Submerge, Learn, Succeed: Enhancing K-12 STEM Education Through Experiential Pedagogy in Naval Engineering

Alexander Grey
Dept. of Political Science
University of Connecticut
Storrs, CT USA
alexander.grey@uconn.edu

Alexandra Hain
Dept. of Civil and Environmental Engineering
University of Connecticut
Storrs, CT USA
alexandra.hain@uconn.edu

Valerie Maier-Speredelozzi
Dept. of Mechanical, Industrial and Systems Engineering
University of Rhode Island
Kingston, RI USA
valerie@uri.edu

Christopher Cochran
GEMS-Net
University of Rhode Island
Kingston, RI USA
ccochran83@uri.edu

Jack Koziatek
GEMS-Net
University of Rhode Island
Kingston, RI USA
john.koziatek@uri.edu

Caleb Hines
Navy-STEM Coalition
University of Rhode Island
Kingston, RI USA
caleb_hines@uri.edu

Caroline Stabile
GEMS-Net
University of Rhode Island
Kingston, RI USA
stokbridge@uri.edu

Kelly Houle
GEMS-Net
University of Rhode Island
Kingston, RI USA
kellyhoule@uri.edu

***Abstract*— This innovative practices paper presents a novel means of integrating naval engineering into K-12 pedagogy. Submarines are central to the U.S. Navy's deterrence strategy. The submarine industrial base (SIB) is facing a dramatic increase in procurement expectations over the following decade; as such, the two regional flagship universities around the largest submarine producer, the University of Connecticut (UConn) and the University of Rhode Island (URI), founded the UConn-URI Navy STEM Coalition to build a comprehensive pipeline to attempt radical new means of integrating technologies crucial to submarine production into K-12 pedagogies. Goals include getting students more interested in learning science, technology, engineering, and math (STEM) topics and more willing to consider careers in naval engineering. Our most innovative pedagogical shift has been integrating these technology lessons through four discrete summer programs for teachers at various points in their careers to embed them in the language and culture of cutting edge naval research taking place at research universities and provide resources for their own STEM modules.**

Keywords*— *K-12 education, experiential learning, teacher training

I. Introduction

While submarines are central to the U.S. Navy's strategies for both conventional and nuclear deterrence, the submarine industrial base (SIB) has been delivering on average only 1.2 submarines per year, which needs to increase dramatically to reach the target of 5 submarines annually by 2030 [1-3]. Department of Defense estimates suggest that achieving this target would necessitate over 10,000 new hires every year for the next decade [3, 4]. To address this issue, the Universities of Connecticut (UConn) and Rhode Island (URI) have initiated a workforce development program which merges science, technology, engineering, and math (STEM) talent with innovative teaching methods to shape a comprehensive recruitment pipeline and boost consciousness of this crucial, expanding national security sector. This program, the UConn-URI Navy STEM Coalition (hereafter "the Coalition"), seeks to integrate cutting-edge naval technology into current K-12 STEM pedagogy to both make STEM topics more accessible to students, and to highlight career opportunities available in the region if they excel at math and science.

Southern New England has long been called the "silicon valley of undersea warfare" for housing the largest submarine shipbuilder – General Dynamics Electric Boat (EB) – and hundreds of smaller manufacturers within the SIB to support procurement efforts [5]. EB needs to hire over 5,000 workers per year, every year, through 2032 [1, 2, 6] This acute need and proximity to both flagship campuses has allowed the Coalition to establish strategic partnerships with industry which has been paramount in ensuring students get lessons that are both more exciting and, more importantly, accurate to the current and future state of submarine technology.

Students decide whether they intend to pursue STEM as a future career far earlier than when they enter college – by the end of middle school they have determined their likely trajectory and changing their minds after this point is difficult [7, 8]. Thus, to make the most impact, Coalition efforts prioritize early and frequent interactions at the K-8 level, though programming engages through the full K-12 range. We endeavor to use naval engineering, and the practical application of submarines, to demystify STEM topics early and to get more students interested in actively pursuing STEM further. Coalition innovative practices have focused on programs designed to train teachers in Navy STEM pedagogy via four modules. The first involves day-long workshops with the Guiding Education in Math and Science Network (GEMS-Net) Program where hands-on lessons in naval engineering are taught to STEM educators at URI. Teachers who are interested in further training can participate in

This research received funding via DoDSTEM through the National Defense Education Program (NDEP), federal grant #HQ00342110016.

daVinci, a week-long residential program at UConn that includes naval engineering design challenges and provides participants with equipment to use in their classrooms for hands-on learning. A similar program, Undersea Naval Innovation Teacher Education (UNITE), is available for pre-service teachers to effectively communicate via science activities with their students, and introduce the broader implications of STEM careers and naval applications. The most advanced innovation the Coalition provides is the GEMS-Net teacher-in-residence (TIR) program, where two K-12 teachers spend one year in engineering labs that are conducting naval research to develop fully integrated naval STEM lessons and artifacts which can be seamlessly implemented in high quality science curricula. Through this robust series, the Coalition has prioritized scalability; by presenting a spectrum from quick, hands-on activities to full, multi-week lesson plans, Coalition resources make naval engineering as accessible to the educator as possible, so they are more likely to take part in the process of getting their students excited about naval engineering..

II. Background

Fundamental to Coalition goals is an understanding of student career aspiration formation. A seminal work in career aspiration theory, Gottfredson (1981) details how factors contributing to self-concept affect career perceptions and aspirations throughout cognitive development from preschool through early adulthood [9]. Their theory proposes an occupational map which determines likely career desire based on on gender, socioeconomic standing, and job prestige. These factors contribute to one's sense of self and, in turn, their occupational desires.

Building on Gottfredson, the work of Nugest et al. (2015) and Elliniadou and Sofianopoulou (2018) finds that students determine whether they will pursue careers in STEM by the end of middle school (8th grade) at the latest [7, 8]. While there are some opportunities to sway students at the secondary level, it is best to engage as early and often as possible during elementary and middle school to destigmatize STEM and excite students about career prospects. This also ensures that populations are targeted prior to the decision between traditional high school and vocational school.

Chan et al. (2019) further use Gottfredson's theory and apply it directly at the secondary level to understand perceptions of engineering in Hong Kong. While Nugest and Elliniadou and Sofianopoulou determine that opinions on STEM broadly are formed prior to the secondary level, Chan et al. suggest that students who have selected into STEM as a career can be further swayed specifically to engineering. They find perceptions of the field were motivated primarily by attitudes towards STEM broadly, leadership capability, and the potential to work outdoors and/or with your hands [10]. Further studies sponsored by the National Academies have found that interest in engineering careers, as well as general interest in STEM education, is bolstered by a pivot to hands-on lesson planning, much like those we deploy in our pedagogical training [11-14].

Moreover, Myint and Robnett (2023) find that, in relation to STEM outcomes, an individual's ability to enter into a long-term career and perceived ability to achieve their desired goals are directly intertwined [15]. This supports the notion that any advances in STEM workforce development will necessitate a simultaneous and robust development in STEM educational attainment – students must first see themselves as successful in math and science before they can entertain seeing themselves building a submarine [9, 15]. Further, Davenport et. al (2021) proposes a "theory of change" which details the development of a bottom-up curriculum approach [16]. This approach presents a curriculum in line with pre-existing content standards to promote STEM careers from early elementary to secondary levels through lessons and outreach activities, ensuring that students receive a robust series of STEM lessons before the traditional decision age at the end of middle school [7, 8, 16].

Thus, when developing innovative new pedagogical structures around creating significantly more interest in STEM fields and promoting submarine workforce development, several facets stand out. First, students decide early on if they will pursue a career in STEM well before college, with the key inflection point happening in middle school [7, 8]; thus the majority of pedagogical efforts should be focused on a K-8 pipeline. Second, with STEM aspirations more than with the humanities, students decide based on their ability to see long-term viability and clearly envision their own success, which requires a new pedagogy that prioritizes inventive ways of engaging self-actualization and building a positive self-image [9]. The best means of doing so, as the National Academies has long advocated, has been through hands-on lessons in the STEM fields, suggesting a pedagogy that gets students out of their chairs and gets teachers away from the whiteboard [11-14]. All of these factors combine in the four pillars of the new systems we have developed within the UConn-URI Navy STEM Coalition.

III. Methodology

The UConn-URI Navy STEM Coalition has adopted four pedagogical approaches for engaging teachers. The goal of this engagement is to enhance K-12 STEM education through the integration of naval science and engineering concepts into STEM education programming in teachers' classrooms during the academic year to promote STEM literacy and awareness of naval engineering opportunities in the region. By providing these separate mechanisms for engagement, the Coalition seeks to ensure that programs are accessible to a variety of teachers at different career stages. We take each in turn:

A. GEMS-Net Teacher Workshops

The Guiding Education in Math and Science Network (GEMS-Net) has existed at URI for 29 years. GEMS-Net is a partnership among the University of Rhode Island's Feinstein College of Education, scientists and engineers, and public school districts. They support K-8 STEM teaching and learning. Partner districts receive ongoing professional development for all teachers, curricula recommendations that align with the Common Core State Standards and Next Generation Science Standards (NGSS), and leadership development for teachers and principals. Additionally, their staff utilizes highly innovative strategies to prepare pre-service elementary and middle school teachers to be leaders in STEM education.

GEMS-Net works with partner districts to ensure that all teachers have access to high-quality curriculum materials and

that teachers attend required initial curriculum-embedded professional learning workshops throughout the school year. At the workshops, teachers engage in curriculum lessons and research-based teaching strategies in STEM education to support their students. In collaboration with the Coalition, GEMS-Net planned to integrate naval engineering topics into workshop themes and curricular resources shared within and beyond partner district classrooms. GEMS-Net also provides advanced workshops to all teachers in partner districts, bringing in-service teachers together to continue professional learning throughout their careers. In partnership with the Coalition, recent advanced workshops have focused on sharing the Coalition resources with teachers, identifying areas where the resources enhance existing science curricula, and providing time and support for teachers to develop their practice around incorporating the Coalition resources. At the workshops, teachers also have the opportunity to tour research labs and talk with engineering students about their post-secondary experience in engineering.

B. daVinci Program

The daVinci Program is a partnership between the Coalition and the Vergnano Institute for Inclusion at the University of Connecticut, a center within the College of Engineering devoted to expanding both student and teacher opportunities across southern New England. The Coalition sponsors one workshop focused on the fundamentals of naval engineering within the wider program. daVinci participants spend one week on the UConn campus, either as commuters if they live locally, or staying in the hotel on campus if they come a long distance to attend. Workshops center on a main engineering design challenge, led by a faculty member within the College and a graduate student, with participants both learning cutting edge research, and constructing lesson plans on how to integrate their workshop into their own teaching int he following year. The program is open to all K-12 teachers and workshops are designed with scalability in mind to be applicable to all age ranges. The daVinci program encourages sending districts to sponsor, at least in part, the cost of a teacher's attendance, but scholarships exist for those from districts with minimal resources – attendance comes at no cost to the teacher.

The Coalition has prioritized ensuring participants in naval engineering workshops bring home significant resources for use in the classroom to maximize hands-on learning, in line with Nugest et al. (2015), Bolden and Tymms (2020), and Kloser (2014) [7, 13, 14]. As such, in 2022 the Coalition workshop revolved around underwater robotics, with participants building a SeaPerch ™ unmanned underwater vehicle (UUV) and learning to code directions for autonomous operations. Teachers brought home the kit they built as well as two additional kits for use with their students. In 2023 the Coalition workshop taught virtual reality applications and 3D modeling in naval engineering, with teachers using SketchUp to model their own submarine, and learning how to use Unity assets to create virtual reality environments. Participants used and took home a Meta Quest 2 headset for use in their classrooms to show students the scale of a submarine, and to give their students a tour from within their own classroom.

C. UNITE Fellows

The new Undersea Naval Innovation Teacher Education (UNITE) Fellows program launched as a pilot program during summer 2024, building on the successes of the GEMS-Net teacher workshops at URI and daVinci at UConn, to reach pre-service teachers who are still pursuing their bachelor's degrees in education and/or teaching certificates in the respective states of Rhode Island and Connecticut. The UNITE program incorporates four experiences for the pre-service teachers. First, in collaboration with GEMS-Net, participants take part in several days of workshops in engineering education similar to those discussed above but modified to meet a pre-service audience. Participants learn strategies for engaging students in engineering design at a variety of grade levels as well as how to integrate Coalition resources into specific science curricular units in which the concepts students are learning relate to the naval engineering projects at URI and UConn. Second, the UNITE participants are connected to current active naval research at both universities, with participants touring and embedding in research labs to see workshop concepts applied to fundamental research (e.g. how simple circuits relate to efficient power transmission and battery storage on naval vessels, or how understanding patterns of motion and computer science concepts relate to programming the movement of drone devices that the military uses).

The third component of the UNITE Fellows Program incorporates field trips to regional submarine industrial base manufacturers. Tours include EB facilities, their suppliers, and the Naval Submarine Base New London. The fourth and final component allows fellows to test lesson plans they have been developing throughout the program by working with K-12 students via other Coalition initiatives. The program runs from mid-May to mid-June, when K-12 school districts are still in session, allowing participants to join the Coalition's existing outreach team, the UConn-URI Navy STEM Crew, on classroom visits. The Navy STEM crew will both train fellows on existing outreach programming and work with them to integrate lesson plans drafted during the UNITE Program into a pilotable activity for deployment in a classroom. Fellows will first work with the Crew over the course of the Program in outreach activities before leading an outreach event when deploying the pilot of their own lesson plan, with the goal of them gaining valuable classroom experience in creating hands-on, naval inspiring STEM lessons, and also creating a new activity for the Crew to deploy going forward.

D. GEMS-Net Teachers-in-Residence

The Teacher-in-Residence (TIR) model is an established component of the GEMS-Net program, wherein a K-8 science teacher will leave their district for 1-2 years to join the full-time GEMS-Net staff. The TIRs are typically established teacher leaders in participating districts. The Coalition leveraged this program, expanding it by funding two TIRs, one each from Rhode Island and Connecticut. Coalition-sponsored TIRs embedded with the National Institute for Undersea Vehicle Technology (NIUVT), a partnership between the flagship institutions to pursue fundamental research for the Navy to better understand the current state of cutting-edge naval research and technologies that are priorities for submarine production. Priority was given to sponsoring teachers from districts in close

proximity to the major shipbuilders or from communities with large populations of military families. The Coalition-sponsored TIRs were tasked with developing content that would support teachers in engaging K-12 students. One method used is planning, filming, and editing short videos in which researchers conducting naval-related projects share their work and ask students about connections between the research and the work in their classrooms. The TIRs also developed related scenario based tasks for students at various grade levels that use data from the research and are aligned to the Next Generation Science Standards (NGSS).

IV. Results

A. GEMS-Net Teacher Workshops

The integration of naval engineering lessons into the traditional GEMS-Net workshops was significantly well-received. As a local industry to both Connecticut and Rhode Island, the nexus between classroom learning and the immediate world around students presented an opportunity teachers appreciated, especially those from districts around major manufacturing hubs. This allowed teachers to show their students how what they are learning in science relates to jobs they could have one day or what they might study in college. This made students more excited to come to science and math lessons. As one participant noted, "[the fifth-grade advanced workshop] helped me to understand how important it is to expose students to engineering as a career choice." This priority of engaging with the pre-secondary workshops ensures those participating are bringing naval engineering into their classrooms prior to the middle school STEM decision point [7,8]. Another suggested, "[t]his workshop really helped me to see all the ways that our science connects to engineering. Very motivating in also helping us to encourage engineering as a possible profession for students later in life." This allows for a wider adaption of best practices the National Academies has been advocating for decades as the Coalition advances naval engineering across the region [11-14].

Another benefit of the Coalition's partnership with GEMS-Net was the opportunity to promote additional Coalition activities for teachers and their students. The Coalition publicized the existence of the Navy STEM Crew and began to schedule classroom visits with interested teachers for the upcoming academic year and to plan follow-up activities to the modules they had developed during the workshop.

Of particular importance, however, was that many participants expressed sentiments similar to " I really enjoyed seeing all of the labs and the work being done at URI/ UCONN." As all below programming involves extensive integration of participants into naval research labs at either or both campuses to deepen STEM pedagogies, we can utilize labs of interest as a launch point to bring teachers into additional programs for further innovative practices. Teachers interested in further training and gaining more equipment for hands-on classroom learning could be directed to the daVinci Program. Workshops are held with enough time for last minute applications to daVinci to still be submitted. Moreover, through the 2023 GEMS-Net workshop, the Coalition recruited one of the two teachers-in-residence to contribute to sustained pedagogical support of Coalition activities. In short, the workshops are important to support teachers in helping their students broaden their understanding of the diverse opportunities within engineering and inspire them to consider STEM and engineering fields as possible college and career opportunities. This is important to help support the STEM-submarine nexus quickly and also to serve as an invaluable gateway for the Coalition to support teachers in their work with students.

B. daVinci Program

While the initial deployment of SeaPerch UUV kits excited teachers, the Coalition found significantly more success and teacher uptake in the pivot to VR applications. Workshop enrollment increased 400% in the transition, and is on course for an additional 25% increase in the July 2024 offering, which will repeat the VR workshop. This is due to the ease of deployment of VR over UUV technology for teachers. While UUVs are more directly-applicable for understanding naval engineering, and a significant hands-on STEM activity, testing of a UUV requires access to a pool or other body of water. For most districts, this necessitates a field trip, and thus requesting additional funds and reworking class schedules. In budget-strained districts, this can make the use of SeaPerch kits difficult. A Quest 2 headset, however, can be easily deployed within the classroom without the need for further time or resources. There is a sacrifice in hands-on learning and depth of naval engineering engagement; however the use of cutting edge VR technology to show students the scale of a submarine does get them interested in the platforms enough to want to learn more. In this trade off, we ask teachers to commit to having Coalition outreach teams come to their classrooms to pair VR work with our own hands-on STEM programming to ensure both halves of our pedagogical system are deployed in the classroom regardless.

C. UNITE Fellows

Several difficulties emerged in the UNITE program compared to other programs, as can be expected as this is the one component of our innovation which was new in 2024. All issues stemmed from recruitment; the Coalition targeted an initial cohort of 30 fellows, but received only 5. This necessitated a shift in some of the planned programming, given the significantly smaller audience. It will, however, allow for far more granular detail in understanding the needs of pre-service teachers and how best to aid them in integrating naval engineering into their thinking around STEM pedagogy. *Post hoc* recruitment assessments have considered how best to market the program and timing to best recruit participants. A stronger emphasis on gaining experience in the classroom is necessary in further offerings, as recruitment was impacted by participants waiting to commit until after determinations were made on summer internships to see if they had been placed in a school distinct for the remainder of the K-12 academic year.

Authors note that this program, as a new offering in 2024, has yet to conclude, and is ongoing at time of submission. Full preliminary data is thus not available. Should this preliminary draft be accepted for full submission, our final submission will include results from the UNITE cohort which concludes in June 2024. We intend to detail which aspects of the program worked best for developing pre-service teachers skills in the classroom, and which areas of their STEM curriculum development

abilities they felt benefited the most and least from UNITE programming.

D. GEMS-Net Teachers-in-Residence

For the 2023-2024 academic year, 2 teachers-in-residence (TIR) were hired using funding through the Coalition's current NDEP grant from the Department of Defense. One TIR was a middle school science teacher who had previously been a GEMS-Net TIR helping with the planning of teacher workshops and activities that were not Navy-specific. The other TIR was specifically recruited from a district with a high military presence due to the proximity of a Navy base and major submarine shipbuilder. Overall, this initiative to hire TIRs who bridge the connection between the Navy STEM Coalition and GEMS-Net has provided numerous synergistic benefits.

The Coalition-sponsored TIRs worked with GEMS-Net staff to develop a variety of curricular resources, including videos and scenario-based data analysis tasks for distribution, which directly tie cutting-edge naval research in topics such as additive manufacturing and human factors to K-8 STEM curricula. These resources prioritize classroom engagement strategies in line with the pedagogical structure of other Coalition activities across classroom outreach initiatives and in line with research best practices [13, 14]. Each module has a brief video that relates to existing lessons within high-quality science curricula for a specific grade level, student-facing tasks, and support materials for teachers, including alignment with relevant NGSS standards. This allows teachers to flexibly use any or all provided materials to meet their needs in various classroom contexts. Coalition-funded materials are open source and freely available for wider distribution, allowing teachers to use submarine production in southern New England as a means of directly relating what students are learning in the classroom to the real world. Such open-source artifacts and resources have been presented at GEMS-Net Teacher workshops during the spring semester of 2024 and were also presented at the National Science Teaching Association (NSTA) national conference in Denver during March 2024, allowing for both local and national distribution, tying to the immediate and wider submarine industrial base. Examples of current open source materials can be found at the following links:

https://web.uri.edu/naval-science-technology/curriculum/
https://web.uri.edu/gemsnet/navy-stem-resources/

The Coalition will continue to replicate and expand this program over the next five years of the program; the Coalition intends to continue funding at least two TIRs through the GEMS-Net program for this duration. We intend to expand pedagogical offerings to meet the full K-8 range with subsequent TIR cohorts and to further grow our reach nationally, ensuring our materials are able to reach all areas with significant concentrations of manufacturing relevant to the submarine industrial base beyond southern New England.

V. Conclusions

The UConn-URI Navy STEM Coalition was established to address the crucial need for a STEM-literate workforce in the submarine industrial base as the Navy seeks to dramatically expand its procurement expectations over the next decade [1-8]. To meet the goal of 10,000 hires year over year, the entire industrial base must significantly rethink how they approach recruitment, and that has required the Coalition to innovate on our pedagogy. While direct K-12 classroom visits have been rewarding and impactful, to meet the scale of the crisis, we have expanded our work to include support for teachers to ensure we are able to magnify our impact and integrate naval engineering STEM lessons within the region, even when we are not in the classroom ourselves, and even in districts with which we do not have the capacity to partner.

As such, we have pioneered four innovative areas for providing K-12 support of increasing intensity and scope to sustain our classroom impact. From workshops with regional teachers to provide professional learning on integrating naval engineering into current science curricula, to year-long residency programs, and from working with pre-service to veteran teachers, the Coalition has created resources to integrate naval engineering across the elementary and middle school grades. Through videos and related resources developed with GEMS-Net and shared in workshops, teachers can use cutting-edge research at research university labs to integrate topics of naval significance into a middle school STEM lesson. After attending daVinci, a teacher can use a VR headset to show their students how big a real submarine is, and get them excited about the prospect of being involved in designing and building one. Across our programming, the Coalition has been able to reach over 6,000 students and dozens of teachers. With further development and integration of our transformative pedagogies, we look forward to the long-term impact of this integration of the real-world applications of STEM to submarines inspiring current 6th graders to become part of those building the next generation of submarines by 2032.

References

[1] A. Grey, "The submarine workforce crisis: admitting realities and restructuring long-term strategy," War on the Rocks. Accessed: Apr. 04, 2024. [Online]. Available: https://warontherocks.com/2024/04/the-submarine-workforce-crisis-admitting-realities-and-restructuring-long-term-strategy/.

[2] Chief of Naval Operations, "Navigation plan 2022," United States Navy, Arlington, VA, 2022. Accessed: Jul. 20, 2023. [Online]. Available: https://media.defense.gov/2022/Jul/26/2003042389/-1/-1/1/NAVIGATION%20PLAN%202022_SIGNED.PDF.

[3] R. O'Rourke, "Navy Virginia (SSN-774) class attack submarine procurement: background and issues for Congress," Congressional Research Service, Washington, D.C., RL32418, Jul. 2023. Accessed: Jul. 22, 2023. [Online]. Available: https://sgp.fas.org/crs/weapons/RL32418.pdf.

[4] United States Government Accountability Office, "Weapon systems annual assessment: programs are not consistently implementing practices that can help accelerate acquisitions," The United States Government Accountability Office, Washington, D.C., GAO-23-106059, Jun. 2023. Accessed: Sep. 04, 2023. [Online]. Available: https://www.gao.gov/assets/gao-23-106059.pdf.

[5] J. Bergman, "Institute to help bulk up silicon valley of undersea warfare officials say," CT.gov - Connecticut's Official State Website. Accessed: May 11, 2024. [Online]. Available: https://portal.ct.gov/oma/in-the-news/2018-news/institute-to-help-bulk-up-silicon-valley-of-undersea-warfare-officials-say.

[6] E. Hallenbeck, "Electric Boat hopes to hire 5750 employees this year," CT.gov - Connecticut's Official State Website. Accessed: Jul. 20, 2023. [Online]. Available: https://portal.ct.gov/OMA/In-the-News/2023-News/Electric-Boat-hopes-to-hire-5750-employees-this-year.

[7] G. Nugent, B. Barker, G. Welch, N. Grandgenett, C. Wu, and C. Nelson, "A model of factors contributing to stem learning and career orientation," International Journal of Science Education, vol. 37, no. 7, pp. 1067–1088, May 2015, doi: 10.1080/09500693.2015.1017863.

[8] E. Elliniadou and C. Sofianopoulou, "A STEM intervention on students' attitudes towards science," in 2022 IEEE Global Engineering Education Conference (EDUCON), Mar. 2022, pp. 386–393. doi: 10.1109/EDUCON52537.2022.9766715.

[9] L. S. Gottfredson, "Circumscription and compromise: A developmental theory of occupational aspirations," Journal of Counseling Psychology, vol. 28, no. 6, pp. 545–579, 1981, doi: 10.1037/0022-0167.28.6.545.

[10] C. K. Y. Chan, N. C. J. Yeung, P. Kutnick, and R. Y.-Y. Chan, "Students' perceptions of engineers: dimensionality and influences on career aspiration in engineering," Int J Technol Des Educ, vol. 29, no. 3, pp. 421–439, May 2019, doi: 10.1007/s10798-018-09492-3.

[11] L. K. Jones and R. L. Hite, "A global comparison of the circumscription and compromise theory of career development in science career aspirations," School Science and Mathematics, vol. 121, no. 7, pp. 381–394, 2021, doi: 10.1111/ssm.12492.

[12] S. W. K. Chiu and W. W. M. So, "STEM career aspiration: does students' social identity matter?," Asia Pacific Journal of Education, Aug. 2022, Accessed: May 08, 2024. [Online]. Available: https://www.tandfonline.com/doi/abs/10.1080/02188791.2022.2108758.

[13] D. Bolden and P. Tymms, "Standards in education: reforms, stagnation and the need to rethink," Oxford Review of Education, vol. 46, no. 6, Jul. 2020, doi: 10.1080/03054985.2020.1781608.

[14] M. Kloser, "Identifying a core set of science teaching practices: a delphi expert panel approach," Journal of Research in Science Teaching, vol. 51, no. 9, pp. 1185–1217, 2014, doi: 10.1002/tea.21171.

[15] E. T. Myint and R. D. Robnett, "Correlates of adolescents' STEM career aspirations: the importance of academic motivation, academic identity, and gender," Eur J Psychol Educ, vol. 39, no. 1, pp. 189–209, Mar. 2024, doi: 10.1007/s10212-023-00681-w.

[16] C. Davenport et al., "A theory of change for improving children's perceptions, aspirations and uptake of stem careers," Res Sci Educ, vol. 51, no. 4, pp. 997–1011, Aug. 2021, doi: 10.1007/s11165-019-09909-6.