Assessment and Experience of Boatbuilding-Based PBL in Two Naval Architecture Programs

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Abstract

Numerous studies highlight the advantages of Project-Based-Learning (PBL) for skills development, motivation, and retention (both in terms of students staying in the major and in terms of retaining learned skills) of engineering students. While all students take design courses leading to their senior capstone projects, they do not all build prototypes of their work. Typically, in naval architecture and marine engineering programs, PBL projects focus on building small models due to time, space, and cost issues with using full-scale vessels. Exceptions to this approach are taken at two colleges, where students may take elective courses that feature full-scale construction of 10-15 ft long plywood craft. At the United States Coast Guard Academy (USCGA), the first-year, 1-credit, course introduces statistical design methods combined with fundamental naval architecture principles leading to an individual design by the end of the first semester. Students then select one of their designs and build it during the spring. Course graduates have the option to serve as mentors, teaching aides and course instructors, building their leadership, technical and communication skills. At the United States Naval Academy (USNA), the fourth-year students build either an off-the-shelf design or one of their own. The students build their boat from construction plans through finishing with decreasing amounts of guidance from instructors. By the end of the course, students can read plans and determine viable construction steps independently and recognize when a design might be improved for fabrication. Along the way they become familiar with the use and maintenance of a variety of hand and power tools. This paper presents the curricula, lessons learned, and assessment using student and faculty feedback of educational impact and motivation, and retention data, which showed significant improvement at both schools.

Background/Introduction

Universally, students in Naval Architecture and Marine Engineering undergraduate programs are taught the basics of vessel design, from hydrostatics through propulsion, and from materials science through structures. Their program of study usually culminates in a capstone design experience where they perform a conceptual design of a ship or small craft. Many programs include hands-on projects ranging from small models to simulated ship components and towing tank models representing their capstone designs [1]. For obvious reasons of size, cost and complexity, hands-on work on full-size vessels is not feasible on most campuses. Exposure to ship and small craft construction is left for internships and work-study arrangements.

PBL activities provide benefits beyond acquiring practical fabrication skills [2]. Importantly, they provide excellent team building opportunities that develop community, belonging and motivation for the students. Additionally, long-term knowledge retention is enhanced both through repetition and the recognition by the students of the skill’s relevance to their career development.

Two colleges created different approaches to providing full-scale hands-on exposure through PBL electives in small craft construction. Third and fourth-year students at USNA and first-year students at USCGA, can take courses in Marine Fabrication Methods and Experiential Engineering: Small Craft Design and Construction, respectively. In these courses the students build 10-15 ft long plywood boats, providing them with an enjoyable, motivational, practical, and educational experience in their major.

The two schools have similar missions to develop officers for commissioning into the sea services of the United States. Both schools confer on their graduates B.S. degrees in a variety of majors, including Naval Architecture and Marine Engineering (NA&ME). Each school has approximately 25 students in that major each year.

A common tenet in naval architecture is that experience in ship operations, maintenance, repair and construction provides important background information for developing successful designs. Significantly, students from each school spend their entire summer participating in professional nautical studies, including ship operation and maintenance. A few students participate in summer internships at shipyards where they learn some construction techniques, but the large majority will not experience fabrication activities during their undergraduate study. For them, the PBL projects described in this paper are the sole opportunity to learn fabrication methods.

Additionally, fabricating small craft as a community building activity that includes STEM development is widespread in North America. An umbrella organization, the Teaching With Small Boats Alliance [3], serves as a clearing house of relevant information. The organization has hundreds of programs and individuals as members and "is committed to sharing knowledge, ideas, and best practices about leadership and program development, hands-on building projects, boat use, and integration of maritime-based lessons into school curricula." These programs primarily focus on K-12 or adults.

Course Description and Construction Requirements

While the goals and populations served for the project differ between the two institutions, the courses share many similarities, primarily in the course requirements, product, and project material requirements. Both projects require students to design a boat capable of being constructed using common construction materials available to a boating enthusiast or professional boatbuilder. Construction techniques taught are the industry standard methods, using fiberglass over plywood construction with framed structural components, common in both recreational and commercial craft [4].

Both courses give students a set of design parameters that students need to meet based upon the building area and materials available. These may include faculty providing a mission that needs to be met or the students conducting their own market research on an end-user. Students then design a vessel capable of meeting their mission and proceed down the abbreviated design spiral. Once a similar ships analysis is conducted, students then proceed to design their vessel via CAD (typically Rhinoceros), with an emphasis on surfaces that are developable and suitable for plywood construction.

In addition to the construction technique and design process, the projects at both schools have similar facility and material requirements. First, building a plywood vessel takes up fabrication shop space, which is often in short supply and is highly used for a variety of other student and faculty projects. The space needs to be large enough to house the finished product, plus about three feet surrounding the vessel, at a minimum. Also, tools, including fixed power woodworking tools need to be in proximity. While the list of tools could be exclusive to using hand tools including hand power tools, i.e., jigsaw, orbital sanders, electric drills, both programs have used common woodshop tools which include a table saw, bandsaw and compound miter saw. Dust removal in this space is also critical for those working and in nearby areas.

Materials for the boat itself typically include three to four sheets of plywood ranging from ¼ to ¾-inch for the bottom, transom, and sides. Plywood should be marine grade if the boat is to have any expected longevity, with sapele or okoume hardwoods being preferred for an intersection of quality and price. ¾-inch thick (nominal) Douglas fir boards of at least 150 mm longer the vessel’s length is required for the structural aspects of the vessel including stem, frames, gunwales, inwales, keelson, chine logs and keel (if fitted). Typically, two pieces of 1 x 6-inch x 20-feet Douglas fir are adequate for completing a boat. Additionally, fiberglass cloth and approximately two gallons of epoxy and hardener (both “slow” and “fast” curing) with fairing compounds (colloidal silica for strength and a lightweight fairing filler) are required. Woven-roving fiberglass cloth (typically 6 ounce “boat cloth”) is also needed in enough material to at least cover the square footage of the outer surfaces of the vessel. Additionally, two sheets of ¾-inch thick Medium-Density Fiberboard (MDF) are required for the vessel's construction frames. In all, a 14-foot long, flat or v-bottom, single-chined boat could be constructed for approximately $1,500 with quality materials.

Ventilation is also crucial for the construction space. Both projects are constructed using epoxy and fiberglass, the epoxy resin giving off fumes which are harmful if inhaled without wearing a respirator fitted with the proper NIOSH filter. In addition, particulates are generated from the multiple sanding processes, and respirators play a critical role in protecting both faculty and students from associated hazards.

USNA Description

The USNA Marine Fabrication course is an elective typically taken by fourth-year students (seniors). The program only has two spaces for engineering electives, and the fabrication course has been well subscribed by students with and without previous construction experience. Enrollment is limited to 12-14 students and two vessels are constructed simultaneously to ensure that every student is fully engaged with the fabrication project. It is a one-semester course, and the instructor typically selects the type of design in advance to procure materials. The first few weeks of the course then begin with a small design segment to identify a market and establish requirements. The students apply the design spiral process to the boat type selected by the instructor, modifying it as necessary to the requirements established by the group. Additional constraints are imposed by the construction space available to the class. When the group agrees that the modifications are satisfactory, construction drawings are produced.

The most recent project developed for the class is a recreational paddleboard for a fishing enthusiast of average paddling skill. this resulted in the following objectives:

- Length: less than 13 ft to fit two hulls in the construction space
- Beam: extra-wide for stability
- Payload: 400 lb to include the fisher, equipment, a cooler, and perhaps a dog
- Weight: less than 80 lb to facilitate easy transport

Construction begins with lofting the plans to the plywood so that every piece can be cut. The students are given the fewest possible number of plywood sheets and encouraged to learn how to use their materials efficiently by fitting pieces carefully. Every piece of plywood is cut by the students using hand and power tools. Occasionally the professional woodworkers employed in the machine shop will lend a hand for a special piece or two if extra skill is required. The students create a jig and begin assembly after all pieces have been cut. Up to this point most of the work is done in one large group, but once boat assembly begins the students typically pick a team and focus on just one hull. This fosters some friendly competition in class and tends to keep the students focused and engaged as they strive to build the "better" boat. Figures 1 and 2 show the students early in the assembly process, stitching the panels and frames of the boats.

Homework in the class is a weekly reflection on the construction process. Students are introduced to new tools and techniques during the week and are encouraged to reflect on the use of the tools and techniques on the project. As the semester progresses, these reflections usually develop increasing sophistication as the students take control of the construction process and take the initiative in proposing modifications.

Faculty workload for this course is somewhat dependent on the project selected, and the experience that faculty and any involved staff have with similar projects. In the last four years, the majority of time spent on the course has been during class on tasks such as explaining goals, directing student efforts, and supervising safe usage of tools and materials. Since homework and grading loads are low, faculty time has largely been spent on preparing class materials. These typically include suggestions or directions for construction tasks, detailed views of construction drawings, and informational notes on materials and tools. To date, selected projects have been familiar to either faculty, staff or both, so class preparation time has been comparable to any other class. Student initiative has been observed to improve when construction instructions are available ahead of time. Given the opportunity, students in the class have preferred to read ahead to get familiar with upcoming procedures. This allows them to make faster progress, particularly when the task of the day finishes ahead of schedule. They are also frequently interested in discussing the construction timeline and proposing improvements.

USNA Project Benefits

The elective opportunities for senior students are scheduled for their final year and come after their most technically rigorous semesters. By this time, youthful confidence has been tempered, and less robust egos can form unduly pessimistic evaluations of their own engineering competence. The fabrication course gives students a more practical approach to engineering, and a chance to rediscover their enthusiasm for naval architecture. Transforming construction drawings and directions into construction actions is an exercise in daily problem solving, and students who enter the course uncertain of their engineering ability finish with strong senses of accomplishment. The class also allows students who have previous fabrication experience to polish their skills and provide some leadership to less experienced students.

Figures 1 and 2. Stitching the bottom and side panels together (left) and assembling the internal frames (right) in the fishing paddleboards.

Discussions initiated by instructors during class encourage students to consider how design is translated into construction. Within a few weeks, students typically form the habit of identifying potential design modifications or improvements to improve the fabrication process. The elective is taken simultaneously with the first semester of ship design; as the students gain facility with the design process, their interaction with their construction project becomes more analytical. The theoretical and applied practices of ship design are mutually reinforcing. In addition, students frequently note that building a boat helps them to digest the information from the ship structures class: they get a visceral understanding of how the structural elements contribute to the strength of the ship.

What the students enjoy most about the class is the tangible reward for their work. In contrast to their other classes where the rewards of education are abstract, at the conclusion of the fabrication course the students have a boat as external, substantial evidence that learning has taken place. The class always celebrates the launch with great enthusiasm and gratification at the proof of their newly acquired skills. This enthusiasm has led to steady enrollment in the course and strong word of mouth among younger students who express anticipation about the course. Figure 3 shows one of the students in the middle of vigorous stability testing during his first ever excursion on a paddleboard. In Figure 4 the class is posing with their new boats.

The structure of the course is beneficial for instructors too. Since almost all student work occurs during class time, the instructor time is weighted toward class preparation and in-class interaction, and not grading. That makes the course a good complement to more traditionally structured courses. To date, this course has not required any extraordinary faculty investment of time such that a course or research buyout might be considered.

Figures 3 and 4. A student demonstrating the stability of the paddleboard in the tow tank facility (left) and the class after the successful launch of both boats (right).

USCGA Project Description

In contrast to the course at USNA, cadets at USCGA typically enroll in the boat design/build course as a first-year student (freshmen). The design portion of the course is an optional one-credit lecture offered during the fall semester. The build or construction portion of the course is offered in a one-credit laboratory format during the spring semester. Both semesters are considered "Satisfactory/Unsatisfactory" electives and do not affect the students' GPA. Students can join each class independently, meaning a student may enroll in the build portion in the spring without participating in the design portion in the fall. Typical enrollment for the fall is upwards of 20 students, and the spring semester sees an enrollment of 12-16 students, with a goal of having no more than 4-6 students per lab section. During the fall, student enrollment is only limited by faculty availability and workload. Computer laboratories are available and/or students can use free trial versions or purchase student versions of the software for their personal computers. Spring enrollment is often complicated by the inability to find three continuous hours for lab in their schedules.

Due to size and area limitations during the boat construction, as well as time constraints, the following design limits for the project were established:

- Length: 10 - 15 feet
- Beam: 5 feet maximum (beamier boats are usually more time-consuming)
- Propulsion: oar, paddle, sail or small outboard
- Style: monohull, single chine, flat or V-bottom
- Construction: plywood/epoxy construction with fiberglass sheathing

In the fall semester, each student designs his or her own boat design according to a mission statement and a set of owner's requirements that *they* define. Once the project is defined, each student completes elements of the classic Naval Architecture design spiral including:

- Market Research and Similar Ships Analysis
- Preliminary Characteristics
- Preliminary Lines
- Weight and Stability Study
- Refined Lines and Development of Lines Plan
- 3-D Printing
- Construction Drawings

Short weekly and bi-weekly homework assignments are employed to assess student learning and to ensure students are successfully achieving design waypoints. Example designs using similar materials and the need to design developable surfaces, are provided for reference [5]. One of the biggest obstacles students face during the design phase of the course is proficiency with design software. To assist with this, students are provided faculty developed tutorials on designing ship hulls in Rhinoceros followed by dedicated tutoring and advising sessions with faculty members to achieve mission parameters with developable surfaces. Upper-class student mentors are also available in and out of class to assist first year students with software hurdles.

Near the end of the semester, students submit their designs on a standardized PowerPoint template which includes their mission statement, principal characteristics, and Lines Plan drawing. All student designs are combined into a Project Design Catalog and in a whirlwind session, each student has 1 minute and 45 seconds to present their design. After the design presentations the students vote, choosing a design to construct during the spring semester (with instructor input on construction feasibility). Any remaining lectures during the fall are used to show the students how to develop in CAD the NC-cut building frames, sides, and bottom pieces.

In the spring semester, students are responsible for constructing the designed boat. The plywood sides, bottoms, and transom, along with the frames are cut with a CNC router. Then students set up a building jig and construct the vessel via the methods discussed above. Instructors engage in conversation regarding vessel structures and construction methods which carry over to larger, recreational, commercial, and military vessel construction methods.

Faculty resources in the fall are similar to other one-credit lecture courses, with about two-three hours of work outside the classroom for each one-hour lecture. The spring three-hour lab is also similar to other lab courses, with 10-15 hours of preparation before the semester and 1-2 hours of time outside of lab per week. Students are not permitted to work on the boat outside class time.

USCGA Project Benefits

A major goal of this project is to expose first year undergraduate students to Naval Architecture and Marine Engineering (NAME). Many first-year students express an interest in the NAME major yet do not have a good understanding of the major or the larger discipline. This manifests itself in disappointing retention numbers, with roughly half of the students leaving the major after the first year. This project aimed to not only provide an opportunity for experiential learning on an actual boat, but also provided faculty mentoring on the profession, career paths, etc., with the goal of increasing retention within the major.

Another project goal is to encourage community building within the NAME major. Engaging in a major-specific project such as this naturally encourages individual interactions. Additionally, lab instructors encourage teamwork, giving students open-ended construction problems with not necessarily one right answer or "correct" construction method. For instance, students may have to cut a piece of wood, and the team is left to decide which tool or method would be best for that job. Other instructors may use one student every lab period as a leader, leading the work group solely, building upon their own leadership skills improving that individual's confidence in the group.

Besides building community within the group of first-year students, the project also aims to foster vertical community among different year groups of NAME students. Past boat build students help in the classroom and lab in subsequent years, teaching lectures and providing in-class and after-hours software support. It is not uncommon to have a sophomore or junior volunteer to teach a lecture on producing a Lines Plan or other technical detail in software.

This parallel and vertical community within the Naval Architecture and Marine Engineering major is critical to the success of the overall Coast Guard. The Coast Guard currently has a shortage of officers who are Naval Architects in both support and maintenance roles for our vessels and in regulating commercial vessels. The Coast Guard Academy supplies approximately 75% of the graduates who fill these roles. Building a community early in the curriculum is proven to improve student success, keeping underperforming and often under-prepared students within engineering. Unlike other institutions, this is vital for the Coast Guard Academy in its support role to sustain larger Coast Guard missions.

USCG Design and Construction Example from AY 2020-2021

The design the students selected in the 2020-2021 offering of the course was a 14.5-foot garvey. The garvey design originated as a shallow draft, easily built boat primarily used for working shallow bays and tidal estuaries. The advantages to this design, particularly suited for this course, include ease of construction, good stability, and exceptional load capacity. A construction rendering of the garvey designed by the Coast Guard Academy cadets is shown in Figure 5.

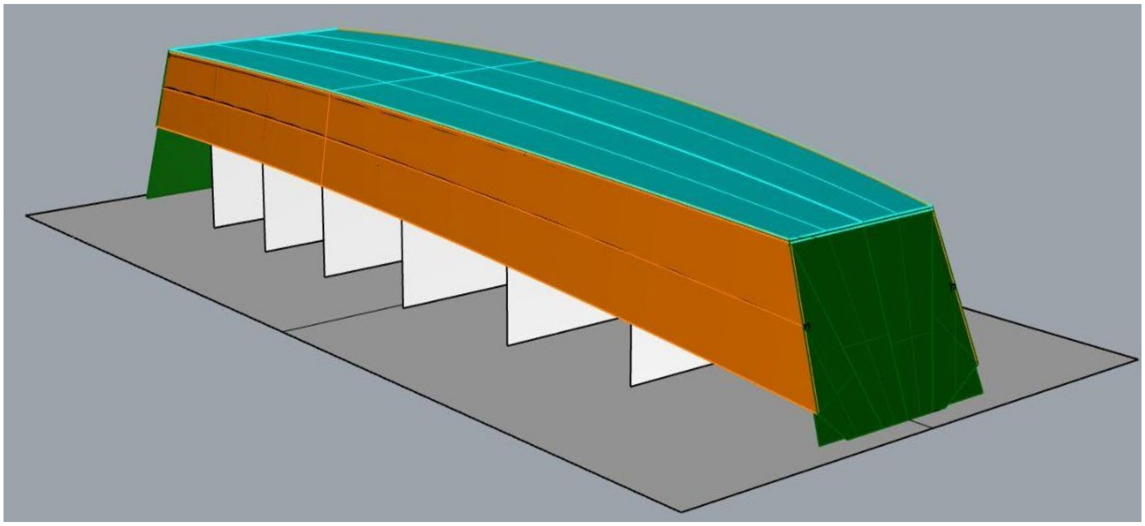
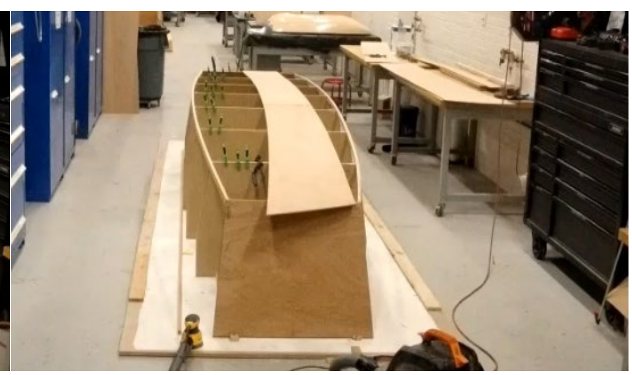


Figure 5. A construction rendering from Rhino7 of the Coast Guard Academy cadet-designed Garvey on the construction jig. This design was the product of the fall semester “design” portion of the course.

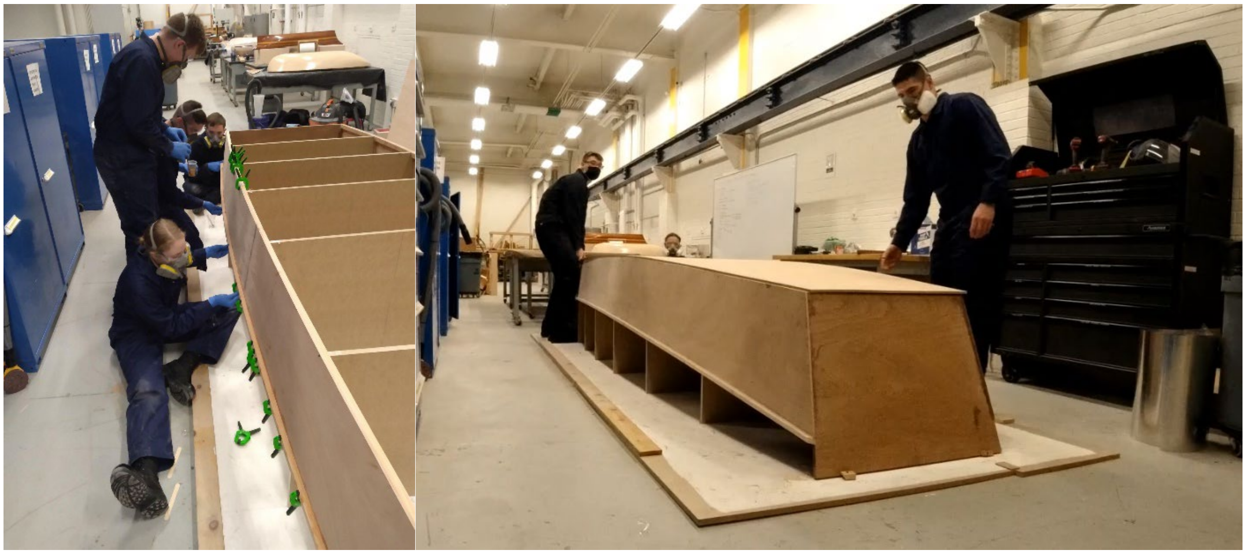
Over the winter break between semesters, the CNC router was used to cut the construction jigs, sides, and bottom of the boat. In this design, the bow and stern transoms were also cut.

During the spring semester, students began the “construction” phase of the course. After a safety brief and the fitting of respirators, the construction process began! First, the baseplate (made from inexpensive BC plywood) was assembled, and the construction grid was laid out, which includes marking the centerline and the longitudinal locations for each construction station. Next, the construction jig, stem and stern are erected on the baseplate. Chine logs are then run from stem to stern in notches cut in the building frames, providing strength and structure for both the sides and bottom planking.



Figures 6 and 7. Erecting the building jig on the baseplate (left) and the building jig, stem and stern with chine logs attached (right).

Since each side and bottom piece of the boat are each made of two separate pieces of plywood, they are scarfed together before they are affixed to the chine log. Once this is complete, the sides and bottom are attached to the chine log. Gunwales, shown in Figure 8, are attached to add additional stiffness to the sides. Figure 9 shows the construction team dry fitting the bottom of the boat to the chine log and sides.



Figures 8 and 9. Gluing on the gunwales (left) and dry fitting the bottom (right).

Once the sides and bottom are attached to the chine logs, a keel is added to provide additional bottom protection. Next, shown in Figure 10, the exterior of the boat is glassed with one layer of 6-ounce boat cloth.

Figure 10. Fiberglassing the bottom of the boat with one layer of 6-ounce boat cloth.

After glassing the exterior of the boat, it is flipped, and the interior is completed. This includes adding an inwale, seat risers, thwarts, quarter knees and any transverse stiffeners. Finishing touches, including hardware (oar locks), interior paint and varnish are shown in Figure 11.

Figure 11. Student designed and constructed garvey.

After construction is complete, the boat is transported to the waterfront where it is launched with the appropriate ceremony and fanfare. During the launch celebration, each student is asked to describe what they thought of the project and the major takeaways.

Figure 12. Launch day at the Coast Guard Academy waterfront.

Sea Trials

Sea trials, an operational test of the boat, is also conducted at the conclusion of the build phase. Ideally the students are involved in this process, so they learn that the process of building a boat does not end with launching. As the trials involve students getting underway in the vessel, safety requirements include the following:

1. All participants involved with launching or operating the vessels wear Type III Personal Floatation Devices (PFDs).

2. All boats are inspected for seaworthiness prior to launch by a Naval Architecture faculty member.
3. Prior to commencing any operation, the USCG Ashore General Assessment of Risk (GAR) form will be completed. All in attendance will participate in the GAR and the sea trial will only proceed if the GAR determines the evolution is Low Risk.

4. Any boat operators will stay within a short distance from shore, and all will be capable of communicating without any external technological assistance.

5. A safety boat will be underway during sea trials in the event a boat needs to be towed back to shore.

6. No vessel-to-vessel transfer of personnel shall occur unless someone is in distress.

7. Each vessel must contain a de-watering device.

8. Weather will be monitored. Sea trials will take place as long as wind is 10 knots or less sustained with gusts of 15 knots or less, and wave height at the dock is less than 6 inches.

To simulate USCG small craft regulations, the test plan specifically includes a swamping and flooding scenario and an operational test of the boat.

1. With no engine attached, each boat is flooded. This test takes place with the boat in shallow water with a water temperature greater than 60 degrees Fahrenheit. No one will be in the boat during the initial flood test. The attitude of the boat and the stability of the boat when swamped will be qualitatively assessed and documented. If the vessel appears stable, one person may sit in the boat.

2. A 5hp outboard engine will be attached to the stern of the boat. The boat was designed to operate with a 9.9hp engine, so the engines used for sea trials are well within the safe horsepower for each vessel.

    a. With one person on board, each vessel will be run with the engine at idle within 50 yards of the dock.
    b. Once the vessel performs and maneuvers safely at idle, the vessel will be run at steadily increasing speeds up to full power. The vessel will also be run in astern propulsion. Maneuverability, structure flexure, and position in the water will be monitored at all speeds.

3. With the engine mounted and the boat tied to the pier, a second person will enter the boat. The vessel's freeboard will be monitored. If there is sufficient freeboard, a third person will enter the boat. The freeboard will be monitored.

Figure 13. Sea trials: the swamping test. The goal was to see if the boat was stable with one-person while swamped. While it was, the reserve buoyancy was insufficient to pass USCG standards for commercial construction, a known design feature. The skiff built the previous year was designed to meet the standards and the students saw first-hand the difference built-in buoyancy provides.

Results

The primary goal of this project was to expose freshman students to Naval Architecture in the context of a project-based learning activity. The hope was to engender an interest in engineering, specifically Naval Architecture and Marine Engineering. To assess this, and other goals of this project, a survey was conducted with 23 students participating in the course over two years. Survey questions were presented using a Likert scale, ranging from Strongly Agree to Strongly Disagree. Text boxes were also used to capture student reactions to specific aspects of the course.

Survey statement: This course increased my desire to become a Naval Architecture and Marine Engineering Major

86% of the respondents either Agreed or Strongly agreed with this statement. One student strongly disagreed with this statement but clarified:

"I enjoyed the class and believe that it gave me a very good overview of Naval Architecture as a Major, but I believe that personally I did not enjoy the work. I simply just don't enjoy the process of designing in MATLAB or the math associated with it as much as I'd expected to. Initially, I really wanted to strongly fall in love with this major, but I just feel like the type of work is not necessarily something I can enjoy. I would still recommend the class, as it helped me to understand the major and I objectively think that it does give a great introduction to the major."

The matriculation numbers into the major also supports these results. Historically, the USCGA NAME major experiences a high level of attrition. For the Class of 2020 and 2021, the retention rate from first to second year was 50%. Since this course has been offered (3 years), the retention rate for the Class of 2024, 2025 and 2026 is 75%, showing a marked improvement. This is attributed to a better understanding of the major and the sense of community and “belongingness” the students feel in the course.

The community is further illustrated by student responses to the following:

Survey statement: I attended an evening help session and/or sought out out-of-class assistance from one of the upper-class mentors.

86% of the respondents indicated that they sought assistance from the upper-class mentors. This is important because…

One former student who took both semesters of the project as a freshman joined as a student instructor as a sophomore. When she joined, she remarked, *“I didn’t realize how much I learned until I started in my sophomore class. I could teach this [CAD] material.”*

In terms of the course itself, the class was highly recommended to other students (100%) and the amount of work associated with the course seems to be appropriate. 80% of the students responded spending 1-2 hours of out-of-class work on the course while the other 20% indicated spending 2-3 hours per week, a reasonable amount for a one-credit course.

The students found the 3-D print of their hull to be extremely enjoyable. Student comments also captured the general challenges associated with learning a new software program. Despite the growing pains with the software during their freshman year, our first cohort of design/build students are now seniors, and their capstone design work, especially in the CAD/rendering of the ship designs is the best we have ever experienced. In fact, all their general arrangements are rendered in 3-D - the first time we have seen this from students.

Challenges

Although the two programs have achieved success in motivating, recruiting, retaining, and educating students, there is not universal acceptance of the programs by either school’s faculty. As with any PBL activity, these programs have some drawbacks. These include cost, space, faculty resources and instructor skills.

Material and tool costs are not insignificant. The annual material expenditure at USCGA for the program is about $1000, with an initial investment cost of about $1500 for the tools and equipment. Material costs at USNA are similar per boat, amounting to about $2000 annually for two boats. Debate exists whether home-grade exterior plywood could replace the more expensive marine-grade plywood currently used. For cost and emissions reasons, quality latex paints replaced the marine industry standard oil-based paints.

Space is a premium in many schools and the amount required for the tools, building jig, and scarfing laydown could be used for other things. At both schools the boats are built in sections of their shop spaces staffed by lab technicians. A minimum area of roughly three times the length x beam of the boat being built is required. Additionally, boatbuilding activities generate noise, dust and fumes incompatible with classroom activities and require exhaust ventilation. A dedicated room or space in a shop is required.

An important consideration is the disposition of the vessel after sea trials. Options depend on both practical and legal restrictions and have included donations to charities, raffling, use in another school program and scrapping. Ideally, the project might be tied to a local need.

Faculty-to-student ratios in these projects are not as efficient as lecture-based education, with USCGA having a 1:15 ratio for the design phase and 1:6 ratio for the fabrication. The latter is due to both the need to manage and observe students handling sharp tools, and the desire to keep every student engaged in the construction process. At USNA the one-semester class averages a 1:12 ratio, which is made possible by having two hulls under construction, older students, and supervision from a staff member of the machine shop.

With increasing faculty loads in many schools, activities which require a faculty member to be dedicated to a small group need justification. Additionally, these programs require skills that most NAME faculty lack, and many faculty have neither the time nor desire to learn them as it takes time away from activities more related to promotion and tenure. For those with the desire to learn these skills, many communities have boatbuilding programs in addition to classes at organizations such as The WoodenBoat School [6]. Nonetheless, for USCGA and USNA the benefits of these programs currently outweigh the resource needs.

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