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Dissolving Interdisciplinary Barriers in STEM Curriculum Through Unconventional Hydrofoil Boat Educational Lab at the College Undergraduate Level

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Abstract

As educational programs for engineering continue to grow in popularity among schools and universities, the corresponding curriculum that gets delivered to students has become increasingly compartmentalized to each specific discipline. This shift has occurred naturally as educational departments desire to highlight direct applicability of their education to their department label. However, much of the knowledge and many of the skills obtained in individual fields of science, technology, engineering, and mathematics (STEM) can be applied to various other STEM fields. Yet, preconceived barriers between each discipline often create mental gaps in the minds of students that render their abilities to think of their education's applicability outside of the department they are enrolled in. Texas A&M University's aerospace engineering department has recognized this issue and created the NUA^{2}NCED Laboratory to help bridge these gaps in students' minds and increase the scope of their education beyond standard aerospace applications.

To create novel aerospace educational activities that accomplish this goal, the NUA^{2}NCED Laboratory has developed an interactive aerodynamics lab using a customly-designed RC hydrofoil boat. This educational lab blends the aerospace engineering principles of vehicle dynamics with an aquatic domain. Students are presented with a lab manual outlining the background, objectives, problem scenario, and procedures of the lab as well as accompanying pre- and post-surveys that capture the students' outlooks on various STEM discipline applicability. Students complete the pre-survey, perform the lab, and then complete the post survey. The shift in the pre- and post-survey data captures the effectiveness of the lab's ability to dissolve the interdisciplinary barriers between various STEM fields. The authors hypothesize that students who conduct this unconventional aerospace lab will experience an expansion in their outlook on various STEM fields' applicability.

Keywords: Unconventional Applications, STEM Education, Dissolving Boundaries, Hydrofoil Lab

Introduction

Studies have shown that boundary crossing competence between disciplines is a crucial piece in the puzzle of obtaining an education in the STEM domain. Specifically, these same studies reveal that engineering students especially face the cruciality of crossing discipline boundaries in order to "address global, sustainability challenges" such as "providing access to clean water, increasing the use of solar energy, and managing nutrients cycles" [1]. Because these complex challenges cannot be overcome within one domain, educational institutions are recognizing the importance of developing interdisciplinary skills within the minds of students. The authors believe that introducing interactive learning activities that tie various domains to the aerospace engineering discipline spurs both greater understanding of aerospace concepts and expands students' outlooks on the applicability of an education in aerospace engineering. Thus, the construction of unconventional aerospace engineering educational labs gives the opportunity for instructors to incorporate interdisciplinary skills within their curriculum.

Research has also shown that as the fourth industrial revolution birthed the "breaking down the silos [of separate engineering disciplines]," two new focuses on the interdisciplinarity in engineering arose. Specifically, the engineering realm saw 1.) the "bolstering of existing fields" with the influx of new technology and 2.) the "evolution of hybrid fields" that seemed to merge several existing fields [2]. As interdisciplinarity has seen significant increase with the continual development of technology, educators are tasked with teaching students the nuances of these hybrid fields in ways that enable the students to bridge the gaps between various fields' applicabilities. Given this, the authors hypothesize that the development of unconventional aerospace activities will also augment the students' ability to apply multiple disciplinary skills when solving a complex problem.

Thus, one of the main goals of the hydrofoil boat educational lab is for students to break down the barriers between the previously-described engineering disciplines. By relating aerodynamics to an aquatic vehicle, students are more capable of recognizing the overlap between the various STEM fields. The interactive activity's demand for in-depth problem solving skills that span over multiple STEM fields addresses both the previously-mentioned growing interdisciplinarity of STEM fields and the importance of relaying the knowledge of these new hybrid fields to the students that will be impacting industry and research in the near future.

Background on Hydrofoil Boat Educational Lab

The hydrofoil boat educational lab was developed by the authors over the course of a year and a half. As with any aquatic vehicle, performance is limited by the frictional drag experienced along the hull as the vehicle travels through the water. Hydrofoils serve as an "underwater wing" attached to the hull of a boat that produces lift to raise the hull out of the water at certain velocities. This decreases hull/water interaction and allows more efficient performance. However, at high velocities, the boat can be over-lifted, and stability is compromised due to unbalanced moments. Given the similarity in the dynamics between these hydrofoil boats and standard aircrafts, the authors chose to design and construct a hydrofoil boat and corresponding educational lab that would allow students to dissolve preconceived barriers between aerospace and other STEM disciplines.

The development of the hydrofoil boat activity itself was divided into five stages [3]. The first stage consisted of the design phase. In this phase, the authors analyzed the velocity (v), surface area (S), and coefficient of lift (C_L) in the aerodynamic lift equation outlined in ***Equation 1*** below.

$$L = \frac{1}{2} \times \rho \times v^2 \times S \times C_L \qquad \textbf{\textit{Equation 1}}$$

This equation was considered with water as the medium through which the wing would be traveling through. After conducting research on hydrofoil design [4], the authors chose a forward surface-piercing hydrofoil paired with an aft fully-submerged hydrofoil with half of the lateral planar projected surface area as the forward foil. Studies yielded an optimal 5° incident angle of attack for the chosen NACA 4412 airfoil [5]. These design decisions can be seen in the forward and aft CAD sections illustrated in **Figure. 1** below.

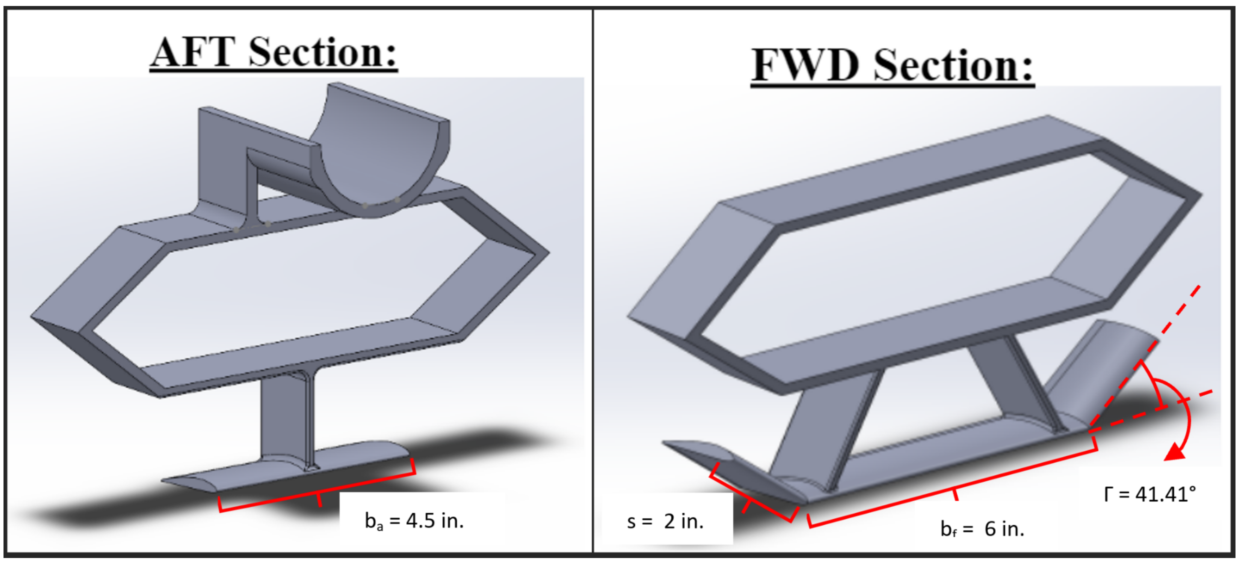


Figure 1. Forward and Aft Hydrofoil Boat Cross Sections [3]

For the propulsion system of the vehicle, the authors chose an EDF 64mm 11 blades ducted fan with 3500KV brushless motor mounted above the aft section. Directional control is achieved through a rudder connected to a servo and control rod mounted aft of the ducted fan. With the propulsion and control mechanisms designed above the water's surface, the water/vehicle interfaces are limited to only the boat's hull, the aft hydrofoil, and the forward hydrofoil. This restricts the interfaces to only the primary source of frictional drag (hull) and the primary design characteristics that attempt to overcome this friction (the hydrofoils).

The second and third stages of the hydrofoil boat activity development were the construction and testing phases. Within these stages, the design phase's trade study decisions were incarnated by 3D printing the forward and aft sections followed with the installation of structural supports, an outer shell, a protective Monokote waterproof coating, power systems, propulsion systems, and control systems. The boat itself underwent various inspections throughout its construction such as waterproof, control, stability, and thrust testing. The fully-constructed hydrofoil boat is illustrated in **Figure. 2** below.

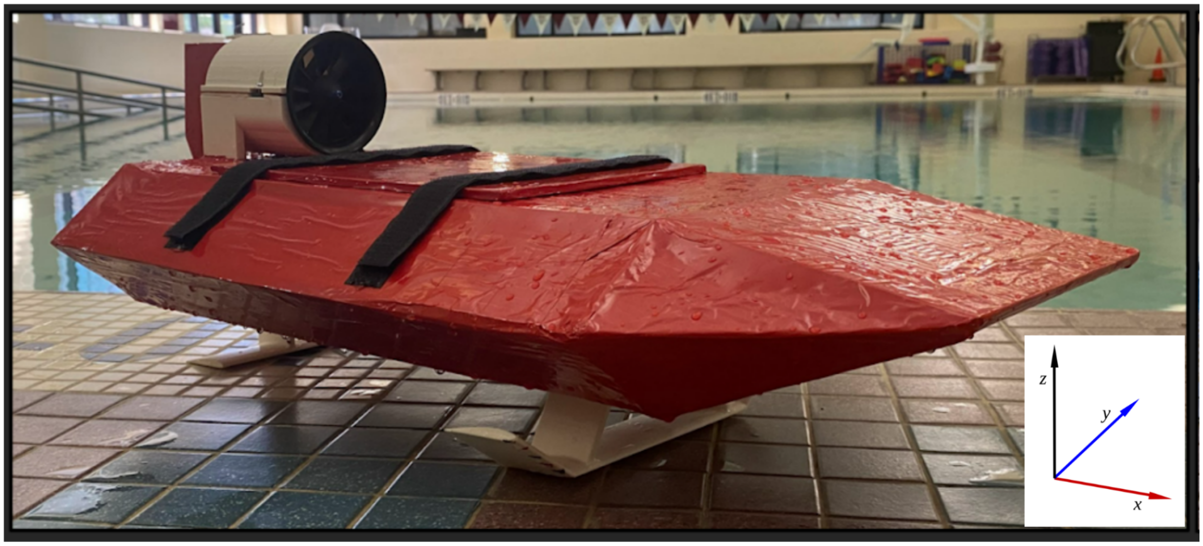
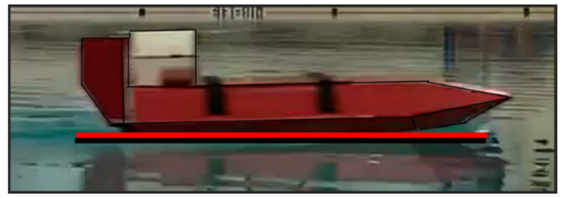
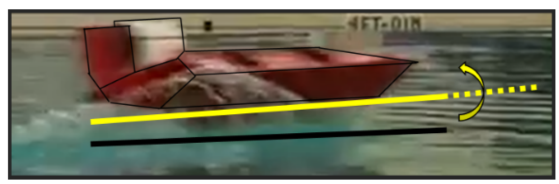
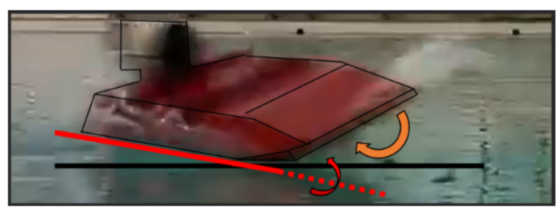


Figure 2. Fully-Constructed Hydrofoil Boat [3]

The next stage that the authors conducted was data processing. This stage entailed video recording the hydrofoil boat at various speeds for twenty trial runs in an indoor, climate-controlled pool. From these videos, the boat's stability performance as a function of velocity could be extracted. Specifically, the velocity could be calculated from the known distance between markers in the pool divided by the time traveled between these markers for each trial. The corresponding stability performance was then assigned one of five classifications as outlined in **Table 1** below.

Table 1. Lift Optimality Category Chart [3]

Lift Optimality Category:	Category Description:	Category Image:
No Lift	The velocity of the boat is too slow to where the lift produced is not enough to raise the boat above the water. The boat's hull can be seen interfacing the water's surface throughout the trial run.	
Under Lifted	The boat reaches a velocity that produces enough lift to partially raise the forward section of the boat, yet the aft of the boat remains significantly lower than the front.	
Optimally Lifted	The boat reaches its critical velocity at which the lift produced matches the weight of the boat and lifts the forward and aft of the boat out of the water while remaining stable (no roll and yaw produced from instability).	
Slightly Over Lifted	The boat reaches a velocity that lifts the boat's hull out of the water, but the extra produced lift due to a higher velocity causes slight instability seen by a roll motion about the x-axis.	
Terminally Over Lifted	The boat reaches a high velocity quickly to where the lift produced by the hydrofoils raises the boat's hull out of the water rapidly, resulting in high instability indicated by rolling and yawing of the boat; throwing the boat off course.	

For the fifth stage of the hydrofoil boat activity development, the authors packaged these trial videos with all design specifications/data of the boat and developed a corresponding lab manual that identified a problem statement and guidance towards completing the lab. Specifically, the students participating in this lab were given a background on the goal of this lab, a mock scenario that they were trying to solve by completing the lab, the data needed to complete the lab, and general procedures to guide them through completing the lab. Furthermore, students were also provided with fillable tables that were needed and additional references that could be explored to reinforce aerospace concepts. Because the hydrofoil boat activity was created with the intent of being implemented into educational curriculum, the final data sets, plots, and classification determinations were packaged in a separate folder by the authors and serve as a "rubric" that is given to instructors/activity administrators to reference when evaluating student performance on the activity.

To capture the hydrofoil boat activity's effectiveness at dissolving interdisciplinary barriers within STEM, the students participating in this lab were given a pre-survey prior to conducting the lab that captured the participants' demographics and outlook on the applicability of various STEM fields. Students were then given a post-survey with similar questions and direct feedback/satisfaction questions after completing the unconventional aerospace lab. The shift in the students' responses yield valuable data that indicates the activity's effectiveness and drives improvements to the activity for future iterations.

Scaled Lab Implementation

From the onset of the hydrofoil boat activity study, the authors set progressive stages leading from activity development to curriculum integration. Each of these stages and the overall flow of research is illustrated in **Figure 3** below.

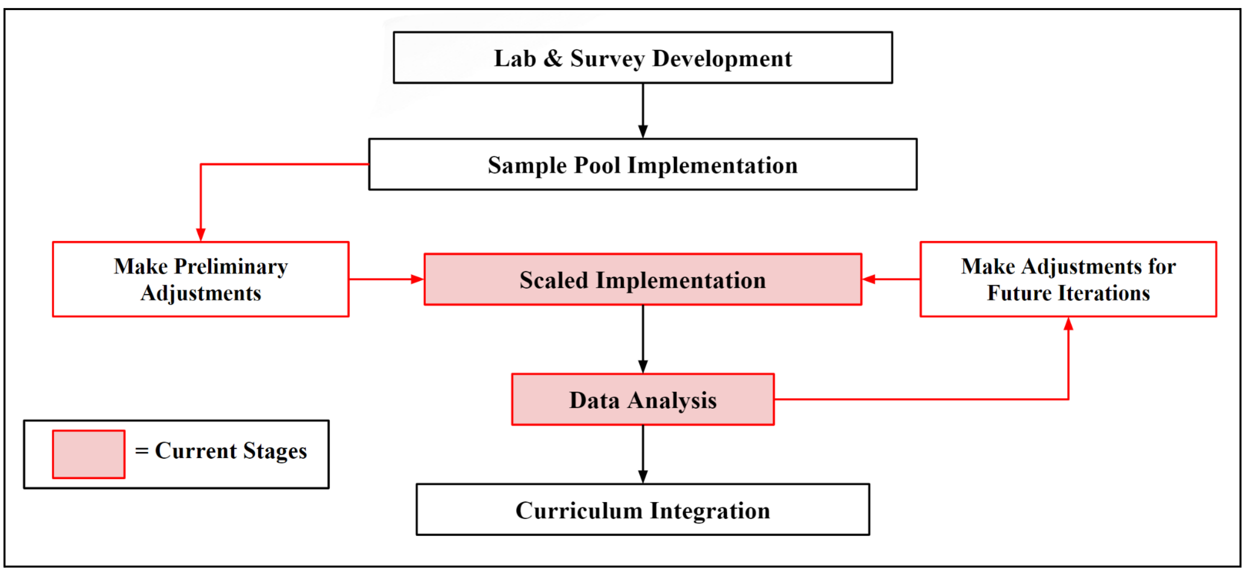


Figure 3. Study Development Stages

The **Lab & Survey Development** stage was discussed in the previous section. The authors conducted the **Sample Pool Implementation** stage in a previous study where this lab was given to a sample group of two undergraduate students at Texas A&M University in the Fall 2022 semester. These students included one aerospace engineering major and one manufacturing and mechanical engineering technology (MMET) major. The authors goals of this small-scale implementation was to validate the methodology of using pre- and post-surveys to analyze the shift in student perspective as well as gather preliminary feedback on the lab itself to make modifications prior to scaled implementation for students enrolled in the AERO 201 course at Texas A&M University. This study's results yielded clear charts that indicated a shift in both of the students' perspectives. While no conclusions regarding the effectiveness of the lab could be drawn due to the small sample size, the means of capturing the students' shifting mindset was verified. Furthermore, this sample group provided constructive feedback regarding increasing the time allotted for completion of the lab as well as providing in-person instructions to accompany the virtual lab format to clarify the desired deliverables of the students [3]. The authors used this feedback to adjust the lab's structure prior to carrying it out for AERO 201 students of whom this study focuses on.

With the **Preliminary Adjustments** stage complete, the authors pivoted towards the **Scaled Implementation** phase. Specifically, this iteration of the lab's implementation was given to an audience of 40 students enrolled in AERO 201: Introduction to Flight course at Texas A&M University. This group was chosen as they represented students who have not yet taken high level major-specific courses. The data obtained from this iteration of the lab yielded valuable information regarding the effectiveness of the hydrofoil boat educational lab on STEM students early in their collegiate educational journey. Moreover, the results of this study drove NUA^{2}NCED Laboratory's pursuit of how to implement unconventional STEM applications into curriculum.

Results

The results of the previously-mentioned pre- and post-survey questions are outlined in the six figures below. The questions in both the pre- and post- survey consisted of three Likert Scale questions that were designed to capture students' interests in various fields of STEM and their outlook on the applicability of aerospace engineering. Two visual overlap questions were then presented to students to grasp their thoughts on how connected various disciplines are with each other. These were structured as slider-type questions where students were presented with two different disciplines and had the ability to drag a slider between 0 (no overlap between the two disciplines) and 100 (complete overlap between disciplines) [3]. The final question of the post survey aimed at gathering direct feedback on the overall effectiveness of the hydrofoil boat activity on shifting students' outlooks on the interdisciplinarity of STEM and their overall interest in STEM.

The results seen in **Figure 4** below display the answers to the first Likert Scale question in the pre- and post-surveys that asked students about their interests in various disciplines of STEM. This data reveals relatively little-to-no change (± one participant as one student did not complete the post-survey; hence, the ±3% variance in each post-survey percentage throughout the results hereafter) in participants' interest in the STEM field (red bar), engineering (purple bar), and specifically aerospace engineering (blue bar) from before and after conducting the hydrofoil boat activity. This minute shift in field interest can largely be associated with the activity being conducted on students already pursuing higher education in aerospace engineering and showing high interest in STEM fields prior to participating in this activity. However, because over 97% of total students showed moderate-to-high interest in all three fields following their participation in the hydrofoil lab activity, the implementation of this unconventional engineering activity proved not to steer students away from their interests in STEM, engineering, or aerospace engineering. Due to no personal identifiable information (PII) being gathered in this study, the authors were not able to remove the pre-survey response of the participant who did not submit a post-survey.

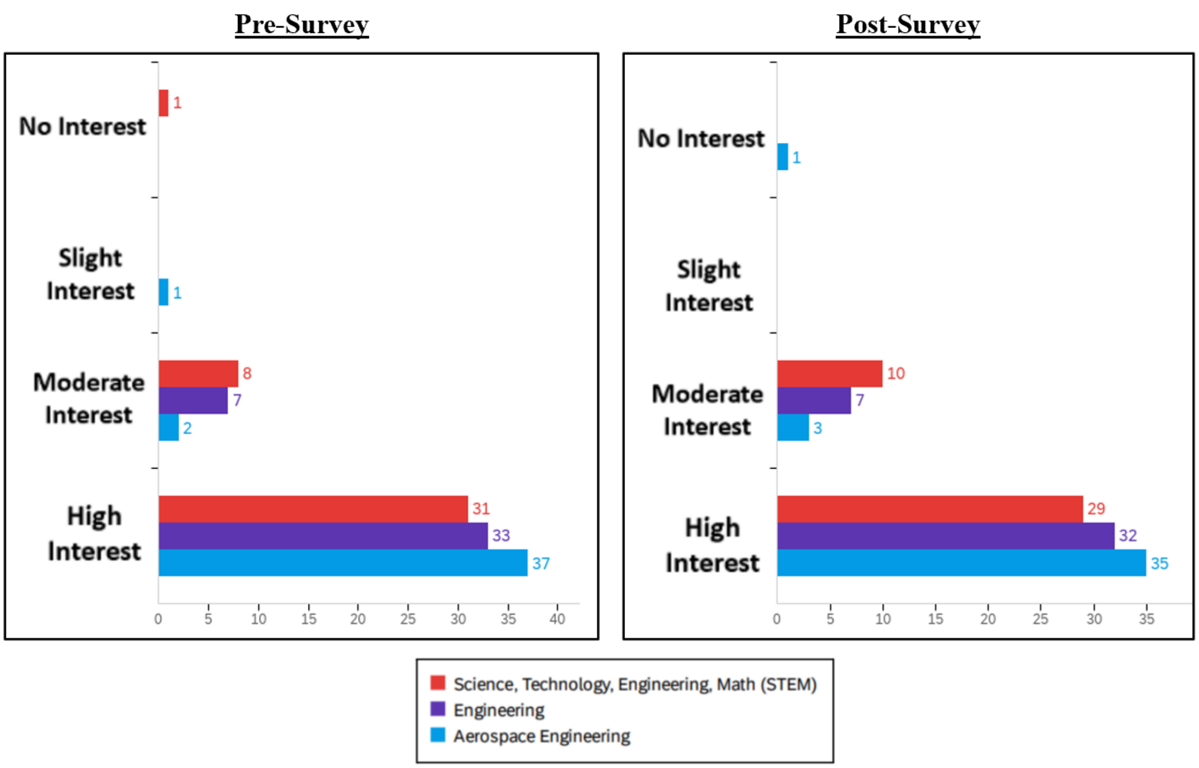


Figure 4. Pre/Post Survey Results for Career Interests

The results seen in **Figure 5** below display the answers to the second Likert Scale question in the pre- and post-surveys that asked students about their outlook on the limitations and career desires associated with pursuing a degree in aerospace engineering. This data reveals that the hydrofoil boat activity did not significantly change students' perspectives on if an aerospace engineer's intended career pursuit lies within the aeronautics/space sectors (red bar). However, the data reveals a shift from 32.5% (pre-survey) to 51±3% (post-survey) of students that agreed that aerospace engineering is more limiting than other engineering fields. Qualitative feedback gathered from participants regarding this matter indicates that this unfavorable shift can be associated with the difficulty of the activity paired with the short amount of time allotted for participants to complete the activity. These concerns will be addressed in the **Lessons Learned and Path Forward** section to come. In a more satisfactory manner, the data reveals that the hydrofoil activity fostered a slight increase in those who strongly agree that aerospace engineers possess technical knowledge that is applicable outside of the aeronautics/space sectors (blue bar).

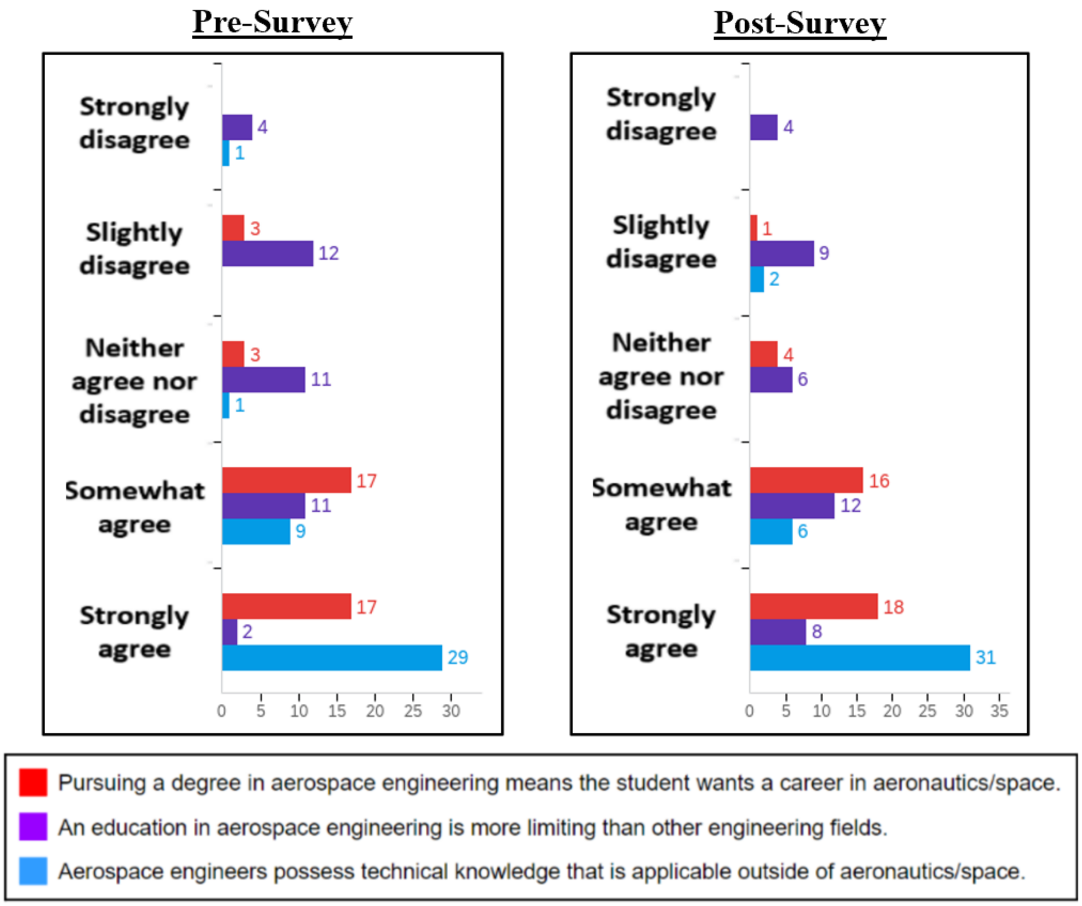


Figure 5. Pre/Post Survey Results for General Aero Applicability

The results seen in **Figure 6** below display the answers to the third Likert Scale question in the pre- and post-surveys that asked students how capable aerospace engineers are at building a career in various industries. This data reveals little-to-no change in students' outlooks on aerospace engineering's applicability to the aeronautics/space industry (red bar). Similar to this activity's previous iteration with the small sample group, this result is to be expected as an aerospace engineer's education possesses a direct tie to the aeronautics/space sector [3]. Students did, however, indicate a slight shift from 67.5% (pre-survey) to 74±3% (post-survey) of students that strongly agreed that an aerospace engineer can build a career within the watercraft industry (blue bar) and automotive industry (purple bar). The authors conclude that this shift is tied with the hydrofoil boat activity's direct tie between these engineering silos. Regarding overall student agreeance with an aerospace engineer's ability to build a career in less-similar industry sectors, participants experienced a significant shift from 57.5% to 69±3% agreeance for the healthcare industry (yellow bar) and little-to-no shift from 80% to 77±3% agreeance for the clean energy industry (green bar). These results reveal that while the hydrofoil boat activity fostered little change in students' already-high outlooks on an aerospace engineer's ability to build a career in a sector with complete overlap, it did yield an slight overall increase in students' perspectives on an an aerospace engineer's ability to build a career in less-related STEM industries.

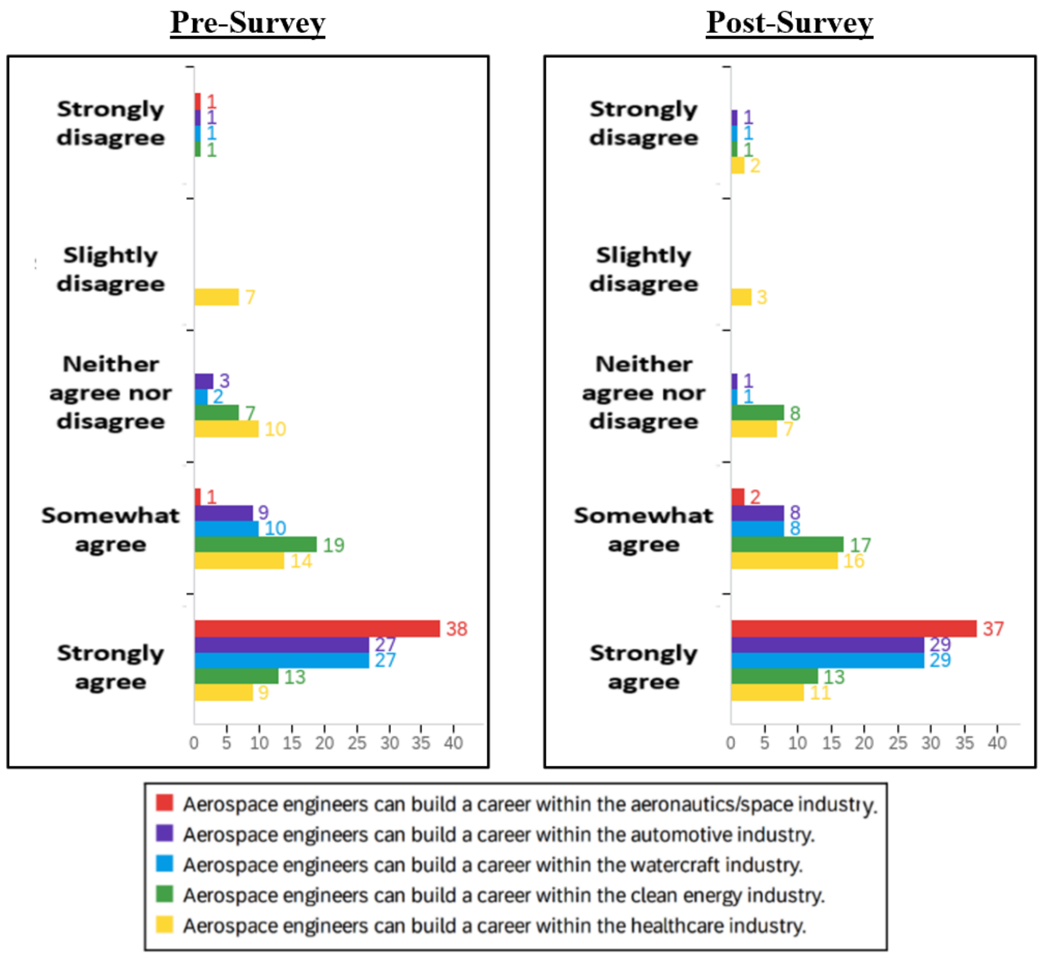


Figure 6. Pre/Post Survey Results for Aero Applicability in Various Industries

The results seen in **Figure 7** below display the answers to the first visual overlap question in the pre- and post-surveys that prompted students to move a slider between 0 (no overlap) and 100 (complete overlap) when presented with various sets of aerospace paired with a different discipline. This data reveals that students found more overlap between aerospace and all other STEM fields after participating in the hydrofoil boat activity other than the already-high overlap between aerospace and mechanical. Specifically, students indicated a minute negative change of 81% to 79±1% overlap between aerospace and mechanical. However, this overlap remained the highest out of all discipline pairs as it is well established that mechanical engineering teaches similar technical knowledge as aerospace engineering. More interestingly, the data illustrates an average 8±1% increase in students' perceived overlap between aerospace and each other STEM disciplines with the highest increase of 13±1% between aerospace and environmental and the lowest increase of 3±1% between aerospace and automotive. This indicates that the hydrofoil boat activity was effective at fostering more recognition by participants of overlap between aerospace and various other STEM disciplines. This agrees with the hypothesized results extracted from previous method-validation iterations of this activity [3].

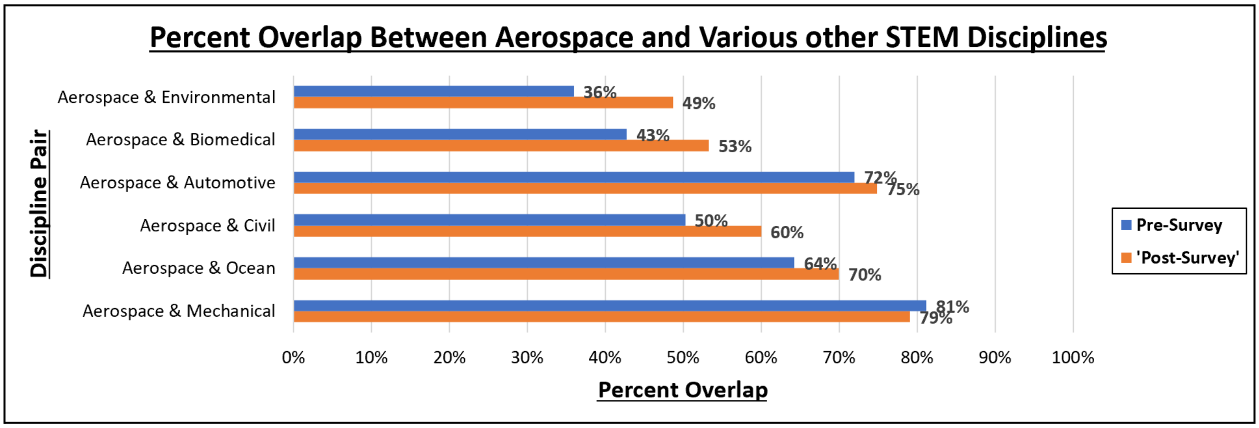


Figure 7. Pre/Post Survey Results for Overlap Between Aero and Other Disciplines

The results seen in **Figure 8** below display the answers to the second visual overlap question in the pre-and-post surveys that prompted students to move a slider between 0 (no overlap) and 100 (complete overlap) when presented with various sets of discipline pairs entirely outside of aerospace. This data reveals that students found greater overlap between each of the non-aerospace discipline pairs after participating in the hydrofoil boat activity. Specifically, the data illustrates an average 7±1% increase in students' perceived overlap between each discipline pair with the highest increase of 10±1% between civil and automotive and the lowest increase (or remain the same due to the variance) of 1±1% between civil and environmental. This indicates that the hydrofoil boat activity was effective at not only linking aerospace to other STEM disciplines, but also effective at dissolving interdisciplinary barriers in STEM external to the hydrofoil boat activity's predominant aerospace focus.

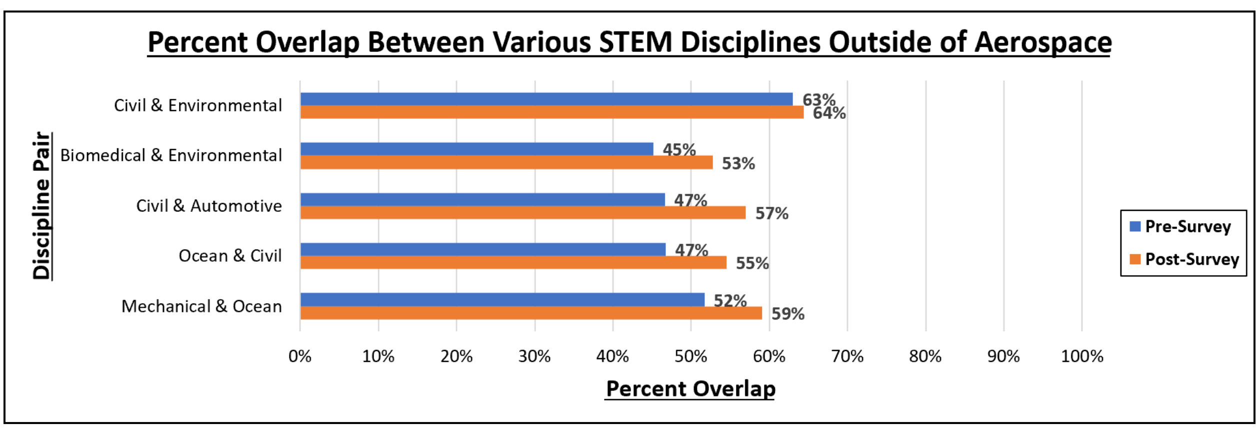


Figure 8. Pre/Post Survey Results for Overlap Between Disciplines Outside of Aero

The results seen in **Figure 9** below display the answers to the direct student feedback questions in the post surveys that asked students if the hydrofoil boat lab helped dissolve boundaries between different STEM fields as well as if the activity increased their interest in pursuing an education in a STEM field. This data reveals that roughly 92±3% of participants agreed that the hydrofoil boat activity helped better relate aerospace engineering principles with other engineering domains while only 8±3% of participants either disagreed or neither agreed/disagreed with this stance (red bar). This data agrees with and validates the previously-mentioned results extracted from **Figure 7**. Additionally, the data reveals that roughly 79±3% of participants agreed that the hydrofoil boat activity helped them relate non-aerospace engineering principles with other engineering domains while 21±3% of participants either disagreed or neither agreed/disagreed with this stance (purple bar). This data also agrees with and validates the previously-mentioned results extracted from **Figure 8**. Furthermore, approximately 69±3% of participants agreed that this activity increased their interest in pursuing an education in a STEM field while 31±3% of participants indicated no effect from this activity in increasing their interest in pursuing a STEM education (blue bar). From this information, the authors conclude that this iteration of implementing the hydrofoil boat activity to aerospace engineering students was overall successful in both dissolving interdisciplinary STEM barriers within and outside of aerospace engineering and slightly eccefctive in fostering increased interest in their pursuit of an education in STEM.

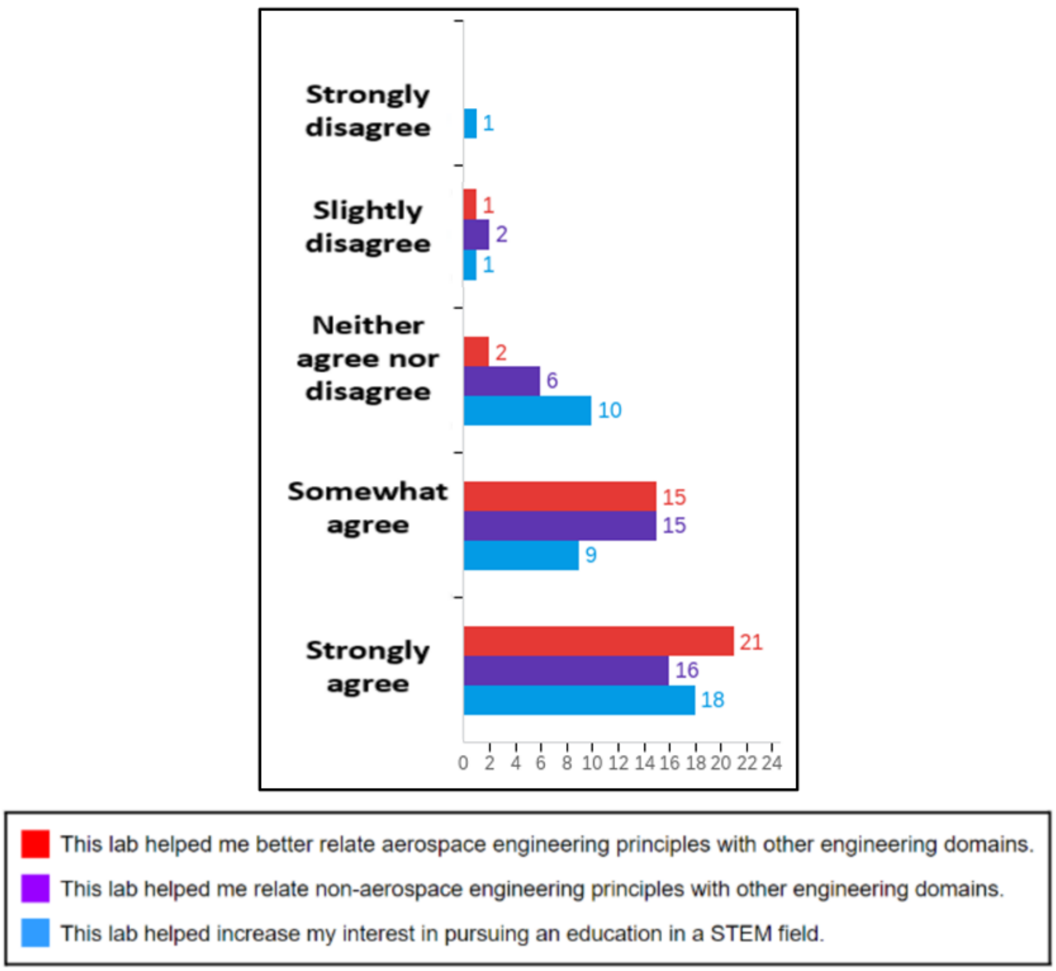


Figure 9. Survey Results for Overall Hydrofoil Lab Effectiveness

Lessons Learned and Path Forward

While the results presented above indicate that the hydrofoil boat educational lab accomplished its goal of helping students recognize the interdisciplinarity STEM fields, the qualitative feedback gathered from the students that participated in this study revealed that several adjustments can be made to enhance the activity's effectiveness and student experience. The first and most dominant feedback gathered from participants was an extension of time allotted to complete the activity. While the authors increased the time from 30 minutes to 50 minutes from the sample group iteration [3] to this AERO 201 student implementation, additional time on top of this extension would be needed in future implementations for all students to complete the lab in its entirety. Moreover, qualitative observations and feedback indicated several instances of participant frustration if he/she was not able to complete the activity. This potentially led to more negative post-survey responses than if all students had finished the activity and obtained the desired solution to the problem statement. Additionally, students expressed the desire for a tutorial/demonstration video for how to extract the data from each of the hydrofoil boat trial run videos rather than just following a procedure list found within the lab manual. The authors as well as the professor of this AERO 201 class see value in including a demonstration video of this sort with regard to both accuracy in the extracted data by students as well as a decrease in time needed to complete the activity as it mitigates students' learning curves with linking listed procedures to exact actions needing to be taken.

As seen in **Figure 3**, this study focused on the scaled implementation of the hydrofoil boat educational lab to AERO 201 students and the corresponding data analysis of the results gathered from this implementation. With the results displayed in the previous section as well as the qualitative feedback from the students that performed the activity, the authors are taking this study's data in two directions. The first is to address the lessons learned mentioned above by adjusting the activity to include an allotted time of 90 minutes to complete and a demonstration video of data extraction methodology to be used by the students. These changes will be used in future iterations of this activity that will focus on further expanding its impact to other college STEM students as well as a transition into K-12 participants.

The second path forward that the authors are taking is creating a more consolidated version of this activity to implement as workout problems in students' curriculum. With this study's results indicating an overall success at dissolving interdisciplinary barriers in STEM, the authors find value in extending this educational lab beyond just an activity offered for an activity credit in AERO 201. Specifically, the implementation of the hydrofoil boat educational lab and similar nuanced interdisciplinary STEM applications that further enhance the multidisciplinary aspects of aerospace engineering as a homework problem within course curriculum is a critical step in bridging the gap between STEM discipline silos. In the case that this lab proves not to capture students' interest in future iterations, the authors have identified additional hands-on activities with the hydrofoil boat such as hydrofoil shape and size optimization activities to compete in an

RC hydrofoil boat drag-type race between student teams. With the introduction of competition and race platforms, these future iterations aim at increasing both interdisciplinarity and student excitement. The NUA^{2}NCED Laboratory has also taken steps towards onboarding various student researchers from majors outside of aerospace engineering to further develop the interdisciplinarity of these unconventional activities.

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References

[1] K. P. J. Fortuin, N. C. Post Uiterweer, J, T. M. Gulikers, C. Oonk, and C. W. S. Tho, "Training Students to Cross Boundaries Between Disciplines, Cultures, and Between University and Society: Developing a Boundary Crossing Learning Trajectory," in *SEFI 48th Annual Conf. Engaging Engineering Education*, Sept. 20-24, 2020. [Online]. Available: https://www.4tu.nl/cee/publications/480-sefi2020-fortuin.pdf

[2] M. Roy, "The Growth of Interdisciplinarity in Engineering Education in the 21st Century," in *2021 ASEE Annual Conf.*, July 26-29, 2021. [Online]. Available: https://peer.asee.org/the-growth-of-interdisciplinarity-in-engineering-education-in-the-21st-century.pdf

[3] Z. Reinert, "Bridging the Gap Between STEM Disciplines Through Unconventional Aerospace Dynamics Educational Lab at the High School/College Introductory Level," in *AIAA SciTech Forum*, Jan. 23-27, 2023.

[4] N. L. Basinger, "Design and Build of a Hydrofoil Boat," *Undergraduate Thesis Collections*, Massachusetts Institute of Technology, May 6, 2022. [Online Document]. Available: https://dspace.mit.edu/handle/1721.1/144707. (Accessed: Sept. 19, 2022).

[5] I. H. Abbott and A. E. Von Doenhoff, "Appendix IV. Aerodynamic Characteristics of Wing Sections," in Theory of Wing Sections: Including a Summary of Airfoil Data. Toronto, Ontario: Dover Publications, Inc., 1959.