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SCAFFOLDING 3D ENGINE ROOM SIMULATION IN MULTIPLE COURSES IN A BACCALAUREATE PROGRAM TO MAXIMIZE STUDENT LEARNING

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Abstract. The increasing complexity of modern marine engineering necessitates highly competent professionals. Traditional educational methods often struggle to provide sufficient hands-on experience due to safety concerns, costs, and logistical limitations. Marine engine simulation software offers a viable alternative for practical training. The Marine Engineering Technology program at Texas A&M University at Galveston has implemented an innovative method to incorporate 3D engine room simulations in multiple courses, thereby maximizing student learning. First-person 3D simulation exposes students to modern vessels and their design. This forces students to become familiar with the equipment function, layout, and location in an engineering setting. Many of the students have never been on a ship before their freshmen year, and this is the first exposure they will receive. This better prepares them to work on the vessel during school for safety and competence. Methods of delivery include individual workstations, virtual reality, and full mission. We have model types in emerging technologies, such as dual-fuel slow-speed, dual-fuel medium-speed, and hybrid vessels (utilizing batteries and power take-off). We have multiple modes of propulsion for steam and diesel gas turbines. The study compares the impact of this effort on student learning by comparing the results of student performance before and after the implementation. Another feature of the study is to compare student learning before and after scaffolding was implemented by incorporating 3D exercises into eight courses, as opposed to the legacy usage in three courses. Results show substantial improvement in student engagement and learning. The metrics used to assess student performance include the lab exercises and reduced time to cover the materials. These indicators are compared for the three legacy courses: Steam, Diesel, and Gas Turbine.

Keywords: Scaffolding; Marine Engineering Education; Simulation Software; Student Learning; Competency-Based Education; Curriculum Development.

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1. INTRODUCTION

The global maritime industry is undergoing rapid technological advancements, characterized by increasingly sophisticated vessel designs, complex propulsion systems, and digital integration. Consequently, the demand for marine engineers equipped with advanced technical skills, robust problem-solving abilities, and practical operational experience is escalating (IMO, 2020). However, traditional marine engineering education faces significant challenges in providing adequate experiential learning opportunities. The high cost of physical engine room laboratories, safety risks associated with operating live machinery, and the sheer logistical complexity of hands-on training often limit student exposure to real-world scenarios.

Marine engine simulation software has emerged as a powerful tool to bridge this gap, offering realistic, risk-free, and accessible environments for training (San Jacinto College, n.d.; Seaplify, 2024). While the benefits of simulation in maritime education are widely recognized, its full potential in fostering deep, long-term learning can be further unleashed through a structured pedagogical approach. This paper advocates for the strategic integration of marine engine simulation software within a **scaffolded learning framework** across the entire four-year marine engineering technology curriculum at Texas A&M University at Galveston. By progressively building knowledge and skills from foundational concepts in the freshman year to advanced operational and troubleshooting scenarios in the senior year, this approach aims to optimize student learning, enhance practical competency, and prepare graduates for the complexities of modern marine engineering.

2. LITERATURE REVIEW

2.1. Scaffolding in Education

The concept of "scaffolding" in education, first introduced by Wood, Bruner, and Ross (1976), is rooted in Vygotsky's (1978) sociocultural theory of cognitive development, particularly the **Zone of Proximal Development (ZPD)**. The ZPD defines the range of tasks that a learner cannot yet perform independently but can accomplish with the guidance and support of a more knowledgeable other (e.g., an instructor, peer, or even intelligent software).

Key characteristics of effective scaffolding include:

- **Contingency:** The level of support is adjusted based on the learner's evolving understanding and performance (Fretz et al., 2007).
- **Fading:** As the learner becomes more proficient, the support is gradually reduced or "faded" until they can perform the task independently (GCU Blog, n.d.).
- **Transfer:** Scaffolding aims to facilitate the transfer of learned skills and knowledge to new, more complex contexts (Collins et al., 1989).
- **Focusing Attention:** It helps learners prioritize and concentrate on the most critical aspects of a problem or task (Cambridge Handbook of the Learning Sciences, 2022).

Research consistently demonstrates the benefits of scaffolding across various educational domains, including STEM education. It enhances information retention, boosts student engagement and self-efficacy, minimizes frustration, and fosters critical thinking and problem-solving skills (GCU Blog, n.d.;

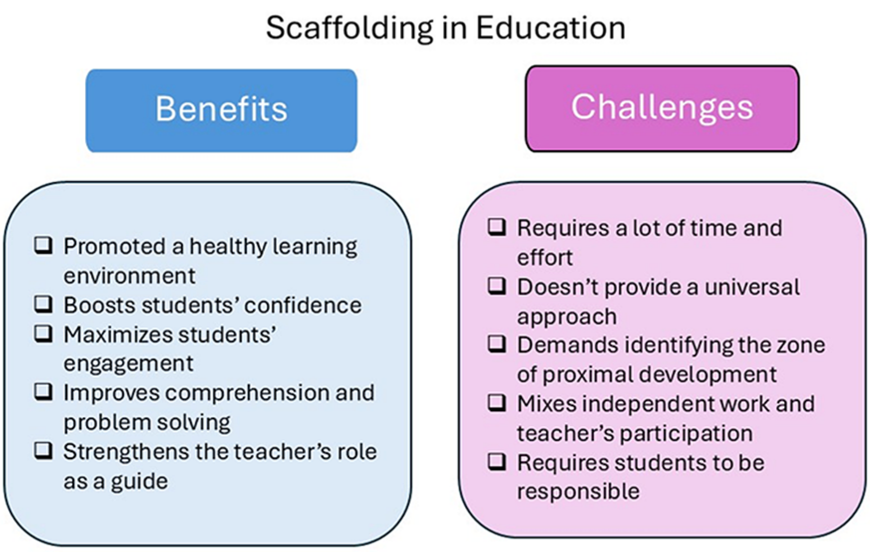

Figure 1. Scaffolding in Education

ResearchGate, n.d.). In complex learning settings, such as engineering, scaffolding is particularly important for managing task complexity and addressing individual learner needs (Hermkes et al., 2022). Both "macro-scaffolding" (curricular design, learning materials) and "micro-scaffolding" (instructor-provided support during learning) contribute to effective learning (Boldrini & Cattaneo, 2013). Furthermore, virtual or computer-based scaffolding, often integrated into simulation environments, has shown to accelerate engagement and learning by providing structured guidance and feedback (Evanick, 2021; ResearchGate, n.d.). In addition to the benefits, scaffolding presents some challenges too as illustrated in Fig. 1.

2.2. Marine Engine Simulation Software in Education

Marine engine simulation software provides a virtual representation of ship propulsion and auxiliary systems, allowing students to interact with realistic controls, monitor performance, and respond to various operational and emergency scenarios without the risks and costs associated with live machinery (Kongsberg Maritime, n.d.). The International Maritime Organization (IMO) has outlined two basic definitions for simulation:

- ERS I: Desktop-based, suitable for procedural and conceptual training.
- ERS II: Full-mission simulators replicating real engine rooms, ideal for teamwork, communication, and emergency drills.

Leading commercial simulators, such as Kongsberg K-Sim Engine and L3Harris On-Board Training System (OBTS), offer a range of functionalities, from desktop-based training modules (ERS I) to full-mission engine room simulators (ERS II) with 3D walk-through capabilities and realistic sounds and alarms (Kongsberg Maritime, n.d.; L3Harris, n.d.).

The advantages of using marine engine simulation software in maritime education are well-documented:

- **Immersive and Realistic Training:** Simulators create highly immersive environments, allowing trainees to interact with equipment, practice procedures, and experience various conditions, including malfunctions and emergencies (Seaplify, 2024; Kompanions, 2025).
- **Safe and Risk-Free Learning:** Students can experiment, make mistakes, and learn from consequences in a controlled virtual environment without endangering personnel, equipment, or the environment (Seaplify, 2024).
- **Cost-Effectiveness and Accessibility:** While initial investment can be substantial, simulators offer long-term cost savings compared to operating and maintaining physical labs. Cloud-based solutions further enhance accessibility, enabling training anytime, anywhere (Kongsberg Maritime, n.d.; Seaplify, 2024).
- **Customizable and Dynamic Scenarios:** Instructors can tailor training modules to specific vessel types, engine models, and create a wide array of dynamic scenarios, from routine operations to complex emergency responses (Seaplify, 2024).
- **Enhanced Knowledge Retention and Skill Development:** The interactive and experiential nature of simulation-based training leads to greater knowledge retention, improved skill development, and faster acquisition of competencies (Kompanions, 2025).
- **Competency-Based Assessment:** Simulators are effective tools for assessing student competence in accordance with international standards like the STCW Convention, providing a structured way to measure proficiency in tasks and duties (DNV, n.d.; IJELS, 2024).

The integration of digital twin technology, which creates a living virtual replica continuously updated with real-time data, further promises to enhance the realism and predictive maintenance aspects of future marine engineering education (Mercator Ocean, n.d.; SciOpen, 2025).

3. PROPOSED METHODOLOGY

Texas A&M University at Galveston, Department of Marine Engineering Technology, is uniquely positioned to implement a progressive, scaffolded approach to marine engine simulation training across its undergraduate curriculum. The core idea is to introduce complexity gradually, providing increasing levels of challenge and autonomy as students progress through their academic years. Drawing on Vygotsky's Zone of Proximal Development, this methodology systematically introduces complexity. In the freshman year, simplified simulation modules will introduce basic components and safety. Sophomore and junior years will focus on routine operations, system interactions, and basic troubleshooting. The senior year will involve advanced diagnostics, emergency response, and optimization scenarios using full-mission or advanced desktop simulators. Support will progressively fade as students gain proficiency, ranging from high instructor guidance for freshmen to minimal intervention for seniors. Assessment will transition from knowledge-based quizzes to per-

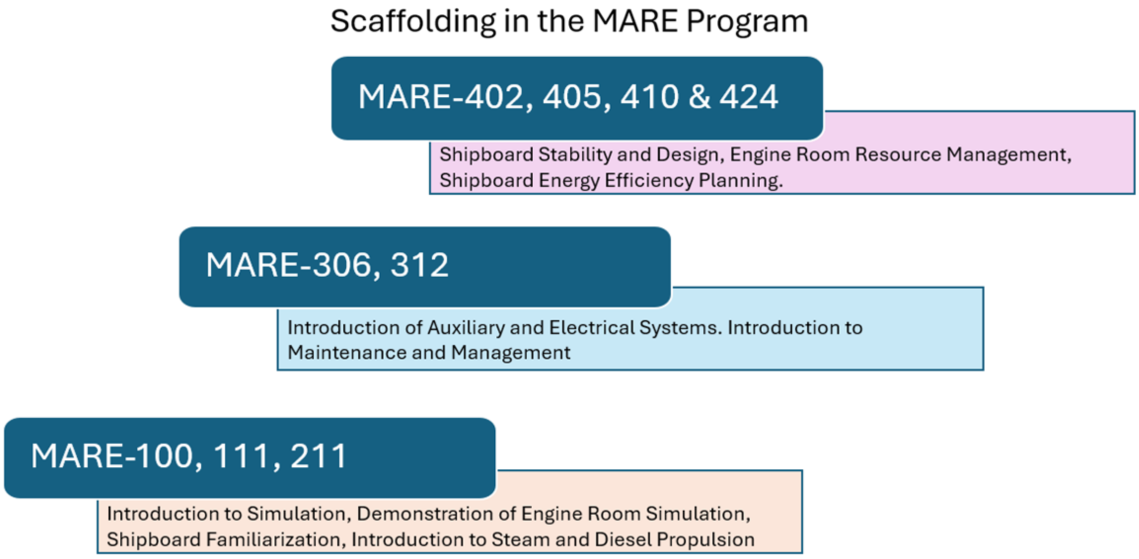

Figure 2. Scaffolding in MARE Program

formance-based evaluations, aligning with STCW competencies. This macro-scaffolding approach will be complemented by micro-scaffolding techniques employed by instructors within each simulation session. Fig. 2 shows the scaffolding of simulation into various courses at freshmen, junior and senior levels.

3.1. Phased Implementation Across the Curriculum

Freshman Year (e.g., MARE 100 – Foundations in Marine Engineering, MARE 111 – Methods in Engineering Technology, and MARE 211 – Steam Propulsion):

- **Focus:** Basic familiarization, safety, and fundamental concepts.
- **Simulation Use:** Simplified modules of the marine engine simulator (e.g., desktop versions, perhaps cloud-based for individual practice). Students will learn to:
    - Identify major engine room components and their functions (e.g., main engine, generators, pumps, purifiers).
    - Navigate the virtual engine room environment and control panels.
    - Understand basic operational procedures (e.g., starting/stopping auxiliary machinery, basic pumping operations).
    - Recognize common alarms and their immediate implications.
- **Scaffolding:** High level of instructor guidance; structured walkthroughs; pre-defined, simple scenarios; checklists for tasks; frequent debriefings focusing on conceptual understanding and safety protocols. The emphasis is on building a foundational mental model of the engine room.

Sophomore/Junior Year (e.g., MARE 306 – Electrical Power II and MARE 312 Diesel Propulsion):

- **Focus:** System interactions, routine operations, performance monitoring, and basic troubleshooting.
- **Simulation Use:** More comprehensive engine models. Students will engage in:
    - Performing sequential start-up and shutdown procedures for the entire propulsion plant.
    - Monitoring engine parameters, analyzing performance data, and identifying deviations from normal operation.
    - Executing routine maintenance procedures (e.g., fuel oil transfer, lube oil purification).
    - Responding to pre-programmed, common fault scenarios (e.g., loss of a pump, high temperature alarm).
    - Team-based problem-solving scenarios, encouraging communication and collaborative decision-making.
- **Scaffolding:** Moderate instructor guidance; introduction of more complex, multi-step scenarios; prompts for critical thinking and diagnostic questions; peer-to-peer learning opportunities; gradual reduction of direct instructions, encouraging students to consult manuals or schematics within the simulation.

Senior Year (e.g., MEEN 402 – Shipboard Automation & Control, MARE 405 – Fundamentals of Naval Architecture & MARE-410 – Marine Engine, Energy & Electrical resource Management):

- **Focus:** Advanced troubleshooting, emergency response, energy management, optimization, and complex decision-making.
- **Simulation Use:** Full-mission simulator or advanced desktop versions with highly realistic fault injection capabilities. Students will undertake:
  - Diagnosing and rectifying complex, cascaded faults that require deep system understanding.
  - Managing major emergency situations (e.g., blackout, fire, flooding).
  - Optimizing engine performance for fuel efficiency and emissions reduction.
  - Developing and executing complex operational plans under varying conditions.
  - Serving as "Officer of the Watch" in realistic watchkeeping scenarios, managing a team in the simulated environment.
  - Potentially integrating with digital twin concepts for predictive maintenance exercises.
- **Scaffolding:** Minimal direct instructor intervention, primarily acting as a facilitator or evaluator; emphasis on student autonomy and self-directed problem-solving; post-scenario critiques and reflective analysis; focus on justification of decisions and strategic thinking. Scenarios will be open-ended, requiring students to define the problem and devise solutions.

3.2. Phased Implementation Across the Curriculum

The chosen marine engine simulation software should ideally offer modularity, allowing for varying levels of complexity and fidelity suitable for different academic years. Features such as interactive schematics, 3D walk-throughs, performance graphing, and a robust fault injection system are crucial.

Assessment will be integrated throughout the curriculum, moving from knowledge-based quizzes in earlier years to performance-based assessments in later years. This includes:

- **Freshman:** Identification tasks, basic operational checklists, multiple-choice questions on system components.
- **Sophomore/Junior:** Practical simulation tasks with performance metrics (e.g., time to rectify a fault, adherence to procedures), short answer questions on system interactions.
- **Senior:** Complex scenario evaluations, debriefings on decision-making processes, team-based project reports, and oral examinations justifying operational choices. The assessment criteria will align with STCW competencies relevant to each level of learning.

4. RESEARCH DESIGN

A quasi-experimental, longitudinal, mixed-methods approach will be used to examine the impact of scaffolding simulation software on student learning, both before and after implementation. The primary research question will include: "How does the implementation of scaffolding within marine simulation software affect the learning outcomes (e.g., skill acquisition, conceptual understanding, decision-making, self-efficacy) of two cohorts of students in maritime education programs?". We will use both quantitative and qualitative data to obtain a comprehensive understanding of the intervention's impact. The control cohort will include past performances of students in scaffolded courses shown in Figure 2. The intervention cohorts will include students in the same courses post implementation.

4.1. Data Collection Instruments and methods

4.1.1. Quantitative Measures: Following quantitative measures will be used.

- **Pre-test/Post-test Assessments**
- **Simulation Performance Metrics**
- **Skill Performance Rubrics**
- **Self-Efficacy Scales**
- **Software Usage Logs**

4.1.2. Qualitative Measures: Following qualitative measures will be used.

- **Student Interviews/Focus Groups**
- **Instructor Interviews**
- **Classroom Observations**
- **Open-ended Survey Questions**

5. EXPECTED OUTCOMES & BENEFITS

Implementing a scaffolded approach to marine engine simulation training is expected to yield numerous benefits for Texas A&M University at Galveston students and the broader maritime industry:

1. Enhanced Conceptual Understanding: By starting with simplified models and gradually increasing complexity, students will develop a robust understanding of marine engine principles and system interdependencies.

2. Improved Problem-Solving and Critical Thinking Skills: Exposure to progressively challenging fault scenarios will hone students' diagnostic abilities, encouraging systematic troubleshooting and critical decision-making under pressure.

3. Increased Practical Proficiency and Operational Readiness: Repeated practice in a realistic virtual environment will significantly improve students' operational skills, familiarizing them with controls, procedures, and emergency responses, thereby reducing the learning curve upon entering the workforce.

4. Greater Student Engagement and Motivation: The interactive and experiential nature of simulation, coupled with achievable challenges facilitated by scaffolding, is expected to increase student interest and motivation in marine engineering.

5. Safer Learning Environment: Complex or dangerous operations can be safely practiced and perfected in a virtual setting without any risk of injury or equipment damage.

6. Cost-Effectiveness: While initial software investment exists, long-term operational costs for hands-on training are reduced, and students gain exposure to a wider range of machinery than typically available in physical labs.

7. Development of "Digital Native" Engineering Skills: Students will become proficient in using advanced simulation tools, a valuable skill set in an increasingly digitalized maritime industry, and will be better prepared for emerging technologies like digital twins.

8. Alignment with Industry Standards: The approach supports the development of competencies aligned with international standards such as the STCW Convention, ensuring graduates meet global requirements.

6. CHALLENGES & LIMITATIONS

Despite the significant advantages, several challenges need to be addressed for successful implementation:

- **Initial Investment:** Acquiring high-quality marine engine simulation software and hardware can require a substantial initial investment.
- **Faculty Training:** Instructors will require comprehensive training not only in operating the simulation software but also in effectively applying scaffolding techniques and designing progressive learning scenarios.
- **Curriculum Integration:** Seamless integration of simulation modules into existing course structures and learning outcomes will require careful planning and coordination across the department.
- **Realism and Transferability:** While highly realistic, simulations are not perfect substitutes for actual hands-on experience. A balance must be maintained, and opportunities for physical lab work or shipboard training should complement the simulation.
- **Software Maintenance and Updates:** Ensuring the simulation software remains current with technological advancements in marine engineering will be an ongoing need.

7. CONCLUSIONS

The integration of marine engine simulation software with a scaffolded learning methodology offers a transformative approach to marine engineering education. By providing progressively challenging yet supported learning experiences from freshman to senior year, Texas A&M University at Galveston can equip its students with unparalleled conceptual understanding, practical proficiency, and problem-solving capabilities. This systematic framework not only enhances student engagement and knowledge retention but also produces graduates who are highly competent, adaptable, and ready to meet the complex demands of the modern maritime industry. This will lead to the graduation of highly competent, adaptable professionals well-prepared for the demands and technological advancements of the modern maritime industry. As technology continues to evolve, this pedagogical model will ensure that marine engineers are not just trained for the present but are prepared to innovate and lead in the future. This paper presents a proposed framework, and empirical results from this study will be presented at a future IMLA conference. The expected outcomes include improved conceptual understanding, enhanced problem-solving and critical thinking, increased practical proficiency, greater student engagement, a safer learning environment, cost-effectiveness, and the development of essential digital engineering skills.

Conflict of interest: The authors declare no conflict of interest.

REFERENCES

Boldrini, E. & Cattaneo, A., 2013. Macro and micro scaffolding to foster problem-solving skills in higher education. *Journal of Problem Based Learning in Higher Education*, 1(2), 17-29. Cambridge Handbook of the Learning Sciences, 2022. Scaffolding (Chapter 3). Available at: https://www.cambridge.org/core/books/cambridge-handbook-of-the-learning-sciences/scaffolding/5AE10BE45F8CA2D5D69B0B0D42C69D59.

Collins, A., Brown, J. S. & Newman, S. E., 1989. Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In: L. B. Resnick, ed. *Knowing, learning, and instruction: Essays in honor of Robert Glaser*. Lawrence Erlbaum Associates, pp. 453-494.

DNV, n.d. *Qualified Marine Assessor (Behavioural Competency Assessment)*. Available at: https://www.dnv.com/training/qualified-marine-assessor-behavioural-competency-assessment-114237/.

Evanick, J., 2021. Virtual Scaffolding-Induced Engagement & Learning Trends by Simulation Phase. *Developments in Business Simulation and Experiential Learning, Proceedings*, 52. Available at: https://absel-ojs-ttu.tdl.org/absel/article/view/3444/3383.

Fretz, E. B. et al., 2007. Supporting middle school science teachers' inquiry-based practice through curriculum materials and professional development. *Journal of Research in Science Teaching*, 44(4), 594-611. Available at: http://dx.doi.org/10.1002/tea.20170.

GCU Blog, n.d. *What Is Scaffolding in Education and How Is It Applied?* Grand Canyon University. Available at: https://www.gcu.edu/blog/teaching-school-administration/what-scaffolding-in-education-how-applied.

Hermkes, M. J., Wetzels, P. & Kirschner, P. A., 2022. Micro-scaffolding for problem-solving performance and learning in complex learning environments. *Educational Technology Research and Development*, 70(4), 1369-1393. Available at: http://dx.doi.org/10.1007/s11423-022-10118-2.

International Journal of English Literature and Social Sciences (IJELS), 2024. Competencies of Marine Engineering Students of a Maritime Higher Education Institution. *International Journal of English Literature and Social Sciences*, 9(3), 205-212. Available at: https://ijels.com/upload_document/issue_files/31IJELS-106202438-Competencies.pdf.

International Maritime Organization (IMO), 2020. *International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), 1978, as amended*. IMO Publishing. Kompanions, 2025. *VR Marine Training: Enhancing Safety in the Maritime Industry*. Available at: https://www.kompanions.com/blog/vr-marine-training-enhancing-safety-in-maritime-industry/.

Kongsberg Maritime, n.d. *K-Sim® Engine*. Available at: https://www.kongsberg.com/maritime/products/simulation/k-sim-engine/.

L3Harris, n.d. *Marine Training & Simulation*. Available at: https://www.l3harris.com/all-capabilities/marine-training-simulation.

Mercator Ocean, 2022. n.d. *Digital Twin Ocean*. Available at: https://digitaltwinocean.mercator-ocean.eu/.

Belland, B. R., 2017. *Instructional Scaffolding in STEM Education*. Available at: https://www.researchgate.net/publication/311998972_Instructional_Scaffolding_in_STEM_Education.

San Jacinto College, n.d. *Maritime Simulation*. Available at: https://www.sanjac.edu/information-for/business-partners/maritime/simulation.

SciOpen, 2025. The application and development of digital twin in the marine domain. *Ocean Engineering and Marine Energy*. Available at: https://www.sciopen.com/article/10.26599/OCEAN.2025.9470001.

Seaplify, 2024. *VR in Engine Room Simulators: Benefits & Challenges*. Available at: https://blog.seaplify.com/vr-in-engine-room-simulators-benefits-challenges/.

Schwarz, C. V., Reiser, B. J. & Davis, E. A., 2009. The Cambridge Handbook of the Learning Sciences. In: R. K. Sawyer, ed. *The Cambridge Handbook of the Learning Sciences*. Cambridge University Press, pp. 370-386.

Vygotsky, L. S., 1978. *Mind in society: The development of higher psychological processes*. Harvard University Press. Wood, D., Bruner, J. S. & Ross, G., 1976.