Educational Practices to Integrate System Engineering Into Engineering Education— A Capstone Marketplace Story

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Capstone Marketplace Universities 2022-2023

George Mason University*

Michigan Technical University*

Stevens Institute of Technology

University of Dayton*

University of Massachusetts Boston*

US Naval Academy*

University of South Alabama*

University of Texas Austin*

(* schools outside SERC's consortium)

2020-2023 Capstones at UT Austin

Self Intubating Airway Device—Multiyear Project

Develop a Self-intubating snake, a multidirectional device that can be loaded with an endo-tracheal (ET) tube and advanced into the mouth of a warrior in need of an airway.

This device can reduce operators' exposure to hostile fire during critical medical interventions.

Figure 1. Overview of Proposed Solution

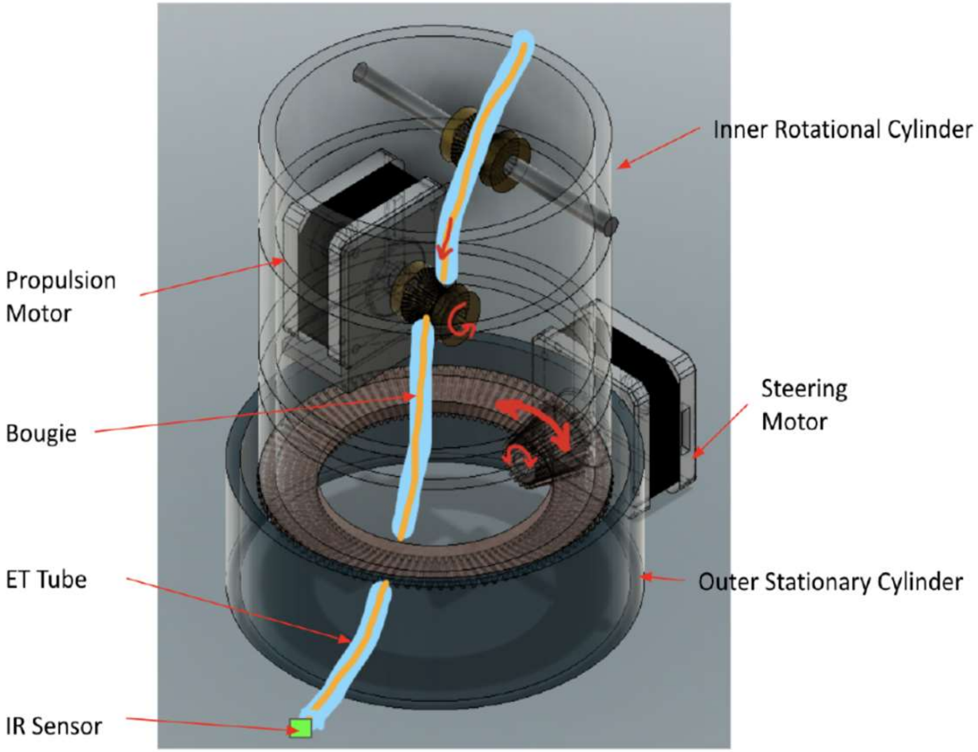


Figure 1. This figure demonstrates how the subsystems will work together. Note the inner and outer cylinders. The outer cylinder will be stationary and will hold the motor that controls steering. The inner cylinder will rotate as a unit, including the propulsion motor, the roller, and the ET tube and bougie.

Team 7: Body Mounted Sensors to Monitor the Physiological Health of Trainees During Training Scenarios

Team Members: Ben Agnello, Kelsey Harvath, Elizabeth Kaechele, Nick Niemi, Cody Tuftee
Advisors: Dr. Smitha Rao and Dr. Jingfeng Jiang
Department of Biomedical Engineering, Michigan Technological University, Houghton, MI

Introduction

The harsh environment of military training exercises poses a great risk to cadets. In order to combat this risk, a system of body mounted sensors is designed to continuously monitor the health of cadets remotely, so they may be removed from the training before reaching critical condition. This will increase the safety and effectiveness of training missions.

Objective

Use body mounted sensors during exercise to determine the physiological condition based upon hypoxemia, hypo/hypertension, arrhythmias, heat stroke, and dehydration.

Materials and Methods

Sensor Selection

The selection of sensors was based around validated efficacy, compatibility, and obtainability. Using a Pugh chart we identified 4 wearable sensors to obtain the physiological parameters of interest (Table 1):

	CORE	Polar H10	hDrop	Garmin Vivoactive 4
Accuracy - Compared to Medical Grade Equivalent	Accurate to 0.21 ℃ [1]	Error ± 1.1-1.4% [2]	At least 70% accurate (no data available)	Pulse oximetry has error of 0.7%-0.8% [3]
What it Measures?	Core Body Temperature	Heart Rate	Hydration Level	Pulse Oximetry
What will be deduced?	Heat Stroke	Arrhythmia and Hypo- / Hypertension	Dehydration	Hypoxemia

The following devices were used for connectivity, analysis, and operability of the system in a remote setting:

- **Raspberry Pi Microcontroller:** Connected to sensors to retrieve, analyze, and send data.
- **USB ANT+ Stick:** Used with the microcontroller to allow for multiple sensors to connect to the microcontroller.
- **External Battery Pack:** Provide power to the raspberry pi.

Materials and Methods (continued)

Connectivity and Analysis of Data

- Sensors connected by ANT+ communication to the microcontroller.
- Unprocessed data is analyzed by the microcontroller.
- Microcontroller displays real time data in an easy to understand display.
  - HRV calculated based on heart rate. Value below 0.5 ms increases risk of arrhythmia [4].
  - Core Body Temperature: Values above 100°F signify an increased risk of heat stroke [1].
- Microcontroller communicates with remote interface via SSH communication protocol.
  - Satellite hotspot is used for remote communication.

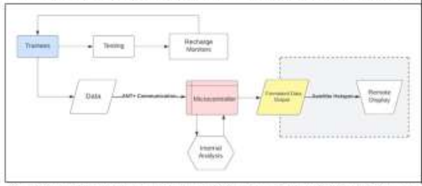


Figure 2: The Operational Flow Diagram depicts the use of the sensor apparatus to measure symptoms of exhaustion.

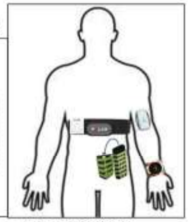


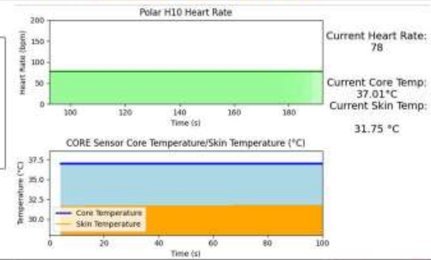
Figure 3: Sensor location diagram.

Validation of hDrop Sensor:

- Submitted a Non-Exempt IRB protocol and gained approval to test 22 test subjects under light exercise in a pilot study.
  - Body weight was used as an experimental baseline for sweat loss to be compared against hDrop sweat loss measurements [5].
  - Body weight measurements were recorded before and after exercise. Treadmill test consisted of four 15 minute walking sessions with progressive speeds broken up by 10 minutes of rest [5].
  - Treadmill speed was limited by 74% of participant's maximum heart rate for safety [5].

Results and Discussion

- Live updates:
  - Heart rate
  - Core temperature
  - Skin temperature



Results and Discussion Cont.

The results from the hDrop validation study revealed a low correlation between the hDrop sweat loss value and the actual weight of water lost.

Figure 4: Correlation plot comparing the measured weight loss by the validated scale and the estimated sweat loss from hDrop. Inconsistency in hDrop measurements is clear in the poor clustering and R value of the line of best fit.

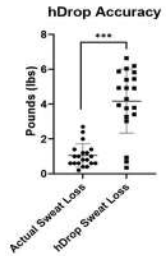


Figure 5: Sweat loss measured in pounds (lb) compared between the hDrop value and actual sweat lost measured by a scale.

Our testing data showed a p-value of less than 0.001 which concludes that there is a statistically significant difference between our results.

Further testing by our team using multiple hDrop sensors in different environments supported that the hDrop can produce consistent estimated sweat loss results but accuracy was still inconsistent with actual measurements.

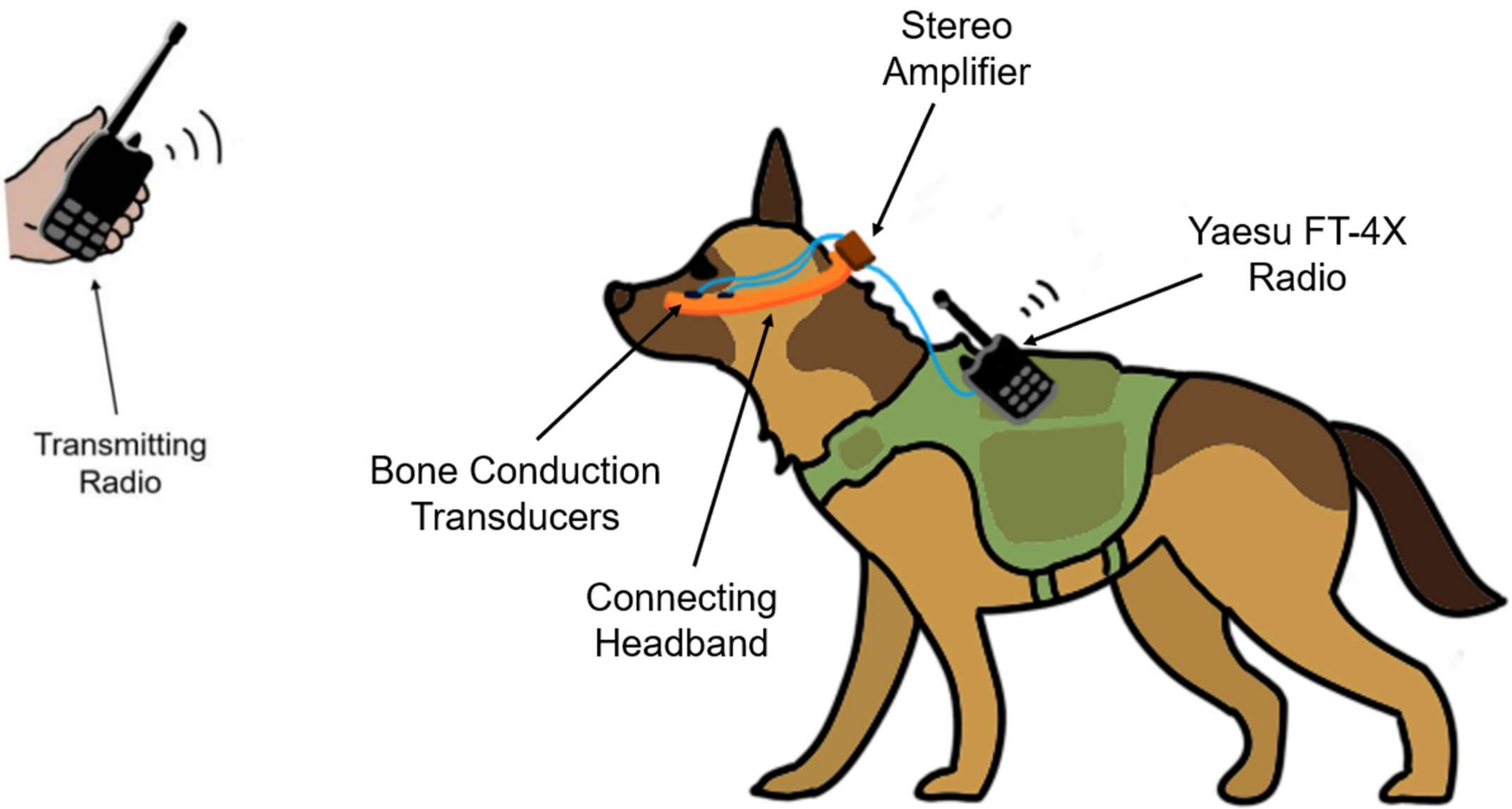
Conclusion and Future Work

- Accuracy testing of the hDrop sensor showed large variations in data that indicate that the sensor may not be very accurate, especially in extreme conditions.
- Need for a sensor that can accurately monitor SPO_2 and blood pressure during exercise.
- Integrate Satellite Hotspot from Army.
- Identify one sensor that can monitor all physiological parameters.
  - Masimo Freedom smartwatch is available for pre-order and measures hydration, SPO_2, heart rate, heart rate variability, and respiratory rate [6].

References

[3] Garmin and G. L. or its subsidiaries, "Garmin vivoactive® 4 | Smartwatch with GPS | Fitness," Garmin. https://www.garmin.com/en-US/p/643383 (accessed Nov. 14, 2022).
[2] "Polar White Papers | Polar USA." https://www.polar.com/us-en/science/whitepapers (accessed Dec. 05, 2022).
[1] "CORE Technology," CORE. https://corebodytemp.com/pages/core-technology (accessed Apr. 11, 2023).
[4] R. E. Kleiger, P. K. Stein, and J. T. Bigger, "Heart rate variability: measurement and clinical utility," Ann Noninvasive Electrocardiol, vol. 10, no. 1, pp. 88–101, Jan. 2005, doi: 10.1111/j.1542-474X.2005.10101.x.
[5] D. Rodin, Y. Shapiro, A. Pinhasov, A. Kreinin, and M. Kirby, "An accurate wearable hydration sensor: Real-world evaluation of practical use," PLoS One, vol. 17, no. 8, p. e0272646, 2022, doi: 10.1371/journal.pone.0272646.
[6] Masimo Freedom, 2022. [Online]. Available: https://freedom.masimoconsumer.com/en-us/. [Accessed: 13-Apr-2023].

Covert Dog Communicator



Slide 5

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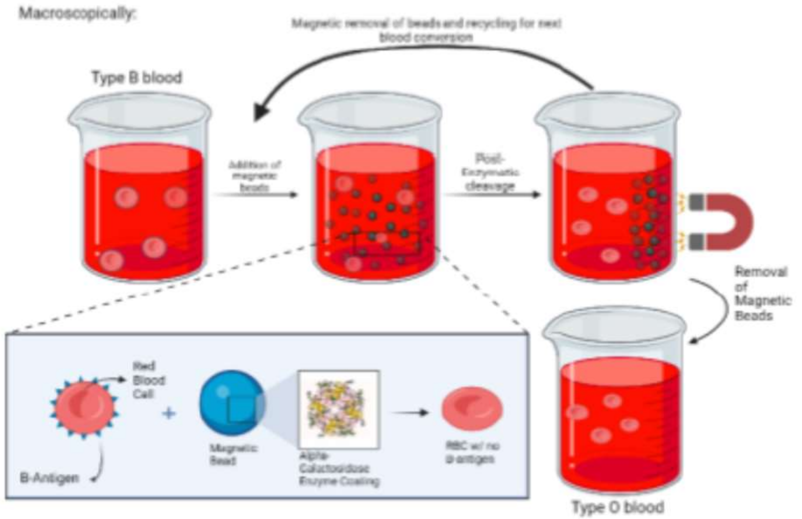
Victor Yi; 2023-04-20

"Any Donor" Blood Transfusions



Statement of Need or Problem

- Ability to deploy any blood type to any individual under combat conditions, preferably utilizing a mobile delivery method
- This is important to the client because combat injuries concerning blood loss take time to find the soldiers blood type which then needs to be matched and replaced. A solution would help to alleviate shortage of blood and time for identification,
- Size - small enough for soldier to carry (max size: 30x65x32 inches), Manageable Cost, Able to treat a majority of populus (if not all), Feasibility by Senior Design Group

Project Objective and Deliverables

- To "move the ball closer," primarily research focused with emphasis on feasibility and delivery of an end product
- Once size and feasibility are discussed, identify sources to retrieve blood, necessary proteins/enzyme, and materials for vector (i.e auto-injector)
- Design Proposal - Dec 9, Prototype - Feb, Design Review - Mar, Final Presentation/Report - May
- November – Create, January → May – Release, Morph, Create, Release, Morph, Create, Release, Morph, Create, Release

University: University of Texas at Austin	**Govt Client:** US Army Special Operations Command
Team Lead: Gwyneth Obediente	**SME:** SGM Jared R.Voller, MSG Scott Moore
Faculty Advisor: Professor Stephanie Seidlits, PhD	**Alternates:** MAJ Charles Moore, CPT Gabriel Valdez, MSG Patricio Vasquez, SFC Jered Martin, SFC Paul Broer, SSG Geoffrey Landers, MSG Kyle Johnson
Capstone Coordinator (at university): Brittain Sobey, Ed.M.	
Budget: $5000	

Research Topic Numeric Designator: 2022 USASOC 07

MTU-- Drone Video to Cell Tower

Problem Statement

Develop a transmitter to be carried on a small drone that can exfiltrate drone video to a commercial cell phone network directly through a cell phone tower.

Identifying Friendly Forces

Friendly Forces

Department of Defense

Luke Artero, Brandon Avila, Hashim Cheema,
Jack Knobloch, Angelina Lee, Nathan Lovgren

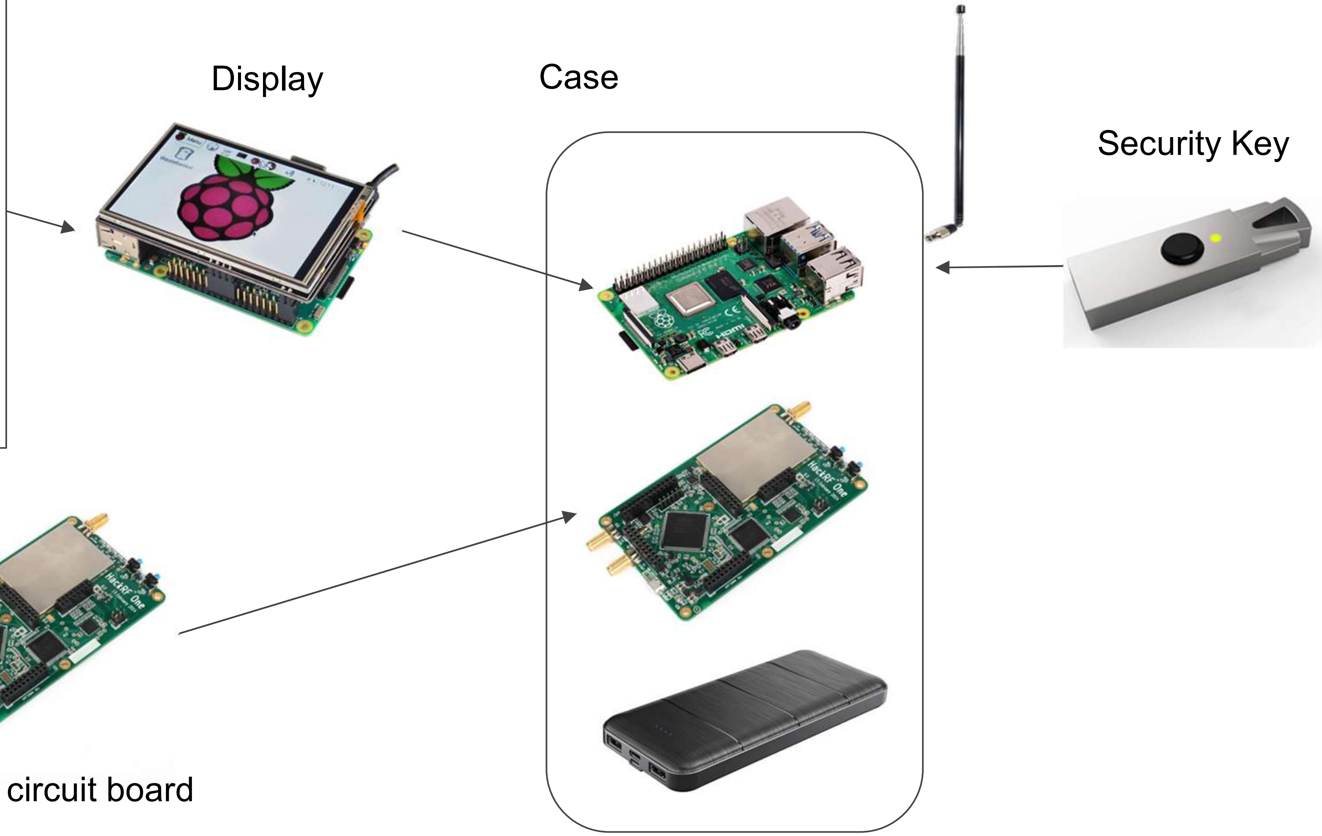
George Mason University

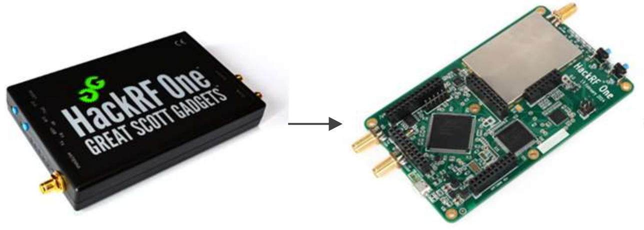
Design - Visual

GUI

Distance Readout Table:

Unit	Datetime	Distance
A	4/15/23 16:15	100m
B	4/15/23 11:23	200m





HackRF is dismantled into case and circuit board

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Capstone Benefits for Govt Customers

- Energizes “innovation” in government organizations
- Harvests “intellectual capital”, often from low level personnel
  - Ideas and solutions can be unconventional and “Out of the Box”
- Increases “bandwidth” of traditional govt R&D efforts
- Low cost. Average project ceiling is $5K for 2 Semesters’ work
- Builds technical data on key subjects
- Can augment other development efforts
- Cultivates unit “MacGyvers” who understand innovation, and who want to work on important projects

Generates student interest in future government employment

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Our Capstone Characteristics

- Real Customers—end users who are Subject Matter Experts
- We start with loose objectives—the “what”, avoid the “how”
- Multi disciplinary team effort
- Team management—time, skills, money, facilities, etc. Team experiences mimic venture capital industry
- Smattering of System Engineering principles—reduce the “box” checking
- Sequential reviews—”wire brushing” of cost, schedule, tech
- Incremental maturation of projects
- Focus on delivery of tangible prototypes. Students must “build something”-- and demonstrate it

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Observations on Student Performances

- Connecting with real customers and their needs is very important
  - Many schools make up hypothetical problems and users
  - Students like the direct contact with experts
- Students want to "dive in" early and start making things
  - Often confuse enthusiasm with capability
  - Don't want to spend time justifying project choices—students want to start cutting, gluing, and coding
- Student energies for conceptualization are very good
- Hand sketching and visual representation skills low
- Typical students have low mechanical abilities and limited technical knowledge of "how stuff works". *Maybe a generational issue?*
- **Students have difficulty in developing parameters and projected performances of what they are designing--when approaches are "unknown"**

Observations on Universities & Faculty

- Institutions and professors often receive grant money with few restrictions. Capstones are commercial contracts with specific performances and deliverables
- Small amounts of Capstone money can be unattractive for the paperwork involved
- Faculty in tenured positions have many other things to do
- Faculty are generally not good at—
  - Working on multi-disciplinary projects outside their specialties
  - Developing "use contexts" for government and military operators
  - Familiarity with contracts & agreements, funding regulations, statements of work, descriptions of deliverables, scheduling, project reviews etc.

Is Engineering an “Art”?

- The “nuts and bolts” history of invention and technical development are superficial details in core engineering courses
- Little focus on “how” developers of the many important tools in engineering were inspired to create them
- Visualization is not a well-developed skill in US engineering education—although this is emphasized in architecture and pure “design” courses

Changes Needed in Technical Education

- Experiential learning is key. "Making" is very important
- Multidisciplinary. Include "whole of project" approaches to getting things done. Engineering as an "integrated" enterprise
- Powerful computer tools have to be meshed with key principles and fundamental skills
- Better understanding of fundamental analytic concepts and engineering "primitives" and what we can teach about <u>how</u> ideas were created
- Need more engineers who can visualize, imagine, analyze, "make", integrate, and evaluate. Engineers with "X-Ray" vision
- **Engineering syllabuses for undergraduates that are "system engineered"**

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How to Learn More

- Capstone Marketplace website:

www.capstonemarketplace.org

- Email us:

capstonemarketplace@stevens.edu

wshephe1@stevens.edu

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Backup Slides

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Ingredients for Innovation?

- Inspiration
- Historical knowledge
- Observation
- Visualization & Imagination
- Artistic skills, teaching the eye to “see”
- Association with diverse concepts and applications
- Ability to translate approaches and solutions from other sources
- Analytic skills
- Hardware and software fabrication skills
- Persistence “doing”, learning from failing
- Competent Integration (SE)
- Critical thinking and honest review
- Questioning what works, what doesn’t, and why

Other Issues

- Institutions often reluctant to do multi disciplinary projects
  - Who is in charge? How is it supported? How is it graded?
- Student teams tasked with other academic requirements, reports, deliverables, and constraints in their design projects. Integrating these with our Capstones can be confusing and adds stress in students' educational environments
- SE education at Undergraduate levels focused on "process". Development of analytical skills from other math and applied engineering courses may not be connected to design projects

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About SERC—the System Engineering Research Center

- The System Engineering Research Center (SERC) is a 22 U.S. university consortium led by Stevens Institute, doing U.S. government-funded research in Systems Engineering (SE).
- SERC sponsors a wide range of faculty and graduate student research
- Part of SERC's resources support the "Capstone Marketplace", a program designed to stimulate "system engineering" thinking in undergraduate engineering teams
- **The Capstone Marketplace leverages existing "Senior Design Projects" at universities--the Marketplace offers educational enhancements for these classes**
- Capstone Marketplace has completed over 150 projects for Department of Defense customers in the past 10 years.

MD2

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What is Different about SERC's Capstones?

Typical University Capstones	Capstone Marketplace
• Most are generated internally at universities, faculty often select topics and pose project problems	• Connects students with military operators, their ideas, and problems—real customers with real problems. • Students can propose their own Capstone topics
• Two semester design projects	• Two semester projects are preferred
• Can include Industry sponsorship and participation	• Industry participation is encouraged • Introduction to common business tools and practices— Reviews include Cost, Schedule, Deliverables, Technical Performance
• Some Capstones are research only	• Tangible deliverables are required—prototype software and/or hardware

Slide 21

MD2 Michael DeLorme; 2023-04-09

2020-2021 Capstone at University of Alabama-Huntsville

Interior Storage for a Submersible

Objective: Design and build a prototype of an internal storage system to accommodate necessary items within a submersible vehicle.

Lack of a specific storage system makes access to essential equipment cumbersome and space is not maximized

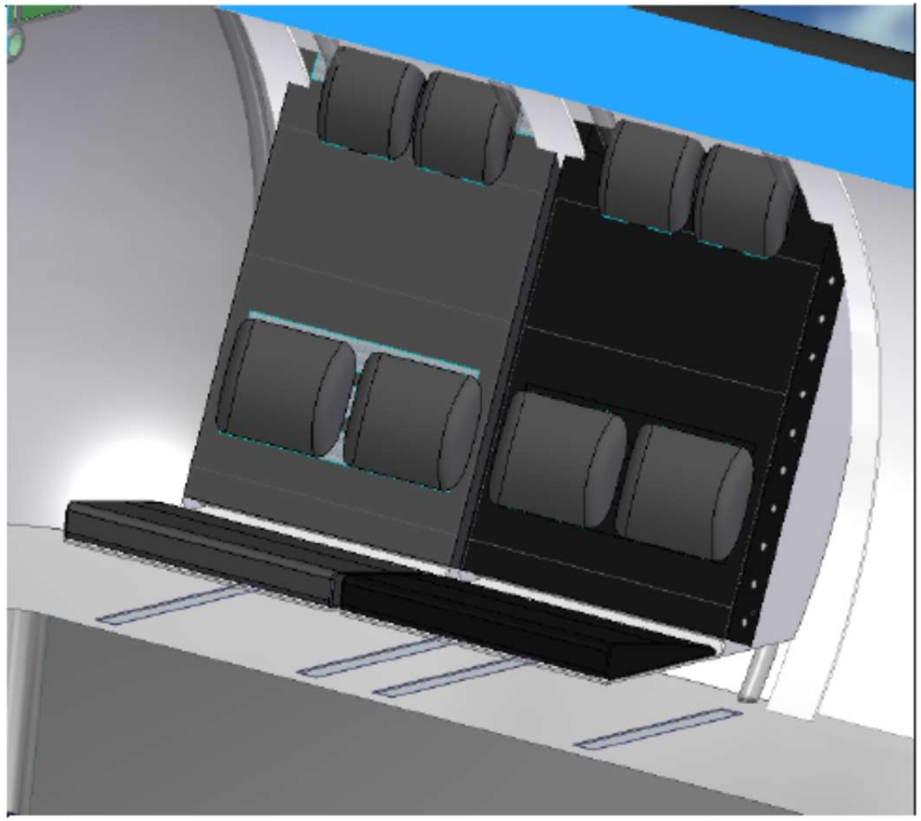

Figure 7.1.2.5: Curvature Storage in Operational Environment. The gray slits are velcro strips attached to the ballast tank (Credit: T. Ruffalo)