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Navy Science and Technology Program: Pathways to Careers in the Navy and Supporting Industries

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1. Introduction

Technological innovation has contributed significantly to US economic growth over the last 50 years. From a national defense perspective, there is a strong demand for quality educational STEM programs [1] for students pursuing careers in the Navy and supporting industries. The Navy and Marine Corps are leaders in Naval Science, Technology, Engineering, and Mathematics (STEM) education. In a framework for the civilian workforce issued by the Navy in 2016 [2], one of the main goals is "Continual improvement in all stages of the civilian workforce career path," which includes funding programs responsive to mission needs. In addition, the Navy and Marine Corps are reimagining Naval STEM [3] by broadening STEM programs to include students from kindergarten through Ph.D., to inspire them to pursue STEM careers and solve naval challenges, and leveraging the diversity that makes America a dynamic and unique nation. Furthermore, available data indicate a severe workforce shortage in the naval community, compounded by an aging workforce and a limited supply of new graduates. A reason for this shortage is the limited number of higher education offering marine engineering and naval architecture degrees [4], which supports the development of non-traditional avenues for naval science and technology education, such as the certificate described here.

To promote Naval STEM education in the Midwest, we launched an undergraduate certificate program titled "Naval Science & Technology" (Naval S&T) in 2019. Students in the Mechanical Engineering (ME) department at the University of Iowa (UI) can earn the certificate by selecting elective courses in the baccalaureate degree. This certificate program replaced and augmented an existing undergraduate certificate in naval hydrodynamics, taking advantage of an expanding departmental curriculum in control, autonomous systems, and artificial intelligence. Therefore, the program objective is to prepare students for a broad range of challenges in naval hydrodynamics and autonomous systems and control with Navy applications and attract and provide students guidance on career paths in support of the Navy. At the current phase of development of this program, our focus is on curriculum improvement, expanding program awareness through outreach activities to college and high school students, and assessing program goals through survey data collection. This paper describes the certificate program and addresses the following questions.

1: What level of initial interest do undergraduate students have in naval science and technology challenges and career paths?
2: Is the Naval Science and Technology program perceived to be effective in preparing for the career students anticipate, whether or not that career is in support of the Navy?

2. Naval Science and Technology Program

2.1 Program curriculum and facilities

The Naval S&T program was launched in 2019. Students need to take at least 18 semester hours (sh) or six courses to earn the certificate, as described in Table 1. Factors influencing the structure of the curriculum include the need to address a broad range of topics relevant to the Navy, constraints on faculty resources available to develop and deliver the program, and the specific technical strengths within the UI. The ME Department at UI administers the program. Naval hydrodynamics has been an area of strength for several decades, and the areas of autonomous systems and artificial intelligence have recently experienced significant growth. Students must take at least two of three available courses in each of these categories and must complete the certificate in a capstone course with a naval science and technology focus. Any remaining courses can be selected from a list of electives.

Table 1. Naval Science and Technology Program curriculum

Naval hydrodynamics courses (students must complete at least two) • ME:4125 Biomimetic Fluid Dynamics • ME:4175 Computational Naval Hydrodynamics • ME:4176 Experimental Naval Hydrodynamics
Autonomous Systems and Machine Learning courses (students must complete at least two) • ME:4111 Scientific Computing and Machine Learning • ME:5114 Nonlinear Control in Robotic Systems • ME:5115 Cooperative Autonomous Systems
Capstone course (students must complete at least one) • Full-year capstone design elective on a naval S&T topic • One semester of supervised independent study on an approved naval S&T topic
General electives • Any additional courses needed to complete the 18 sh certificate requirement can be selected from a list of approved courses on control, robotics, artificial intelligence, fluid mechanics, materials, and manufacturing.

Several laboratory facilities support the certificate curriculum, including a fluid mechanics laboratory with an educational towing tank and advanced instrumentation for fluid mechanics measurements, and laboratories for control and robotics, which contain a variety of ground, air, and water robots with multi-camera motion capture systems. Detailed information about the offered courses and facilities for the Naval S&T certificate can be found in [5].

2.2 Current State of the Curriculum

Recently, several courses have been updated according to the program's needs and students' feedback. Summaries of the developments and examples of course activities are described below.

ME:4150 Artificial Intelligence in Engineering is one of the approved elective courses for the Naval S&T certificate. This course introduces students to fundamental concepts of artificial

intelligence (AI) and its applications in engineering disciplines. The emphasis is on students' understanding that AI can enable the computer to perform intelligent engineering tasks such as decision making, problem-solving, and machine learning. New educational modules developed for the Fall 2021 semester include (1) genetic algorithms for design optimization; (2) classification via machine learning; (3) convolutional neural network and its application for image processing; (4) signal analyses and fault diagnosis; and (5) reinforcement learning for motion planning. Each module consists of concept explanation, algorithm delivery, real-world application, and python sample codes. The modules can be used as the reference for students in course projects (not limited to ME:4150) and capstone projects.

A project on image-based ship classification was added to the course. Students were required to download pictures from www.shipspotting.com, choose either a binary or multi-class classification problem, and employ convolutional neural networks (CNN) to classify the ships depicted in the images. For example, one student proposed a four-class classification project to classify aircraft carriers, cruise ships, destroyers, and tankers for a given picture. He collected 1000 images as the training set, 200 as the validation set, and 200 as the testing set. Figure 1 includes several image examples for this project. In addition, the student utilized a few techniques on CNN, which have been discussed in the course of ME:4150, including data augmentation, pre-trained VGG-16 neural network, and dropout. Finally, the accuracy of the testing set can be up to 93%.

Figure 1. Examples from each of the four image categories: aircraft carrier, cruise ship, destroyer, and tanker (www.shipspotting.com).

ME:5114 Nonlinear Control for Robotic Systems is a core course in the Naval S&T certificate. The course exposes students to nonlinear analysis and control systems theory, focusing on nonlinear autonomous and nonautonomous systems as well as the applications of the nonlinear control design tools on robotic systems. In the Spring 2021 semester, state-of-the-art techniques in the community of control and robotic systems were added to the course, including linear quadratic regulators, model predictive control, Kalman filters, optimal control, and data-driven control. In addition, most examples in the lectures were solved numerically via python so that

the solutions could be easily interpreted for students to understand. Several educational modules were developed, focusing on (1) Stability analysis of autonomous systems; (2) Stability analysis of nonautonomous systems; (3) Nonlinear control via feedback linearization; and (4) Nonlinear control via backstepping.

ME:5115 Cooperative Autonomous Systems is also a core course for the Naval S&T certificate and is designed to expose students to nonlinear systems modeling, simulation, analysis, and controls, as well as numerical optimal control and planning. In the Fall of 2021, several advanced topics were added to ME:5115 to introduce current state-of-the-art techniques in the community of control and cooperative autonomous systems. Those topics include RRT*, A*, Artificial Potential Functions, and Dijkstra's algorithm. In addition, most examples in the lectures were solved numerically via MATLAB, and the results were simulated via Simulink. Several educational modules were developed, such as (1) Modelling and Simulation of Autonomous Vehicles; (2) Path Following and Control Design; (3) Optimal Motion Planning using Numerical Optimal Control.

Figure 2. Undergraduate students working on QCar (left) and BlueROV2 (right)

A QUANSER Autonomous Vehicle Research Studio was recently purchased to support the program, including Qbots, Qdrones, and QCars, which are sensor-rich autonomous ground and aerial vehicles. The robots are ideal self-driving vehicle platforms for validating dataset generation, mapping, navigation, machine learning, artificial intelligence, control, and other advanced self-driving concepts. In addition, the program has six BlueROV2s that are high-performance underwater remotely operated vehicles. Each of them is equipped with a 6-thruster vectored configuration, camera, sonar, and other open-source electronics and software. Undergraduate students worked on QUANSER robots and BlueROV2 in the Fall of 2021 (Figure 2) and did some preliminary testing (Figure 3). Profs. Xiao and Cichella, the instructors of ME:5114 and ME:5115, have designed new course projects implementing QUANSER robots and BlueROV2 with advanced control techniques for students in the Spring and Fall of 2022.

Figure 3. BlueROV2 testing in the towing tank at the Fluid Mechanics Laboratory

ME:4175 (Computational Naval Hydrodynamics) serves the dual purpose of introducing the students to computational fluid dynamics (CFD) with specific applications to naval hydrodynamics and introducing general concepts in naval engineering, including propulsion, maneuvering, and seakeeping. The course was first offered in 2016, using the powerful in-house naval hydrodynamics CFD solver, REX. Although students were able to perform complex simulations involving propellers and vessels, the software relies on libraries that are expensive and/or export-controlled such that students cannot take the software with them after completing their degrees. Therefore, the course has been recently redesigned for the Spring 2022 offering to implement OpenFOAM, an open-source solver that is not specifically tailored to naval applications. Additionally, the US Navy has developed its version of the solver, named NavyFOAM [6], thus providing familiarity with the OpenFOAM environment is also beneficial to the students. A new feature of the course will include online tutorials based on the work developed during the course offering in Spring 2022.

2.3 Extra-curricular Student Organization

A student organization, Iowa Marine Autonomous Racing Club (IMARC), has also been established, focused on designing and building autonomous boats for participation in national and international competitions, such as the Association of Unmanned Vehicle Systems International (AUVSI) 's RoboBoat competition. The organization is open to any undergraduate students at UI and currently has students who majored in Mechanical Engineering, Electrical and Computer Engineering, and Computer Science.

The competition team consists of three technical subgroups: (1) hull and propulsion, (2) software, and (3) hardware. The Naval S&T program courses support the team in many ways. Specifically, naval hydrodynamics courses address the technical challenges faced by the hull and propulsion subgroup. On the other hand, the control and autonomous systems courses can provide the needs of the software and hardware subgroups. The IMARC, therefore, provides students with an experience that is highly complementary to the curriculum and also teaches students who are unable to complete the curriculum due to lacking prerequisites or schedule conflicts. Understanding the synergies between the curriculum and the activities of the student organization is of great interest; however, in recent years, only a few students have participated in both entities (due to the nascent nature of the programs and COVID-19-related restrictions on

student activities) such that data are limited. In the present work, our analysis will be based more broadly on extra-curricular activities in general.

2.4 Other on-campus and off-campus outreach activities

ENGR:1100 "Introduction to Engineering Problem-solving" is the first engineering course for freshmen students in the College of Engineering (CoE) at UI. In addition to a lecture session, the course has up to 18 lab sessions taught by nine engineering faculty members who can freely design engineering-related projects. In each lab session, students work in small groups on in-class and outside-of-class projects. Prof. Xiao, one of the Naval S&T faculty, was an instructor of two lab sessions in the Fall of 2021. He developed a few class projects for ENGR:1100 involving artificial intelligence, machine learning, and data science. One of the datasets used in the course was from experimental testing of amphibious vehicle trajectories through the surf zone, using a wave basin at the Iowa Institute of Hydraulic Research (IIHR), as shown in Figure 4.

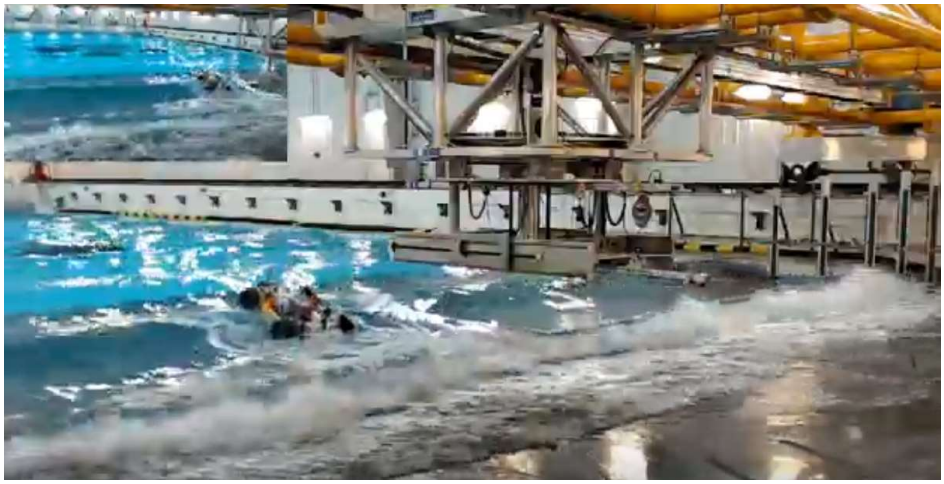

Figure 4. Self-propelled amphibian on surf zone.

The work describes the results of concurrent experimental and computational campaigns to study the unconstrained dynamics of self-propelled amphibians during transit of surf zone. Part of the generated data was utilized for students of ENGR:1100 to conduct regression problems. Students were required to determine the proper features from time, thrust power, steering angle, and velocity for the most accurate prediction of amphibian position in the surf zone. Students also compared two machine learning methods, polynomial regression and k-nearest neighbors, and decided the best model.

There was another class project in which students used reinforcement learning to solve a multi-bandit problem. In addition, to introduce the engineering design process in ENGR:1100, the naval ship design process was used as an example. The students were also invited to tour the robotics laboratory used in the Naval S&T curriculum. In addition, Naval S&T faculty have been invited as keynote speakers in FIRST Tech Challenges events. On Sept 18, 2021, Prof. Cichella presented a seminar on robotics at a local high school during the worldwide reveal of

the new FIRST Tech Challenge game, called FREIGHT Frenzy. He exposed the students to the UI's robotics research and the Naval S&T certificate program.

3. Methodology

This study targeted students who enrolled in Engineering courses in 2020 and 2021. Two different online surveys were developed to answer the questions provided in Section 1. One survey inquired about students' previous background and general interest in the Naval Science & Technology challenges, navy career, and the program. Students were asked to rate different levels of agreement or disagreement, including strongly, moderately, and slightly, with the three interest statements. This survey was conducted in ME Sophomore and Professional seminars and two lab sessions of ENGR:1100. Another survey focused on student self-reported competency of specific skills and knowledge that the program aims to achieve and perceptions of the helpfulness of the course in pursuing the career they anticipate. This competency survey was conducted in core Naval S&T program courses.

The first survey included the following statements for the students to rate the agreement:

1. I am interested in pursuing a civilian or service career in the Navy or one of its industry contractors.
2. The Science & Technology challenges faced by the Navy and its industry contractors sound interesting to me.
3. At this point in my undergraduate education, I believe that I have a sufficient understanding of career paths in the Navy or its industry contractors to make informed decisions about selecting or not selecting those paths.
4. Please indicate your level of interest in completing the certificate in the Naval Science & Technology Program.

Also, the first survey collected the following information from the students:

5. In high school or university, have you, or do you participate(d) in any engineering-related extra-curricular activities or clubs (e.g., FIRST Tech Challenge, robotics club, IMARC, ASME, SAE, etc.). Please explain.
6. Do you have any family members or friends employed in civilian or service roles in the Navy, or employed by any of its industry contractors (e.g., Rockwell Collins, Electric Boat, …), in which your relationship with that person has influenced your knowledge of or interest in naval science & technology? Please explain.

In addition to assessing the level of competence in each program goal (see Table 2 in Section 4.2) in the second survey, the students were asked the following question: Are you interested in pursuing a career in the Navy and supporting industries?

1. If yes, has this course prepared you for a career in the Navy or its supporting industries? Please describe.
2. If no, has this course prepared you for the career that you anticipate having (please also describe your anticipated career)?

A total of 257 students completed one or more surveys in 2020 and 2021. Of the participants, male students were 82.5%, first-generation students were 20%, and under-represented minority students were approximately 8%. Of 257 students, 39 students completed two surveys, three

students completed three surveys, and two students completed four surveys so a total of 308 responses were collected.

4. Results

4.1 Students' Interests

A total of 252 student responses to the first survey were examined to seek the answer for the first question: "What level of initial interest do undergraduate students have in naval science and technology challenges and career paths?". Generally, sophomore seminars hosted ME sophomore students who just started to take ME core and elective courses, while professional seminars have both junior and senior students. It shall be noted that this survey was conducted in sophomore and professor seminars in 2020, and the same group has presented the results [5]. In this paper, we added the data from the survey in 2021. In addition, the survey was, for the first time, conducted on first-year students in ENGR:1100, who can be from various engineering majors and undecided.

Interest in a particular industry or subject has been shown to be a significant factor in determining early career trajectories for engineering students. In a study of 30 early-career engineers, Winters and Matusovich [7] showed that, of those whose early-career trajectories aligned with their goals near the end of their undergraduate studies, a significant majority were driven by primarily interest. Other factors included the economy and family responsibilities. In the present study, a majority of students (76.6%) indicated their interest in the S&T challenges faced by the Navy (76.6%), whereas 37% of students reported their interests in pursuing a career in the Navy or its supporting industry, and 29% indicated their interest in completing the certificate program (Figure 5). This pattern is similar to both male and female students. However, female students reported much less interest in pursuing a career in the Navy and completing the certificate program than male students.

These results may be interpreted as the students thinking more critically about their willingness to commit to a decision as the object of the decision becomes more concrete. Whereas there is no cost to possessing an interest in naval S&T challenges faced by the Navy, most students would need to make a decision on completing the certificate program within about a year of completing the survey in order to avoid graduation delays, and it would be too late for some students that completed the survey. Nevertheless, the level of interest suggests that other barriers to participation may exist, which may be mitigated through targeted advising of students. Currently, less than 5% of students in the Mechanical Engineering program graduate with the certificate, although many more complete some courses in the program.

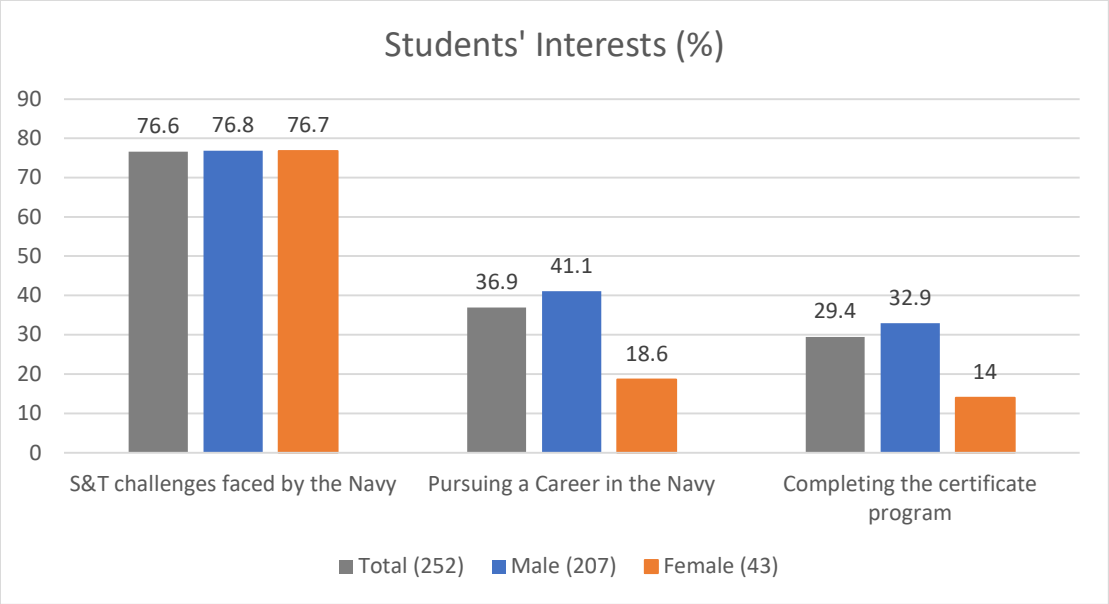

Figure 5. Students' interests in Naval S&T challenges, Navy career, and Naval S&T certificate program.

Next, we compared student interests related to their previous experiences in engineering-related extra-curricular activities and their relationships with a person who is in the Navy or its industry. Of 252 responses, 98 indicated they had such experiences, and their interest was slightly higher than the students without experiences, as shown in Figure 6.

Of the survey participants, only 34 reported that they have relationships with a person who is employed in civilian or service roles in the Navy or its industry contractors. Their interests in pursuing a career in the Navy and completing the program were higher than students who do not have such relationships (Figure 7).

Although we have not yet conducted statistical tests of significance on these results, the preliminary outcomes suggest that students who participate in extra-curricular activities are somewhat more likely to be interested in completing the certificate program. The program provides many hands-on learning experiences for students, and emphasizes realistic engineering challenges and interaction with Navy engineers. Since these types of experiences are often an attraction for students who participate in extra-curricular activities, this may explain the apparent correlation. However, having a relationship with someone in the Navy appears to be an even stronger influence on student interest in Navy careers and the certificate program, despite not having significant differences in the levels of interest in naval S&T challenges.

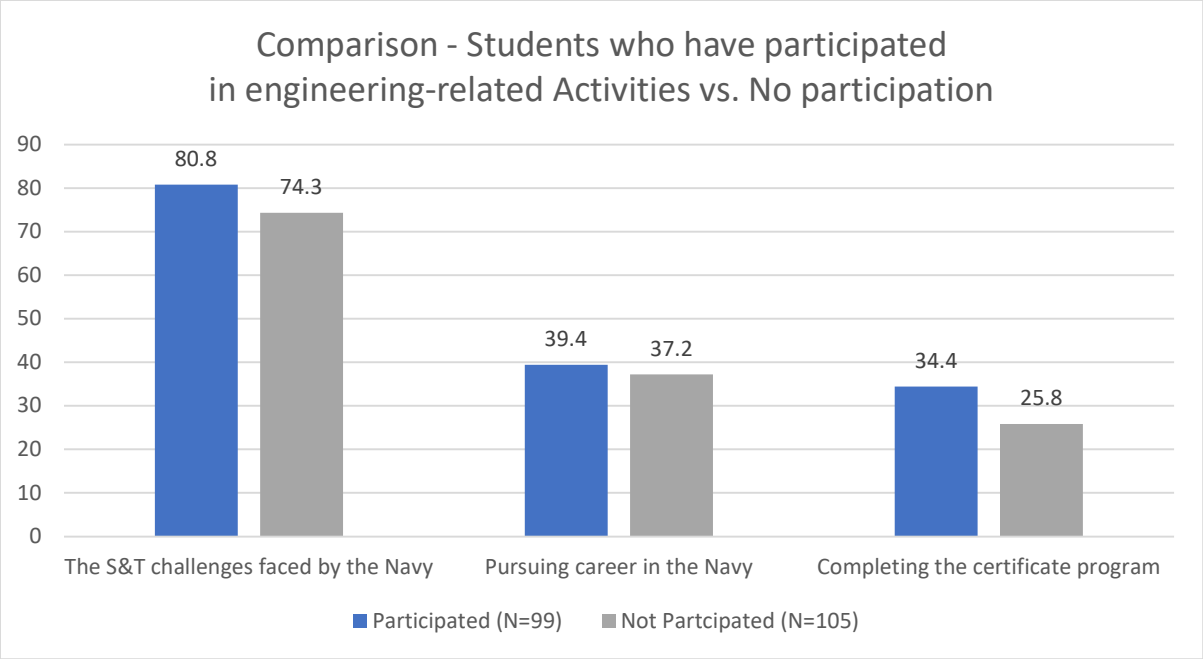

Figure 6, percentages of students who responded yes or no for extra-curricular activities, who are interested in Naval S&T.

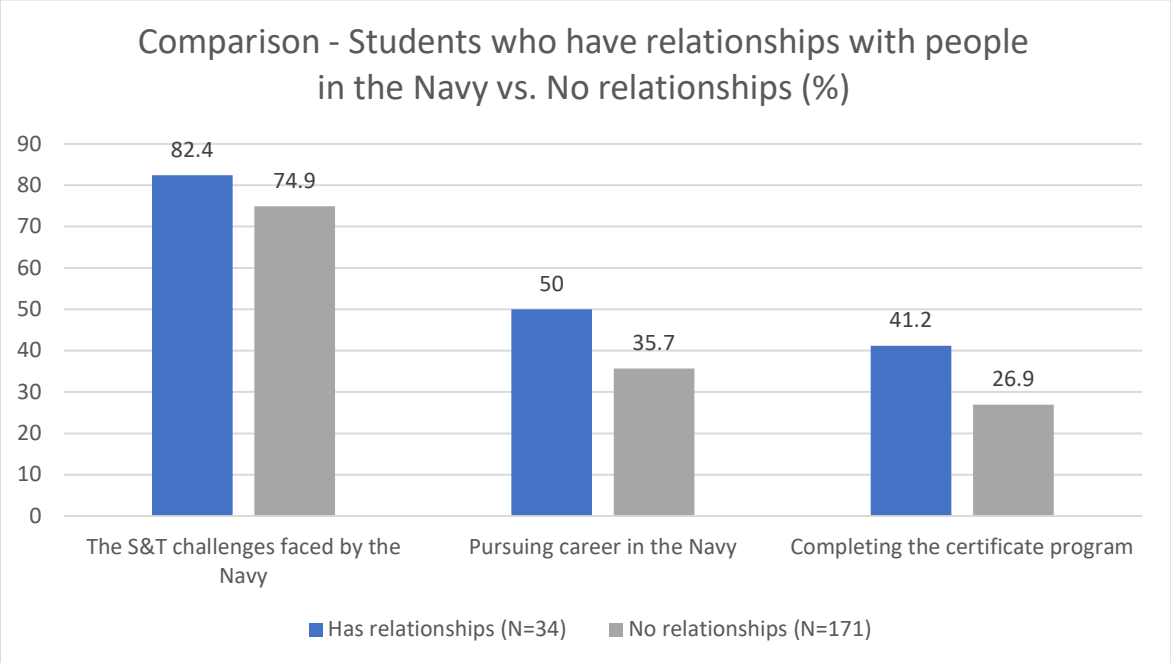

Figure 7, percentages of students, who have any family members or friends employed in civilian or service roles in the Navy or its industry contractors, are interested in Naval S&T.

4.2 Student Competency and Perception of the Helpfulness of the Course

The second research question focuses on the program's effectiveness by addressing "Is the Naval Science and Technology program perceived to be effective in preparing for the career students anticipate?" This particular question was addressed, instead of focusing on preparation for a career in the Navy, due to the nascent nature of the program and the small percentage of students who graduate from the ME program and pursue careers with the Navy. It is therefore important for the program to be broadly relevant in order to be sustainable and impactful.

To answer this question, we examined 56 students' responses to the competency survey that was conducted in the core Naval S&T program courses, including ME:4125, 4150, 4176, 5114, and 5115 in 2020 and 2021. The four program goals were mapped to the course goals of the core courses. For example, the first program goal was embedded in the course goals of ME:4125 and 4176, the second goal in ME 4150, 5114, and 5115. However, the third and fourth goals were embedded in all core course goals. Students were asked to express their perceived level of competence in each course goal using a Likert scale, with 1 representing not competent at all and 7 as very competent. Table 2 shows mean student ratings. The average student competency rates were moderate (4.05 ~ 6.18) across courses. In particular, student competency of the third goal, developing leadership skills in science and technology, is consistent across course courses.

Table 2: Students perceived levels of competence in topics aligned with program goals. Scores are presented using a Likert scale in which 1 represents not competent at all and 7 represents very competent.

Program Goals	**ME:4125**	**ME:4150**	**ME:4176**	**ME:5114**	**ME:5115**
1. Establish an ability to work effectively in naval hydrodynamics.	5.854		4.875		
2. Establish an ability to work effectively with autonomous marine systems.		4.857		5.725	6.18
3. Develop leadership skills in science and technology.	5.75	5.44	5.38	5.55	5.61
4. Provide context to develop impactful careers in naval science & technology.	5.53	4.17	5.5	4.05	5.88

Of the 56 responses, 26 expressed interest in pursuing a career in the Navy and its supporting industries, and 20 of those students (77%) reported that the course they were taking prepared them for a career in the Navy. The following were directly extracted from the student comments on how the course prepared them for a career in the Navy:

"I think the investigations we have done in this class, especially the lab and project component, have prepared me well to perform similar experiments investigating more complex and involved fluid dynamics problems. The theory was additionally beneficial, especially when it comes to initially setting up expectations for a project, and providing a baseline to go off of." *(from ME:4125)*

"I think it has been a great introduction for understanding the role of experimental engineering in hydrodynamics. It has made me interested in pursuing more classes/opportunities in research/experimentation." (from ME:4176)

"*I have a better understanding of the use of controls for cooperative systems and could apply this to different systems (with some difficulty). The main benefit is gaining a general understanding and knowing what I do not know. With the information from this class, getting up to speed on a controls project would take less time, and I would be more likely to know how to find documentation to assist me." (from ME:5115)*

5. Conclusions and discussions

In the second year after the Naval S&T certificate program was launched, the program faculty have put efforts into curriculum improvement and outreach to college and high school students. The improvements in the program core and elective courses will enhance students' science and technology background and their understanding of opportunities and challenges in the Navy and its supporting industries. Although the program is hosted by the ME department at UI, the program reaches students in other engineering disciplines. Furthermore, by collaborating with the outreach program at the college of engineering, the program faculty build a solid relationship with regional high school students and teachers.

The survey data provides some exciting, positive feedback to assess the current state of the Naval S&T program. Of over 200 students, who participated in the first survey, 77% were interested in the challenges faced by the Navy, and 29% expressed interest in the program. Whereas male and female students reported similar levels of interest in naval S&T challenges, the percentage of female students expressing interest in naval careers and the certificate program was less than half that of male students. It is particularly interesting that female students expressed substantially lower levels of interest in naval careers and the certificate program, despite having similar levels of interest in naval S&T challenges. We plan to explore the underlying factors governing these differences further in future surveys and focus groups. Based on the survey data, it also appears that participating in engineering-related extra-curricular activities has a positive influence on students' interest in the Naval S&T program; however, the data suggest that having a relationship with someone employed by the Navy is even more influential in promoting interest in Navy-related careers and in the certificate program.

The second survey targeted the students taking at least one of the Naval S&T program courses. Most of them are mechanical engineering majors. Half of the students, who participated in this survey, were interested in pursuing careers in the Navy or its support industries. Most of them indicated moderate competence levels in the skills and knowledge the program aimed to achieve and reported that the courses prepared them for the Navy career path. According to the data in Table 2, the program plans to take the following steps to improve students' level of competence aligned with the program goals: (1) inviting the Navy officers and its support industry professionals to give career-related seminars; (2) Designing more marine-related course examples and projects.

Furthermore, the survey data helps the program to propose the next strategic plan for recruiting and retaining more students in the future, including (1) The program faculty will contact the students who are interested in the Naval S&T program and discuss with them the possibility of enrolling in the program, (2) The program will open a media channel with short instructional videos to attract K-12 students in engineering and Navy-related programs, (3) The program faculty will host summer workshops for regional high school students on the topics of autonomous systems, control, and artificial intelligence and the application in Naval S&T, and (4) The program faculty plans to promote the undergraduate program to a graduate program for post-graduate students, including employees in the Navy and its support industries.

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