraduates; namely, “PNAOE” and “ISD”. PNAOE is a lecture that aims to enhance sophomores’ interest in naval architecture. ISD, on the other hand, is a capstone design course for seniors.

Related works

Project-based learning is where students are assigned a project to execute and take the initiative to solve project-related problems. It is very effective for developing students' practical design ability (Hanai et al., 2007; Ito et al., 2007; Matsuzawa and Ohiwa, 2007).

Besides project-based learning, collaborative learning is also an important and effective learning method. Terenzini et al. (2001) examined the students of undergraduate engineering courses, who are taught using collaborative learning methods, and found they differed from traditional lecture and discussion courses in their ability to promote the development of engineering design, problem-solving, communication, and group participation skills. Moreover, according to Gokhale (1995) and Goodsell et al. (1992), collaborative learning increases participants' interest, promotes critical thinking through the active exchange of ideas in small groups, and can help students develop the sense of community. Shared learning also gives students an opportunity to engage in discussion and it makes them to achieve at higher levels of thought and retain information longer than students who work quietly as individuals (Johnson and Johnson, 1986; Totten et al., 1991).

Because of these merits of project-based and collaborative learning, the students of two lectures (i.e., PNAOE and ISD) are required to form small groups to complete term projects. This paper presents the objectives, contents, characteristics, and learning outcomes of the two courses. This paper is based on the author's textbooks (Lee et al., 2011) and lecture notes (Lee, 2006; Lee, 2009).

COURSE FOR ENHANCING THE INTEREST IN NAVAL ARCHITECTURE: PLANNING PROCEDURE OF NAVAL ARCHITECTURE & OCEAN ENGINEERING

In this course, students are encouraged to (1) increase their interests in naval architecture and (2) learn how to apply their knowledge in ship designing. This lecture is comprised of "Designing a Model Ship," and "Constructing a Model Ship."

Designing a model ship

This is a sophomore course (PNAOE) in which students build a model ship in 15 weeks as a term project, and a model ship contest is held to evaluate the achievement of the students. Students design and build a model ship in accordance with the given subjects. The contest evaluates the speed and maneuverability of each model ship. We use the term "project" to encourage students' interest in naval architecture by learning the relationship between practical ship designing and theory.

Determining the main dimensions of a ship

In this course, students learn what the main dimensions are and how to determine them. The main dimensions, such as length (L), breadth (B), depth (D), draft (T) and block coefficient (CB), have to satisfy certain design criteria, such as physical, economic, and regulatory constraints. Among these constraints, physical constraint is the most important because they are related to floatability of a ship. The basic theories that the students learn for determining a ship's main dimensions are as follows.

- Hydrostatic equilibrium

For a ship to float, its total weight must be equal to the buoyancy force exerted on the immersed body.

- Archimedes' principle

The buoyancy force exerted on an immersed body has the same magnitude as the weight of the fluid displaced by the immersed body.

- Total weight of a ship

The weight of a commercial ship is usually comprised of the lightweight and the deadweight. According to the definition of these weights, the physical constraint, the so-called weight equation, is described as follows:

$$\mathbf{F}_{\text{Buoyant}} = \mathbf{W}_{\text{displacement}} = \mathbf{W}_{\text{total}}$$

where $\mathbf{F}_{\text{Buoyant}}$ is the force exerted on a ship, $\mathbf{W}_{\text{displacement}}$ is the weight of the fluid displaced by the immersed body, and $\mathbf{W}_{\text{total}}$ is a ship's total weight.

$$\mathbf{W}_{\text{total}} = \text{LWT} + \text{DWT}$$

where LWT is lightweight and DWT is deadweight, we get the following equation.

$$\mathbf{W}_{\text{displacement}} = \text{LWT} + \text{DWT}$$

At this point, displacement can be represented in terms of the main dimensions. The deadweight is given by the owner's requirement. Therefore, the lightweight should be estimated using the appropriate assumption. Because a ship consists of the hull structure, outfit, and machinery, the lightweight can also be estimated as follows.

$$\text{LWT} = W_s + W_m + W_o$$

where W_s is steel weight, W_m is machinery weight, and W_o is outfit weight. W_s , W_m , and W_o can be assumed to depend on the main dimensions and can be estimated by the weight of the basis ship. The physical constraint is used to roughly determine the main dimensions. After hull form variation, the main dimensions are precisely determined.

Hull form design, compartment design, and structural design using software

To help students determine the main dimensions and design the hull form, compartment, and structure of a ship, software such as EzOptimizer, EzHULL, EzCOMPART, and EzSTRUCT are provided. The software has been jointly developed by the author's laboratory (Advanced Ship Design Automation Laboratory, Department of Naval Architecture and Ocean Engineering, Seoul National University) and EzGRAPH Co., Ltd. Students learn in the lectures how to use the software. The procedures of ship design using the software are as follows.

- First, students design the hull form of the model ship using the commercial software “EzHULL” (see Fig. 1).

Fig. 1 Designing the hull form using “EzHull”.

- Second, students design the compartment of the model ship using “EzCOMPART” (see Fig. 2). In this procedure, the stability of the ship and the capacity of each compartment are checked.

Fig. 2 Designing the compartment using “EzCOMPART”.

- Third, students design the structural members of the model ship using “EzSTRUCT” (see Fig. 3). In this procedure, the strength of the model ship is checked.

Fig. 3 Structural design using “EzSTRUCT”.

Constructing a model ship

Students construct a model ship based on the theory explained in Chapter 1. Each year, various subjects for the term projects are suggested in this lecture, and the subjects are listed in Appendix B. In this section, the procedure of constructing the model ship is presented using an example of the term projects.

- Students design, cut, and assemble the structural members of the model ship. Figs. 4 and 5 show the structural members of a model ship and the assembly process.

Fig. 4 The structural members of a model ship.

Fig. 5 Assembly of the structural members.

- Then, the students attach the shell plates of the model ship to the frames (see Figs. 6 and 7).

Fig. 6 Attaching the shell plates to the frames of a model ship.

Fig. 7 The hull form after attaching the shell plates.

- Finally, students paint the model ship to make it waterproof and refine the hull form. After constructing the model ship, students examine the performance of their model ship using a trial run in a towing tank (110 m in length, 8 m in width, 3.5 m in depth). The towing tank is the equipment of the department of Naval Architecture and Ocean Engineering of Seoul National University in Korea. Fig. 8 shows the trial run of a model ship.

Fig. 8 Trial run of a model ship.

Contest to evaluate model ship

The contest evaluates the model ship according to the following criteria.

- Speed: how long it takes to go to the specified location.
- Maneuverability: how long it takes to go to the specified location and return to the departure point.

To encourage students' interest in naval architecture, there are several awards in the contest such as best speed, best maneuverability, and best creative design. Students are also graded according to their model ship's performance in the contest.

CAPSTONE DESIGN COURSE: INNOVATIVE SHIP DESIGN (ISD)

The goal of this capstone design course is to (1) develop students' ship designing skills, (2) develop students' ability to solve engineering problems using the knowledge gained from their previous lectures, and (3) acquire teamwork and communication skills with other people in a group.

Course overview

The course introduces students to the following basic concepts of ship designing.

○ Weights of ship	○ Buoyancy	○ Ship stability
○ Powering	○ Hull form design	○ General arrangement
○ Hull structure	○ Outfitting	○ Economics

A team of 6-8 students complete a term project based on the given owner's requirements regarding the following tasks:

○ Determination of principal dimensions of ship	○ Estimation of weight
○ Estimation of cargo hold volume	○ Calculation of freeboard
○ Prediction of speed and power	○ Determination of propeller principal dimensions
○ Selection of main engine	○ Design of hull form by hull form variation method
○ General arrangement design	○ Naval architectural calculation such as volume hydrostatics, trim & stability, and longitudinal strength
○ Structural design of the midship section	

To help students complete the tasks, the following procedure is used.

- (1) Find applied problems.
- (2) Construct mathematical models.
- (3) Find a solving scheme (algorithm).
- (4) Develop software.
- (5) Write reports and make presentations.

For example, (1) if students need to determine ship's main dimensions, (2) they will construct a mathematical model using physical, economic, and regulatory constraints. To determine the optimal dimensions, they will set up the objective function. (3) They will then find the solving scheme (4) and will develop the optimization software using the technical knowledge acquired in their sophomore or junior classes. (5) After that, students will report and present the results of the term projects, including the procedure for completing the tasks.

Capstone design projects

Several types of ships or ship automation systems are suggested as subjects for the term projects. Fig. 9 shows the configuration of this course and examples of the subjects for the term projects. The subjects for the term projects are revised annually in accordance with the needs of the shipbuilding industry.

Fig. 9 Configuration of the "Innovative Ship Design" course.

Students select subjects for the term project and use their technical knowledge to complete it. Moreover, this lecture guides students in the development and use of their own software (see Figs. 12 and 13). Through the software development process, students learn exactly where the technical knowledge is applied and how the software is developed.

An example of the term project, the basic design process of the "25,000 displacement ton light aircraft carrier" is shown in the following figures (Figs. 10-17) and Table 1. Figs. 12-14 show the uses of the software developed by the students for completing the tasks. All the subjects of the term projects, provided in this lecture, are listed in Appendix A.

Fig. 10 Hanger design of the light aircraft carrier.

Fig. 11 Deck design of the light aircraft carrier.

Result Summary								
DRAFT M	DISPL M	DISPL SW	DISPL FW	LCF	LCB	VCB	TPC	MTC/100
5.0	16121	16524	16121	-4.087	0.413	2.769	42.6	4.3
5.2	16959	17383	16959	-4.604	0.178	2.884	43.3	4.5
5.4	17811	18256	17811	-5.094	-0.063	3.000	43.9	4.7
5.6	18674	19141	18674	-5.441	-0.304	3.115	44.5	4.8
5.8	19548	20037	19548	-5.708	-0.540	3.231	45.1	5.0
6.0	20432	20943	20432	-5.923	-0.768	3.346	45.6	5.1
6.2	21326	21859	21326	-6.085	-0.988	3.462	46.0	5.2
6.4	22228	22784	22228	-6.222	-1.198	3.577	46.5	5.3
6.6	23139	23718	23139	-6.339	-1.398	3.692	46.9	5.4
6.8	24059	24661	24059	-6.421	-1.589	3.807	47.3	5.5
7.0	24987	25611	24987	-6.484	-1.769	3.922	47.7	5.6
7.2	25922	26570	25922	-6.538	-1.940	4.036	48.1	5.7
7.4	26865	27537	26865	-6.582	-2.103	4.151	48.5	5.8
7.6	27816	28511	27816	-6.611	-2.256	4.266	48.9	5.9
7.8	28773	29493	28773	-6.637	-2.402	4.380	49.3	6.0
8.0	29738	30482	29738	-6.657	-2.539	4.494	49.6	6.1
8.2	30710	31478	30710	-6.672	-2.670	4.608	50.0	6.2
8.4	31689	32482	31689	-6.677	-2.794	4.722	50.4	6.3
8.6	32675	33492	32675	-6.675	-2.911	4.836	49.3	6.4
8.8	33640	34481	33640	-6.644	-3.027	4.947	49.6	6.4
9.0	34611	35476	34611	-6.933	-3.136	5.058	49.9	6.5
9.2	35589	36479	35589	-6.920	-3.241	5.169	50.3	6.6

Fig. 12 Hydrostatics calculation using the software developed by students.

Input

LWL: 246.34, LBP: 204.6, B: 34.8, Tl: 6.8, Ta: 6.8, T: 6.8, Volume: 20469, Sr: 275, Sbk: 180, Cb: 0.5695

Cm: 0.9653, Cwp: 0.7402, Cp: 0.8193, LCB: 1.22, BilgeRadius: 2.4, At: 0, Abt: 185, Hb: 12, v: 15, i+k2: 1.4

Sectional Shape of Stern: ☐ Param with gondola, ☒ "V" shape, ☐ Normal, ☐ "U" shape

Existence of Bulb: ☐ Yes, ☒ No

Output

i+k1: 1.4869059618, Rf: 693494.73545, Rapp: 37881.067154, Rb: 0, Rv: 14075.435027, Rtr: 0, Ra: 112440.68543, Rt: 1195558.6442, EHP: 9224930.4993

Calculation Close

Fig. 13 Resistance estimation using the software developed by students.

Input

MCR: 55519, NCR: 58967, RPM: 94.42, Z: 5, SCH: 4.3134, SM: 15, Draft: 6.8

Calculation

Output

Ae/Ao: 0.85582, V: 17.0, W: 0.3161456001127, Va: 10.326201438297, J: 0.4316082918043, Eta0: 0.434473, D: 7.12779, Pi/D: 1.26905, Kt: 0.1950289292950, Kq: 0.0197696765215, Tp: 2214.11326800958, Ts: 2213.9554051221, Tp-Ts: 0.1568029637367, Ae/Ao (keller): 0.5806202176775, Ae/Ao (burnill): 0.2704814971713

Graph showing E/Hf, Kt, and Kq curves.

Fig. 14 Determination of the main dimensions of the propeller using the software developed by students.

Table 1 Main dimensions of the light aircraft carrier.

Main dimensions	
Length over all (m)	246.34
Breadth (flight deck) (m)	34.8
Depth (m)	21.45
Design draft (m)	6.8
Lightweight (ton)	17,450
Maximum speed (knots)	28
Engine power (NMCR) (hp) (NMCR: Nominal Maximum Continuous Rating)	134,400
Block coefficient (Cb)	0.5695

Fig. 15 Design of light aircraft carrier's hull form using "EzHULL".

Fig. 16 Design of light aircraft carrier's compartments using "EzCOMPART".

Fig. 17 Structural design of the light aircraft carrier using "EzSTRUCT".

Evaluation using a ship design contest

To give students an opportunity to have their achievements assessed, this course encourages them to compete in the ship design contest organized by the Society of Naval Architects of Korea. Students who join the contest usually manifest more interest in ship design and achieve higher grades than other students.

In the ship design contest, students always received one of top 3 prizes. The results of the contests are listed in Appendix A. For the contest, teams from ISD prepared for 6 weeks, and the teams consisted of 6-8 students. The other teams prepared for 54 weeks, and consisted of 10-20 students. This demonstrates how the ISD course is intensive and effective for improving students' design skills.

CONCLUSIONS AND FUTURE WORK

This paper presented the curricula and results of two courses based on collaborative and project-based learning. These two lectures were established to enhance undergraduates' design ability. During the course, students learned the applications of the technical knowledge that they had gained in their sophomore or junior classes. Software for the course was developed by students and also partially provided by the author's laboratory. Students participated in a model ship contest and a ship designing contest, which motivated their interest in naval architecture. The results of the ship design contest show the lectures were effective and intensive for enhancing students' design ability. In the future, the subjects for the projects in the two lectures will be updated to reflect the latest issues in the naval architecture industry.

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APPENDIX A

Year	Design objective	Participation in ship design contest		Award list
		Specified theme	Free theme	
2002	15,000 Displacement Ton Light Aircraft Carrier		O	2 nd Prize
	80,000 GT ¹⁾ Cruise Ship		O	2 nd Prize
	30,000 ton SWATH ²⁾ Cruise Ship		O	3 rd Prize
	145,000 m ³ LNG ³⁾ Carrier			
	214 Class Submarine			
	320,000 DWT ⁴⁾ Twin Skeg VLCC ⁵⁾			
	182,000 DWT Double-side Skin Bulk Carrier			
	8-Seater WIG ⁶⁾			
	9,000 TEU ⁷⁾ Container Carrier			
	240,000 m ³ LNG-FPSO ⁸⁾			
	450,000 DWT ULCC ⁹⁾			
2003	160,000 m ³ LNG Carrier			
	40,000 Displacement Ton LHD ¹⁰⁾		O	2 nd Prize
	2,500 Displacement Ton Submarine			
	225,000 m ³ LPG Condensate FSO ¹¹⁾			
	6,000 GT Research Icebreaker			
	12,000 TEU Container			
	100,000 Displacement Ton Aircraft Carrier			
	6,400 Unit Multipurpose Car Carrier			
	3,400 GT Car Ferry			
	100,000 GT Cruise Ship			
	148,500 DWT Shuttle Tanker			
2004	115,000 DWT Ice Class Tanker			
	25,000 Displacement Ton Light Aircraft Carrier		O	2 nd Prize
	15,000 TEU Container Carrier			
	200,000 m ³ LNG Carrier		O	3 rd Prize
	Cabin Modeling Computer Program		O	
	Container Loading Computer Program			

Year	Design objective	Participation in ship design contest		Award list
		Specified theme	Free theme	
2005	210,000 m ³ Ice Class LNG Carrier			
	20,000 Displacement Ton Nuclear-powered Ice Breaker			
	112,500 GT Cruise Ship		O	1 st Prize
	33,000 DWT Drillship			
	8,300 Displacement Ton Nuclear-powered Submarine			
	250,000 m ³ LNG Carrier	O		2 nd Prize
	4,100 TEU Container Carrier	O		2 nd Prize
2006	18,600 Displacement Ton Nuclear-Powered Ice Breaker		O	2 nd Prize
	42,000 GT Ro-Ro ¹²⁾ Passenger Ship		O	2 nd Prize
	180,000 m ³ LNG Carrier		O	2 nd Prize
	3,000 Displacement Ton Nuclear-powered Submarine		O	2 nd Prize
	145,000 m ³ Ice Class LNG Carrier		O	
	180,000 DWT New Panamax Class Bulk Carrier	O		
	280,000 m ³ LNG FSRU ¹³⁾		O	2 nd Prize
2007	210,000 m ³ LNG RV ¹⁴⁾		O	2 nd Prize
	110,000 m ³ PNG ¹⁵⁾ Carrier			
	84,000 m ³ CNG ¹⁶⁾ Carrier			
	200,000 m ³ LNG FPSO			
	170,000 m ³ Methane Hydrate FPSO			
	110,000 m ³ LPG ¹⁷⁾ Carrier		O	
	4,200 TEU Container Carrier			
2008	320,000 DWT VLCC	O		
	3,000 GT Education and Training Ship of Korea Coast Guard		O	2 nd Prize
	4,800 TEU Container Carrier			
2009	87,400 DWT Tanker for New Panamax Canal	O		
	210,000 m ³ LNG carrier with Fuel Cell Hybrid-powered Engine		O	2 nd Prize
	7,500 TEU Container Carrier			
2010	Korea Coast Guardship with Reducing the Fuel for Environment		O	

¹⁾ GT: Gross Tonnage²⁾ SWATH: Small Waterplane Area Twin Hull³⁾ LNG: Liquefied Natural Gas⁴⁾ DWT: Deadweight Ton⁵⁾ VLCC: Very Large Crude oil Carrier⁶⁾ WIG: Wing in ground⁷⁾ TEU: Twenty-foot Equivalent Unit⁸⁾ FPSO: Floating Production Storage Offloading⁹⁾ ULCC: Ultra Large Crude oil Carrier¹⁰⁾ LHD: Landing Helicopter, Dock¹¹⁾ FSO: Floating Storage and Offloading¹²⁾ Ro-Ro: Roll-on Roll-Off¹³⁾ FSRU: Floating Storage and Regasification Unit¹⁴⁾ RV: Regasification Vessel¹⁵⁾ PNG: Pressurized Natural Gas¹⁶⁾ CNG: Compressed Natural Gas¹⁷⁾ LPG: Liquefied Petroleum Gas

APPENDIX B

Year	Design objective	
	Type of ship	Function / Control
2004	Free selection	- Propulsion system - Maneuvering system
2005	Crane ship	- Propulsion system - Maneuvering system - Cargo loading/Unloading system by crane
2006	Cargo ship	- Propulsion system - Maneuvering system - Distance-keeping system by infrared sensor
2007	Free selection	- Position control system for a ship by PID control
2008	Floating crane	- Position control system for a ship by PID control - Position sensing system for a ship and for a cargo by gyroscope

1st prize, Trimaran in model ship contest 2004.

1st Prize, Crane ship in model ship contest 2005.

1st prize, Crane ship in model ship contest 2006.

1st prize, Position control system in model ship contest 2007.

1st prize, Floating crane in model ship contest 2008.