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The Crab Boat Engineering Design Challenge

The authors share their experiences from developing a rigorous Integrative STEM Education design challenge that promoted T&E education programs and strengthened community connections.

Introduction

"Crab cakes and football, that's what Maryland does!" (Abrams, Levy, Panay, & Dobkin, 2005). Although the Old Line State is notorious for harvesting delectable blue crabs, the movie Wedding Crashers failed to highlight something else Maryland does well – engineering design competitions. This article discusses how a multi-state engineering design challenge raised science, technology, engineering, and mathematics (STEM) awareness through collaborations with university, U.S. military, community, and industry partners. The design challenge presented in this article tasked students with designing a remote controlled scaled model of a crab boat. Their boat had to maneuver within a Chesapeake Bay course and collect as many miniature crab baskets as quickly as possible. An event highlight video and other resources are available on the competition website (UMES, 2016). The authors also provide recommendations to develop similar engineering design challenges.

Engineering Challenges in Maryland

For a number of years Maryland has developed and hosted low cost engineering design competitions. Many of these have been facilitated through the Baltimore Museum of Industry

(BMI) located on the Inner Harbor. There were a number of goals behind the engineering challenges such as creating an awareness of STEM across Maryland, providing a way for students to do more STEM activities beyond their technology and engineering (T&E) courses, and building relationships with local industry and military personnel. Over the years these engineering challenges have provided informal STEM learning opportunities for thousands of children. Currently BMI hosts elementary, middle, and high school level engineering design competitions situated in a variety of T&E contexts (e.g., design a theme park, build a cargo airplane) (BMI, 2016).

In the summer of 2015 teachers on the eastern shore of Maryland indicated interest in Maryland's engineering design competitions, but the long distance to Baltimore made it difficult to participate. Teachers expressed the need for a challenge unique from popular SeaPerch and robotics competitions, so the Eastern Shore Crab Boat Engineering Design Challenge was conceived. This challenge was modeled after the very successful and rigorous Cargo Ship Challenge facilitated at Baltimore's Inner Harbor for many years (BMI, 2016). Similarly, the University of Waikato in New Zealand annually hosts a speedboat engineering design competition for its first year engineering students (University of Waikato, 2015). The speedboat design challenge attracted approximately 40 teams in 2015! The authors believed a design challenge in the context of a crab boat would attract a similar level of interest since many Delaware, Maryland, and Virginia (Delmarva) students were aware of the significant influence that the crab industry has on the Chesapeake Bay region.

Developing the Crab Boat Engineering Challenge

Before advertising the challenge to the public, the authors developed a set of event guidelines and regulations. They used the Cargo Ship Guide (BMI, 2016) as the foundation for creating the Crab Boat Engineering Challenge Rules (UMES, 2016). The criteria for testing the boat remained relatively the same, however some of the boat design criteria (e.g., cabin as opposed deckhouse) had to be modified to accurately depict a crab boat. The authors met with crabbers in the Ocean City, Maryland area to discuss crab boat design criteria and help formulate the rules. This was a very informative experience and helped make the competition realistic. It was determined that the Chesapeake Deadrise was unique to the eastern shore of Maryland, therefore this was the specified design for the competition.

To ensure accuracy of the design criteria, a retired naval architect reviewed the guidelines and provided feedback regarding calculations for the scale of the ship designs, basket rate, metacentric height (stability), and roll period (time it takes the boat to tilt left a specified number of degrees, then right the same amount of degrees, and finally return to stable). Boats were required to be designed and built at a scale of one-inch equals one foot. The vessel could be no longer than 40 inches (including the rudder and propeller), the beam (width of the boat) could not exceed 12 inches, and the maximum draft (portion of the boat under water) could be no greater than two inches when the vessel was empty. The crab baskets, which consisted of metal bird suet cages loaded with rocks to weigh approximately 16 ounces, had to be carefully hand loaded by students at three distinct dock locations within the course. The full set of rules can be found on the event webpage (UMES, 2016).

From these rules a rubric was developed to help judges easily and accurately rate each team's performance. This rubric provided scores for four different aspects of the competition: 1) the written report, 2) boat design and construction, 3) student responses to the judges' questions at the competition, and 4) boat performance. The written report required students to present information regarding the influence that the Department of Natural Resources has on crabbing, environmental impacts of crabbing within the Chesapeake Bay, scientific and mathematic concepts applied in designing and testing their boat, a detailed budget of all materials used, and accurately scaled drawings or computer generated designs of their vessel. The full rubric can be accessed from UMES (2016).

Inherent in most engineering design competitions is the risk of injury. With this event there was the possibility of individuals slipping or drowning. To limit their liability the authors chose to implement risk transfer and risk control methods (Love, 2013). First they inquired about the insurance policies carried by the host site and their school. This is often the most expensive cost associated engineering design competitions. The authors worked with their school's attorney to develop safety guidelines and a liability waiver to be signed by all attendees prior to the event. One of the safety guidelines required students and coaches to wear a life jacket when near the dock areas.

In September an interest meeting was held at a local high school and streamed online to discuss the rules. At this meeting teachers were provided resources for teaching STEM concepts embedded within the design challenge and a list of suggested vendors. A hands-on teacher's workshop was offered in December to demonstrate methods for teaching corresponding STEM concepts and help teams construct various components of their boat. Additionally, a working vessel was launched at the university's pool so teachers had a better understanding of the procedures for the competition. Throughout the entire process the authors assisted teachers, and in some instances teams collaborated to share resources (e.g., visits with local ship builders). This type of collaboration was encouraged as long as the teams' boat designs were unique.

Constructing the Crab Boats

One advantage of this engineering design challenge as opposed to other STEM competitions is that it was relatively inexpensive for teams to participate. The authors were able to secure numerous sponsorships to avoid charging a registration fee. Kelvin Educational® donated the boat motors, so on average teams only spent between $200-$300 on materials, most of which were reusable (e.g., remote control, propeller, batteries, motor). Some teachers opted to do this design challenge as an after school club, while others were able to integrate it into their advanced T&E classes because it applied concepts that addressed an array of standards (Table 1).

Table 1

Standards Addressed Through the Crab Boat Engineering Design Challenge

Student Action(s)	Standard(s) Addressed
Research ways that crabbing and marine technology impacts the environment as well as marine life (e.g., crabs). Provide solutions for reducing these impacts.	STL 5:L NGSS: HS-ESS3-4 NGSS: HS-LS2-7 CCSS: ELA-Literacy.RST.11-12.7
Research historical information about marine technology and boat characteristics (e.g., hydrodynamics, draft) to inform the design of their own vessel.	STL 18:J
Research, design, build, and troubleshoot their boat to increase its efficiency.	STL 9:K STL 10:J STL 11:O STL 12:M NGSS: HS-ETS1-3
Apply integrated math and science concepts (e.g., Archimedes Principle, Ohm's Law) that are necessary for their boat to operate.	STL 3:J CCSS: MATH.HSG.GMD.A.3
Apply electronic technology concepts needed to power and remote control their boat.	STL 16:N
Utilize various manufacturing methods to construct their boat.	STL 19:M
Calculate the basket rate of their boat.	CCSS: MATH.HSA.REI.B.3
Communicate information to the class, instructor, and competition judges about how they applied engineering design and STEM concepts throughout the design challenge.	CCSS: ELA-Literacy.SL.11-12.4

Incorporating this design challenge in advanced T&E classes was found to be more advantageous for student participation. Teachers who advertised the design challenge as an after school club provided opportunities to all students in their school, however those who integrated it in their advanced T&E courses yielded greater participation, especially from female and minority students. This difference in participation could be the result of a number of factors such as students having other after school commitments.

Teams used many types of materials to construct their boat hulls. One used Divinycell foam that was donated from a local ship builder. The advantages of this special foam are that it is lightweight, buoyant, and can be glued with epoxies that would disintegrate other types of foams. Disadvantages of the Divinycell foam are that it is expensive and difficult to bend when trying to create curved boat hulls. Other teams steamed wood strips to achieve a curved structure and then water sealed it using fiberglass. Some considered using tin with rivets or spot welds for their hull. The weight of the tin and limited metal working equipment were cited as reasons for not using this design.

One team used a ribbed interior design for its lightweight yet robust structure. Each piece was designed using 3D software and then printed on paper as a stencil to cut the ribs out of wood. Alternatively, teams could have 3D printed the ribs after designing them with the software. Varghese (2010) described a variety of additional hull designs and fabrication methods used by students in the University of Waikato speedboat competition. One fabrication method they discussed was vacuum forming, which has been highlighted as an excellent process for integrating STEM concepts (Love & Valenza, 2011).

One team's ribbed boat structure being constructed.

After their hull was constructed, teams needed to determine how to operate the rudder system, which often proved to be the most challenging task. Some of the more successful boats used a twin rudder design with two paddles that provided more steering stability. This design had two paddles mounted at the center of the boat within a few inches of each other. When remote controlled they both moved the same direction via a servomotor. Some teams separated their rudders, placing one near each of the outer edges of their boat, which made steering more difficult. During construction and testing of prototypes teams were able to apply the engineering design process to make adjustments and develop more efficient designs.

Propellers were another critical component of the boats. These could be bought from remote controlled boat and aircraft companies (ZippKits, 2016) or schools had the option to 3D print a custom design. There are free 3D printable boat propeller designs readily available online (Yeggi, 2016). For higher-level STEM applications, students could create and test various propeller designs to determine what factors (e.g., pitch, rake [slope of the blade], diameter, number of blades, revolutions per minute) increase efficiency. This could further inform original student designs or the modification of existing 3D printable designs accessed online. Varghese (2010) described a number of characteristics that increase propeller efficiency and presented an analysis of multiple designs.

An additional challenge was ensuring a watertight seal where the stuffing tube (propeller shaft) exited the boat while still allowing the propeller to spin. Leaks in this area could ruin the electronic controls or cause the boat to fill up and sink. Teams were able to minimize leaks by creating a waterproof bulkhead and using a flexible propeller shaft that spun inside of a greased lithium stuffing tube. It was critical for teams to test their boats in a local pool or pond prior to the competition to check for leaks and maximum efficiency.

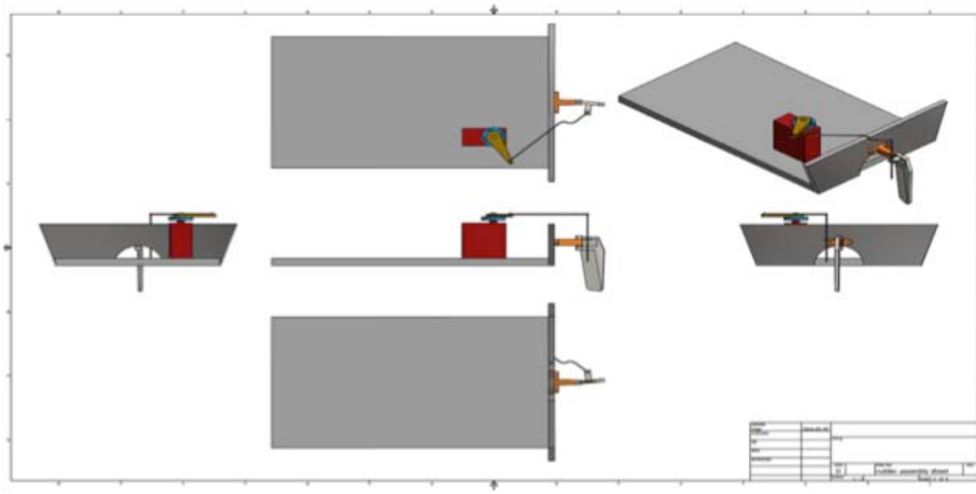
The electronic components to remote control the boat comprised of a pair of six-volt lithium or NiCd batteries wired in parallel to a speed controller or a microswitch, a servomotor for each propeller, a transmitter, and a receiver unit. Students had to design an electronic circuit that could provide enough power to propel and steer their boat via remote control. The propeller speed decreased from the water resistance, however students found that connecting multiple batteries in parallel would increase the speed of the propeller. The trade off of this was the weight of the additional batteries. To reverse the polarity of the current to the motor for steering purposes a microswitch was used. Ensuring that these electronic components were not exposed to water was critical. Some teams built them into small plastic containers directly on the boat deck while others created a removable deck under which the electronic components were housed.

Integrative STEM Education Applications

This engineering design challenge was embedded with numerous opportunities to naturally integrate STEM content and practices. From a science lens this activity prompted students to investigate topics such as buoyancy, displacement, stability, and environmental effects of technology. Two excellent videos demonstrating Archimedes' principle were provided on the event website (UMES, 2016). Teachers were encouraged to use these resources when helping students calculate the volume of their boat hulls, which would be difficult to calculate with a tape measurer. Students also had to investigate how their boat hull design would impact its stability. This was essential to ensure the boat did not tip when loaded with crab baskets and making sharp turns.

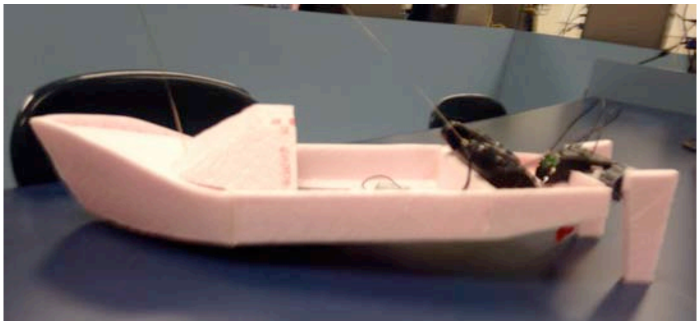
To test science concepts and inform their designs, there were a number of mathematical concepts that students needed to apply. As mentioned previously, determining the displacement was important, which influenced modifications to their boat hull and decreased the amount of drag. Varghese (2010, p. 70) provides an example of how to calculate draft to increase boat speed and efficiency. Also during the design phase students were expected to measure and calculate the angles of the boat hull and propeller blades. Once students understood these basic concepts they had to apply them to design and construct their vessel to scale. Within their written report they had to calculate a total cost for all materials used. Lastly, students had to determine their ship's basket rate, which was one of the major judging criteria used to identify a winner.

- Basket Rate = [(Fixed Costs) + (Operating Costs)]/(Baskets Carried x Distance Traveled)
    - Fixed Costs = length x width x draft when loaded x $10
    - Operating Costs = time to complete the course in seconds x $10 x number of motors.
    - Baskets Carried = total number of baskets carried in boat.



One team's design using Inventor.

Technological and engineering practices served as the vehicle for applying the aforementioned science and math concepts. Throughout this entire challenge students were immersed in the engineering design process. The scientific investigations and mathematical calculations informed modifications to their designs. Students had to utilize 3D software (e.g., AutoCAD, Inventor, SolidWorks, or Google SketchUp) to develop designs for various components of their boat. During the design process some of the teams built miniature prototypes out of styrofoam to examine hydrodynamics, Archimedes principle, draft, and stability. This allowed students to test out their designs and easily make adjustments without wasting costly materials. They then had to take those refined designs and turn them into a tangible product using various manufacturing processes. Some teams were able to utilize newer manufacturing technologies such as 3D printing, and demonstrate how it could be applied to produce parts (e.g., propellers, structural components) with specific functionality characteristics. After their boat was constructed students had to research what materials or products could help reduce the hydrodynamic friction of their boat hull.



An example of a prototype tested by teams before constructing their larger scaled model.

Students load crab baskets into their boat during the competition.

School and Community Collaboration

This event relied upon assistance from numerous sponsors and community members, which also helped foster relationships with the UMES technology and engineering education program. As previously mentioned Kelvin Educational® donated the motors. The U.S. Army funded the lunches and event shirts for all participating students and coaches. Army personnel helped judge the event and spoke with students about the various STEM career opportunities in the military. The lunches were prepared by a local career and technical high school's culinary arts program.

In addition to this assistance, an easily accessible venue with waterfront access was needed. The University of Waikato holds their speedboat engineering challenge at a lake in the center of their campus. This attracts visitors while also raising university-wide awareness of their engineering program. Finding the proper host site is a key component of any engineering design competition. The authors collaborated with the University of Maryland Center for Environmental

Science (UMCES) to host this event. This also provided an opportunity for UMCES faculty to lead a campus tour while educating participants on their renowned oyster farming research.

K-12 T&E education programs and UMES T&E teacher education students also benefited greatly from the event. UMES T&E education students and a local high school teacher with expertise in graphic design collaborated to create the logo and signs for the event. This teacher also assisted UMES students with manufacturing the award plaques using a CNC router. The plaques were intentionally designed to include the UMES T&E education program logo and serve as a free recruitment tool displayed in award winning schools. UMES T&E education students also helped judge and facilitate the event so that they would be better prepared for helping their future students participate in engineering design challenges. Lastly, these undergraduate students learned about communication technologies while making the event highlight video (UMES, 2016).

In addition to the event website and award plaques, there were a number of other sources that helped advertise the event and T&E education programs. Pre and post-event articles were published in UMES's campus newsletter and in *PropTalk*, a Chesapeake Bay boating magazine distributed throughout Delmarva. Newspapers from the home areas of the award winning teams (Annapolis and Ocean City) featured articles discussing the results of the event. One of the most notable advertisement opportunities was broadcast by the local television station which interviewed the authors on its morning talk show. All of these media sources publicized the benefits of K-12 T&E education programs and the teacher preparation program at UMES. Free and innovative strategies like these are needed to promote the work of T&E education programs (Caccavale, 2016).

One of the award plaques created by the UMES T&E students.

Lessons Learned from the Challenge

Teams found that two batteries connected in parallel to one motor greatly increased the propeller speed. Also, it was known from prior Cargo Ship Challenges that a cordless drill motor would provide more power, however they are much more expensive. To make the competition as fair as possible and encourage students to focus on the design elements of their boat, all teams were required to use Kelvin® number 850887 project motors. Pouring rain and strong winds during the competition created choppy water conditions that affected the maneuverability of the vessels due to their lightweight. As more crab baskets placed in the boat their navigation greatly improved. Teams made some innovative last minute adjustments to the rudder and weight of their vessel to counter these weather conditions.

Students make last minute modifications to their boat before the challenge.

Despite students and teachers finding this engineering challenge very engaging and rewarding, there were a limited number of female and minority students who participated. Past engineering design challenges hosted at another location (the Baltimore Museum of Industry) attracted more diverse groups of participants. The authors created the engineering design challenge rules and judging criteria to encourage all students to participate. What methods and how much effort teachers put into recruiting female and minority students are unknown. In future competitions the authors plan to invite female and minority naval architects and marine engineers to speak with students about the career opportunities and authentic applications directly related to this design challenge. Teachers should use the inspiring naval architecture video of Emily White (Fisheries and Marine Institute, 2015) to encourage more females to participate. The authors also hope to recruit more schools with female and minority instructors who will participate in the event. These female and minority professionals will serve as role models and should help increase diversity in future engineering challenges.

Developing Similar Design Challenges

Those who reside in a landlocked state can still facilitate a challenge similar to the one presented in this article. It can be hosted at a nearby pond or a school pool where it is deep enough for the boats to maneuver. All potential safety hazards must be considered when hosting an engineering design competition. It is recommended that educators work with their school's attorneys (called solicitors in some states) to limit their liability through risk transfer and risk control strategies (Love, 2013). The rules presented on the event (UMES, 2016) and BMI (BMI, 2016) websites serve as templates to develop an engineering design challenge in a context that interests students. Similar to the process employed by the authors in designing this event, rules can be modified from other engineering design challenges to create a unique competition.

Conclusions

This engineering design competition started out as a small event but attracted interest from a number of schools and informal STEM programs. Numerous teachers indicated that they read about the results in their local newspaper or *PropTalk* magazine and would like to enter a team in 2017. The broader impacts of this event demonstrated the benefits that engineering design challenges have for promoting T&E education programs, and highlighted how these competitions can be utilized to engage students in applying STEM concepts to design a working technological system. This challenge serves as one exemplar of Integrative STEM Education (Wells & Ernst, 2012/2015) through its ability to naturally address many of the Standards for Technological Literacy, as well as some of the Next Generation Science Standards, and Common Core State Standards in the context of an authentic engineering design solution. Educators are encouraged to use the Crab Boat Engineering Design Challenge as a foundation for creating their own engineering design competitions.

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