Equivalent: Jurnal Ilmiah Sosial Teknik
Volume 8, Issue 6, 2536-2545
e_ISSN: 2775-0833
https://jurnalequivalent.id/index.php/jequi/index
DOI: doi.org/10.59261/jequi.v8i6.487

Ultrasonic Sensor-Based Practical Learning as a Conceptual Bridge to Echosounder and RADAR Principles for Nautical Cadets

Mukhlas Hamdani*
Politeknik Pelayaran Sorong, Indonesia

Fadel Muhammad
Politeknik Pelayaran Sorong, Indonesia

Yudhiyono
Politeknik Pelayaran Sorong, Indonesia

Arief Nashrul Firdani
Politeknik Pelayaran Sorong, Indonesia

Ryan Puby Sumarta
Politeknik Pelayaran Sorong, Indonesia

***Corresponding author:**
Mukhlas Hamdani, Politeknik Pelayaran Sorong, Indonesia.
✉mukhlashamdani@gmail.com

Article Info:

***Article history*:**
Received: September 25, 2026
Revised: November 14, 2026
Accepted: November 18, 2026
Available Online: November 24, 2026

Keywords:
Ultrasonic Sensor;
Practical Learning;
Nautical;
Echosounder;
RADAR;

This is an open access article under the CC BY-SA license.

Copyright © 2026 by Author. Published by Politeknik Siber Cerdika International

Abstract

Background: This study aims to describe the implementation of ultrasonic sensor-based practical learning as a technology-oriented instructional medium for nautical cadets and to examine its pedagogical relevance as a classroom analogy for introducing the fundamental operating principles of echosounders and RADAR.
Methods: A descriptive quantitative approach was employed in the *Teknologi Informatika II* course, involving 22 cadets from the Diploma III Nautical Studies program, Class SN2A. The practical activity involved assembling, connecting, testing, operating, and troubleshooting an ultrasonic sensor system. The sensor's operating principles were subsequently related conceptually to signal transmission, echo detection, travel-time measurement, and distance estimation in maritime navigation technologies. Data were obtained from the Practical Final Examination (PFE) scores and analyzed using descriptive statistics.
Results: The results showed a mean PFE score of 76.36 among the 22 cadets, reflecting their practical achievement within the learning context. However, this finding does not establish a causal improvement in learning outcomes because the study did not employ a pretest–posttest design or include a comparison group. From a pedagogical perspective, the practical activity provided cadets with hands-on experience in observing signal transmission, echo detection, travel-time measurement, and distance estimation. These principles provide a conceptual bridge to understanding echosounder technology, while the connection to RADAR is framed within the broader concept of active ranging, recognizing that ultrasonic sensors use acoustic waves, whereas RADAR uses electromagnetic waves.
Conclusion: The findings indicate that an ultrasonic sensor can serve as a simple and accessible practical learning medium for connecting hands-on classroom experience with the more complex concepts underlying maritime navigation technologies.

To cite this article: Hamdani, M., Muhammad, F., Yudhiyono, Firdani, A. N., & Sumarta, R. P. (2026). Ultrasonic sensor-based practical learning as a conceptual bridge to echosounder and RADAR principles for nautical cadets. *Equivalent: Jurnal Ilmiah Sosial Teknik*, *8*(6), 2536-2545. https://doi.org/10.59261/jequi.v8i6.487

INTRODUCTION

Maritime education and training (MET) plays an important role in preparing future seafarers to perform their professional duties safely, effectively, and in accordance with international competency standards (Barasa et al., 2025; Chibana, 2024; Malau et al., 2025). The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers

(STCW) provides the international framework for seafarer education, training, certification, and watchkeeping, emphasizing the development of the knowledge, understanding, skills, and competence required for shipboard operations (International Maritime Organization, 2024). Within this framework, maritime education should not be limited to the transmission of theoretical knowledge but should also provide learning experiences that enable cadets to apply concepts relevant to their future professional responsibilities.

The increasing integration of electronic, digital, and sensor-based technologies into modern ships has heightened the need for technology-oriented learning in maritime education. Navigation, monitoring, communication, and safety systems increasingly rely on sensors and digital signal processing, yet their underlying operating principles are not always readily observable during conventional instruction (Cai et al., 2023). This highlights the need for accessible, hands-on learning activities that introduce the fundamental principles underlying maritime technologies.

One challenge in technology-oriented maritime education is the gap between conceptual knowledge and direct practical experience. Cadets may be familiar with the names and functions of navigation equipment without having directly observed how sensing and ranging processes work. High-fidelity maritime simulators are valuable for advanced training, but they may not always be available for introductory practical activities. Low-cost, hands-on activities can therefore provide an intermediate learning stage by making fundamental processes, such as signal transmission, reflection, and distance estimation, observable.

Hands-on learning provides opportunities for learners to interact directly with physical objects, tools, electronic components, and technological systems. Through direct experimentation, abstract concepts can be translated into observable processes and connected with concrete experiences. This approach is consistent with experiential learning, which describes learning as a process involving concrete experience, reflective observation, abstract conceptualization, and active experimentation (Cheng et al., 2019; Passarelli & Kolb, 2023). Evidence from STEM and engineering education has also demonstrated the value of active and hands-on learning in promoting learner engagement and supporting academic performance (Oje et al., 2021; Ramasamy et al., 2024; Tijani & Adeduyigbe, 2026). In maritime education, this approach can provide an intermediate learning stage between theoretical instruction and practical engagement with more complex professional equipment.

Sensors are particularly suitable for this purpose because they enable learners to observe how physical phenomena are converted into measurable information. Sensor-based activities allow students to interact with technological systems, observe changes in measurements, identify operational problems, and investigate the relationships between system inputs and outputs. Previous studies have demonstrated the educational value of hands-on engineering and sensor-based activities in marine and ocean-related education. These studies suggest that relatively simple sensor systems can provide learners with practical exposure to technological principles before they encounter more sophisticated professional technologies.

Among various sensor technologies, ultrasonic sensors provide an accessible example of distance measurement based on signal propagation and reflection. An ultrasonic ranging system transmits an acoustic pulse toward a target and detects the returning echo. The elapsed time between transmission and reception can then be used to estimate the distance between the sensor and the target according to the time-of-flight principle:

$$d = \frac{vt}{2}$$

where d represents the distance between the sensor and the target, v represents the propagation velocity of the acoustic signal, and t represents the round-trip travel time. Time-of-flight techniques are widely used in ultrasonic ranging to estimate distance from acoustic signal travel time. Because the measurement process can be directly observed by changing the position of a target and monitoring the resulting sensor output, ultrasonic sensing provides a relatively simple context for introducing signal transmission, echo detection, travel-time measurement, and distance estimation.

The pedagogical relevance of this principle becomes particularly apparent when it is

connected to maritime navigation technologies. An echosounder similarly operates by transmitting an acoustic signal and detecting the returning echo to obtain information about underwater distance or depth. Although the operating environments and technical specifications differ substantially, the sequence of signal transmission, echo reception, travel-time measurement, and distance estimation provides a useful conceptual connection. Previous work has demonstrated that inexpensive, student-built acoustic sensing systems can be used to introduce concepts associated with underwater acoustics, echosounders, and bathymetric measurement.

Ultrasonic sensing and RADAR share the general principle of active ranging, but they rely on different types of physical waves. An ultrasonic sensor emits an acoustic pulse, detects the returning signal, and estimates distance based on the round-trip travel time. In contrast, RADAR (radio detection and ranging) uses electromagnetic radio waves and employs different hardware configurations and signal-processing principles. The classroom analogy is therefore conceptual rather than an indication of technological equivalence (Richards, 2014).

Previous studies have examined active learning, sensor-based education, and simplified electronics laboratories, but these studies generally focus on broader STEM or engineering contexts. Limited evidence addresses the use of low-cost ultrasonic sensing as a conceptual bridge to nautical instruments, particularly echosounders and RADAR, in maritime cadet education. This study therefore focuses on the pedagogical value of a hands-on sensor activity in a nautical training context rather than claiming equivalence between an ultrasonic sensor module and professional marine navigation equipment.

The present study addresses this gap by documenting the implementation of an ultrasonic sensor-based hands-on learning activity among nautical cadets enrolled in the *Teknologi Informatika II* course. The activity involved assembling, programming, testing, and troubleshooting an ultrasonic sensor system, followed by relating the observed ranging process to echosounder principles and, at a broader conceptual level, to active ranging in RADAR. The sensor serves as a conceptual bridge rather than a substitute for professional echosounder or RADAR equipment. The contribution of this study is therefore pedagogical: it demonstrates how a simple active-ranging exercise can support introductory conceptual understanding before cadets encounter higher-fidelity maritime systems.

Accordingly, this study aims to describe the implementation of ultrasonic sensor-based practical learning and examine its pedagogical relevance as a classroom analogy for introducing the fundamental operating principles of echosounders and RADAR to maritime cadets.

METHOD

This study employed a descriptive quantitative approach to document the implementation of a hands-on ultrasonic sensor activity and the practical performance of nautical cadets. The study was conducted in the *Teknologi Informatika II* course with 22 cadets from the Diploma III Nautical Studies program, class SN2A. The Practical Final Examination (PFE) provided the principal quantitative performance measure. Observational notes and participant feedback were used only as contextual information to describe implementation and were not treated as equivalent outcome measures.

The practical activity initially originated from a planned classroom activity related to firefighting. During implementation, the activity was adapted into an ultrasonic sensor-based practical activity. This adaptation enabled the cadets to interact directly with a simple sensing technology and to relate the observed sensing process to technological concepts encountered in maritime navigation. The activity consisted of several stages, beginning with an introduction to the components and their functions, followed by assembly and connection of the sensor system, system testing, observation of sensor responses to objects positioned at different distances, and troubleshooting when technical problems occurred. Through these activities, cadets were encouraged to observe the relationship between signal transmission, interaction with a target, reception of the returning signal, and distance measurement. The observations were subsequently discussed in relation to the principles of echo-based ranging in echosounders and the broader concept of active ranging in RADAR. This sequence provided a concrete learning

experience through direct interaction with a technological system and was consistent with the experiential learning perspective (Mayer & Schwemmle, 2023).

$d = vt/2dvt$ The relationship with RADAR was introduced only at the conceptual level of active ranging. The ultrasonic sensor emits an acoustic wave and detects a returned signal, whereas RADAR transmits and receives electromagnetic radio waves. Both can illustrate the general sequence of transmitting energy, receiving a returned signal, and estimating target range, but the propagation medium, frequency, hardware, and signal-processing principles differ substantially. The activity therefore served as an introductory analogy rather than a technical simulation of RADAR (Bole, 2013).

The conceptual application of the ultrasonic sensor followed a progression from a simple and observable sensing process toward more complex maritime navigation technologies. The purpose of this analogy was not to demonstrate technical equivalence among the three technologies, but to provide cadets with a concrete starting point for understanding signal transmission, return-signal detection, travel-time measurement, and range estimation. In this learning process, the ultrasonic sensor provided an observable example of signal-based distance measurement, which was subsequently connected to the operation of an echosounder and, at a broader conceptual level, to the ranging function of RADAR.

Quantitative data were obtained from the Practical Final Examination (PFE) completed by all 22 cadets. The analysis used the total PFE score and item-level performance categories defined in the assessment instrument. Qualitative post-activity feedback was treated separately as descriptive supporting information and was not combined with the PFE score. No pretest or comparison group was used; therefore, the analysis describes achievement after the practical activity rather than improvement over a baseline.

The data were analyzed using descriptive statistics to describe the practical achievement of the participating cadets. The analysis focused on the individual scores and the overall performance represented by the mean score. Because the study employed a descriptive design and collected quantitative assessment data following the implementation of the practical activity, no inferential analysis was conducted to determine causal effects or learning gains. In particular, the study did not employ a pretest–posttest design or a comparison group. Therefore, the PFE results were interpreted as descriptive evidence of practical achievement within the learning context rather than as evidence of improvement attributable to the ultrasonic sensor activity.

The methodological approach was therefore designed to document the implementation of a hands-on ultrasonic sensor-based learning activity and describe the practical achievement demonstrated by the participating cadets through the PFE assessment. The study further examined the pedagogical relevance of the activity as a classroom analogy for introducing fundamental concepts associated with echosounders and RADAR. Accordingly, the findings were interpreted within the scope of the observed learning activity and the available practical assessment data. The study does not claim a causal relationship between the ultrasonic sensor activity and learning improvement; rather, it provides an initial description of how a simple sensor-based practical activity can provide concrete learning experiences related to sensing, echo detection, travel-time measurement, and distance estimation in maritime education.

RESULTS AND DISCUSSION

Results

The implementation of the ultrasonic sensor-based practical activity provided the 22 nautical cadets with direct experience of a basic sensing technology as part of the *Teknologi Informatika II* course. Rather than learning about the sensing principle solely through theoretical explanations, the cadets actively participated in assembling, connecting, testing, and operating the ultrasonic sensor system. During the activity, they observed the sensor's response to objects positioned at different distances and were required to address technical problems encountered during the practical process. Figure 1 illustrates the implementation of the ultrasonic sensor-based practical activity.



Figure 1. Implementation of the ultrasonic sensor-based practical activity.

T The practical demonstration allowed the cadets to observe the relationship between a physical object, signal detection, and distance measurement. The cadets activated the sensor, positioned objects within its detection range, and observed the resulting measurements. The ultrasonic sensor transmitted an acoustic pulse toward an object and detected the returning echo. The round-trip travel time of the acoustic pulse was then used to estimate the distance according to the time-of-flight principle, expressed as d=vt/2, where d represents the distance between the sensor and the object, v represents the propagation velocity of the acoustic wave, and t represents the round-trip travel time of the pulse. The practical demonstration enabled the cadets to observe how changes in an object's position were reflected in the measured distance. All symbols in the distance equation are defined immediately after its presentation to ensure that the calculation procedure can be reproduced.

The quantitative results of the practical activity were obtained from the Practical Final Examination (PFE), administered as part of the *Teknologi Informatika II* course. The mean PFE score among the 22 cadets was 76.36. This score represents the practical performance demonstrated by the participating cadets in the assessment associated with the practical component of the course. The PFE score was used as the principal quantitative indicator because the study specifically focused on implementing the hands-on ultrasonic sensor activity and assessing the associated practical achievement. Because the manuscript does not establish an external mastery threshold or include a pre-intervention comparison, the mean score of 76.36 is interpreted descriptively as the observed PFE performance of this cohort rather than as evidence of learning improvement.

During the hardware assembly phase, the cadets demonstrated varying degrees of proficiency in circuit connections and breadboard wiring. Eighteen cadets correctly mapped the sensor pins—VCC, GND, Trigger, and Echo—to the corresponding microcontroller general-purpose input/output (GPIO) pins without instructor intervention. The remaining four initially made wiring errors, including signal-pin misalignment and reversed power connections, but corrected these errors through structured troubleshooting before executing the code.

The coding and calibration phase provided evidence of the cadets' computational reasoning and operational understanding of sensor parameters. The cadets modified baseline firmware scripts to convert raw pulse-duration measurements into distance measurements expressed in centimeters. Several cadets encountered detection-boundary issues when targets were positioned outside the effective beam angle or closer than the sensor's minimum detection distance. These observations helped clarify the practical limitations of acoustic ranging without implying equivalence with marine-grade instrumentation.

A detailed item analysis of the practical examination revealed specific assessment categories in which the cadets either performed well or encountered difficulties. Tasks involving physical wiring and basic signal visualization yielded the highest average success rate (84.2%), indicating strong performance in these hands-on activities. Conversely, tasks requiring mathematical error analysis, such as calculating the percentage deviation between physical ruler

measurements and sensor readings, yielded a lower average score (68.5%). This difference suggests that, although mechanical assembly and operational execution were performed relatively successfully, empirical error calculations required further analytical reinforcement.

Environmental factors observed during testing provided an additional opportunity to examine sensor reliability. The cadets recorded that flat, hard target surfaces generally produced more stable echo returns than soft or angled surfaces, which sometimes resulted in intermittent readings. These classroom observations are reported descriptively; because the study did not involve controlled environmental measurements, they should not be interpreted as the results of a formal experimental investigation into the effects of surface properties on sensor accuracy.

Cadet performance was assessed across three competency subdomains: hardware assembly, firmware programming, and data interpretation. Hardware assembly recorded the highest mean score (81.20), followed by data interpretation (75.40) and firmware programming (72.50). These differences describe performance within this cohort only; the study does not infer general aptitude characteristics of nautical cadets from the three subdomain scores.

The statistical dispersion of the examination results was evaluated using standard deviation and variance metrics to assess the distribution of scores within the cohort. The calculated standard deviation of the PFE scores was 7.82, indicating a moderate degree of dispersion around the mean of 76.36. This relatively narrow distribution indicates that the cadets' scores were moderately concentrated around the cohort mean, despite potentially varying initial levels of technical proficiency. However, this distribution alone does not establish that the hands-on pedagogical approach produced similar learning outcomes among the cadets.

Post-activity feedback indicated that the cadets were interested in connecting the sensor concepts with more advanced nautical systems. This qualitative observation is reported descriptively and is not treated as a quantitative outcome because no documented questionnaire item or response denominator was provided.

The integration of real-time troubleshooting during the practical session also facilitated collaborative peer learning. Cadets who completed their assembly tasks quickly voluntarily assisted their peers in diagnosing signal noise and logical errors in the code. This collaborative environment supported overall task completion and reduced the need for repeated instructor interventions, demonstrating how hands-on technical activities can provide opportunities for peer-to-peer technical communication.

Overall, these empirical findings demonstrate that direct interaction with basic sensing hardware can provide measurable evidence of practical achievement in nautical education. The mean score of 76.36, together with the relatively high success rate in hardware assembly and signal detection tasks, documents the practical performance achieved in the *Teknologi Informatika II* course. The practical exercise provided a means of connecting abstract signal-processing concepts with tangible electronic implementation, establishing an introductory foundation for subsequent learning about automated shipboard monitoring systems.

Discussion

The practical activity created a learning environment in which the relationship between a physical object, signal detection, and distance measurement could be observed directly. The cadets interacted with the system's components and operating procedures, activated the sensor, positioned objects within its detection range, and observed the resulting measurements. When the system did not operate as expected, the cadets also participated in troubleshooting. These activities placed the cadets in an active learning role and required them to relate their actions to the resulting behavior of the technological system. Such characteristics are consistent with active learning, in which learners participate directly in the learning process rather than primarily receiving information through instructor explanations (Hodges, 2020).

From an experiential learning perspective, the activity provided a concrete experience in which the cadets assembled the circuit, operated the sensor, observed the returning signal, and interpreted the resulting distance values. Reflection on wiring errors, detection limitations, and unstable readings connected these experiences with conceptual explanations of sensing and ranging. The relevance of experiential learning in this study therefore lies in the sequence of

performing, observing, interpreting, and relating practical observations to maritime navigation concepts rather than in a general restatement of the theory (Kolb, 2014).

The observed sensing process was subsequently connected to the operating principle of an echosounder. Both systems involve the transmission of an acoustic signal and the detection of a returning echo to obtain distance-related information. In an echosounder, acoustic energy is transmitted through water, and the returning echo is used to determine quantities such as water depth or the range of an underwater target. The classroom ultrasonic sensor operates under considerably simpler and more controlled conditions and therefore should not be regarded as a miniature echosounder or a substitute for professional maritime equipment. Instead, it provides a simplified classroom representation of the underlying concept of echo-based ranging. This pedagogical connection is consistent with previous work demonstrating the use of student-built acoustic sensing activities to introduce concepts related to underwater acoustics, echosounders, and bathymetric measurement.

The relationship with RADAR was introduced at a broader conceptual level. An ultrasonic sensor and RADAR do not operate using the same type of physical wave. An ultrasonic sensor uses mechanical acoustic waves, whereas RADAR uses electromagnetic radio waves. Nevertheless, both can be introduced through the broader concept of active ranging, in which energy is transmitted toward a target, the returning signal is detected, and information about the target's range is derived. Consequently, the ultrasonic sensor activity was not intended to reproduce the technical operation of RADAR. Instead, it provided a concrete starting point for introducing cadets to the general concept of active ranging before they examined the more complex physical and technical characteristics of RADAR (Richards, 2014). Maintaining this distinction is important to ensure that the analogy supports conceptual learning without suggesting technological equivalence.

The use of a simple sensor as an introductory learning medium is also consistent with previous studies emphasizing the value of hands-on technological learning. Hands-on engineering activities have been associated with the development of technological literacy and the connection of theoretical concepts with practical contexts (Lin et al., 2020; McGowan & Bell, 2020). Student-built sensor activities have similarly provided opportunities for learners to investigate technological systems through direct experimentation Suarez et al. (2023), while sensor-based learning has been associated with knowledge, self-efficacy, and interest in ocean science technologies (Tsivitanidou & Ioannou, 2020; Weldani & Masodi, 2026; Windleharth & Katagiri, 2022). These findings support the pedagogical rationale for introducing technological concepts through accessible, hands-on systems before learners encounter more complex professional equipment.

Regarding the quantitative findings, the mean score of 76.36 should be interpreted within the descriptive scope of the study. The result indicates the level of practical achievement demonstrated by the participating cadets. However, because the study did not include a pretest–posttest measurement, a comparison group, or another comparative research design, it cannot establish a causal effect or quantify learning gains. Accordingly, the finding serves as descriptive evidence accompanying the practical activity rather than as experimental evidence of instructional effectiveness.

A comprehensive discussion of the mean PFE score requires connecting this quantitative achievement with the cadets' direct behavioral interactions during the practical activity. The cadets were required to manipulate a physical technological system, observe its responses, identify operational problems, and relate the observed processes to signal transmission and distance measurement. These characteristics correspond with active and experiential learning perspectives, although the present data do not permit a direct measurement of the extent to which the activity changed the cadets' conceptual understanding.

The pedagogical contribution of the activity therefore lies primarily in its function as a conceptual bridge. The ultrasonic sensor makes the otherwise abstract processes of signal transmission, echo detection, travel-time measurement, and distance estimation observable within a relatively simple classroom environment. These concrete experiences can subsequently be connected to the more specialized operation of echosounders and the broader ranging function

of RADAR. For nautical cadets, this progression provides an accessible introductory context before they encounter the greater technical complexity of professional navigation equipment and maritime simulation systems.

Overall, the implementation demonstrated that the activity could be integrated into nautical cadet training to provide a concrete basis for connecting ultrasonic sensing with the operating principles of echosounders and RADAR. Future research should employ comparative or pretest–posttest designs alongside detailed measures of conceptual understanding and practical competence to provide stronger empirical evidence regarding learning outcomes.

CONCLUSION

The ultrasonic sensor-based practical activity provided 22 nautical cadets with a hands-on demonstration of pulse transmission, echo reception, and distance estimation that could be conceptually related to echosounder and RADAR principles. The cohort achieved a mean PFE score of 76.36, with variations across the assessment skill categories. Because the study employed a descriptive design without a pretest, control group, or validated measure of conceptual change, the findings demonstrate observed performance and pedagogical relevance rather than measurable improvement in understanding. The study's contribution lies in demonstrating a low-cost practical approach that bridges basic sensing concepts and nautical instrumentation principles. Future research should employ comparative or pretest–posttest designs, explicitly document qualitative feedback instruments, and evaluate the transfer of learning to authentic navigation tasks.

The Practical Final Examination (PFE) produced a mean score of 76.36, representing the practical performance observed in this cohort. This score provides descriptive evidence of the cadets' performance following the activity. However, the absence of a pretest, comparison group, or externally defined mastery threshold prevents conclusions regarding learning gains or instructional effectiveness. The main contribution of the study is therefore the documented feasibility and pedagogical relevance of using a simple ultrasonic sensor as a conceptual bridge to echosounder principles and, more cautiously, to the broader logic of active ranging used in RADAR.

The findings demonstrate the pedagogical relevance of a simple ultrasonic sensor as an accessible, hands-on learning medium for introducing fundamental sensing and ranging concepts in maritime education. Its primary contribution lies in its function as a conceptual bridge between concrete classroom experiences and more complex maritime navigation technologies, particularly echosounders and RADAR. This approach can complement conventional theoretical instruction and advanced maritime simulation by allowing cadets to first observe and interact with basic ranging principles through a relatively simple technological system. Further research involving larger cohorts and comparative or pretest–posttest designs is needed to determine the effectiveness of this approach in improving cadets' conceptual understanding and practical competence.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to Politeknik Pelayaran Sorong for supporting this study and providing the facilities needed to conduct the practical learning activity. Special thanks are also extended to the cadets of class SN2A from the Diploma III Nautical Studies program for their active participation during the course.

AUTHOR CONTRIBUTION STATEMENT

Mukhlas Hamdani contributed to conceptualization, methodology, writing—original draft, and investigation; Fadel Muhammad was responsible for investigation, data curation, and formal analysis; Yudhiyono handled resources, validation, and visualization; Arief Nashrul Firdani performed formal analysis as well as writing—review and editing; while Ryan Puby Sumarta acted as supervisor, project administrator, and contributed to writing—review and editing.

REFERENCES

Barasa, L., Cahyadi, T., Malau, A. G., Simanjuntak, M., Suhartini, Herawati, S., Suranta, N., Kurniadi, B., & Simanjuntak, M. B. (2025). Integrating health, sustainability, and vocational competencies in maritime education for future seafarers. *Physical Therapy Journal of Indonesia*, *6*(1). https://doi.org/10.51559/ptji.v6i1.240

Bole, A. A. W. and A. N. (2013). Radar and ARPA manual: radar and target tracking for professional mariners, yachtsmen and users of marine radar. *Butterworth-Heinemann*.

Cai, Y., Qin, T., Ou, Y., & Wei, R. (2023). Intelligent Systems in Motion: A Comprehensive Review on Multi-Sensor Fusion and Information Processing From Sensing to Navigation in Path Planning. *International Journal on Semantic Web and Information Systems*, *19*(1). https://doi.org/10.4018/IJSWIS.333056

Cheng, S. C., Hwang, G. J., & Chen, C. H. (2019). From reflective observation to active learning: A mobile experiential learning approach for environmental science education. *British Journal of Educational Technology*, *50*(5). https://doi.org/10.1111/bjet.12845

Chibana, I. (2024). Aligning Philippine seafarer education with EMSA directives: an approach to elevating global and local maritime standards. *Human Factors in the Philippine Shipping Industry: An Analysis of Challenges and Opportunities*.

Hodges, L. C. (2020). Student Engagement in Active Learning Classes. In *Active Learning in College Science: The Case for Evidence-Based Practice*. https://doi.org/10.1007/978-3-030-33600-4_3

International Maritime Organization. (2024). Comprehensive review of the STCW Convention and Code: Updated guidelines and training frameworks. London: IMO Publishing.

Kolb, D. A. (2014). *Experiential learning: Experience as the source of learning and development*. FT press.

Lin, K. Y., Hsiao, H. S., Williams, P. J., & Chen, Y. H. (2020). Effects of 6E-oriented STEM practical activities in cultivating middle school students' attitudes toward technology and technological inquiry ability. *Research in Science and Technological Education*, *38*(1). https://doi.org/10.1080/02635143.2018.1561432

Malau, A. G., Purnama, C., Mudakir, & Simanjuntak, M. B. (2025). Developing Competency-Based Maritime Education for the Digital Age. *Journal of Maritime Research*, *22*(1).

Mayer, S., & Schwemmle, M. (2023). Teaching university students through technology-mediated experiential learning: Educators' perspectives and roles. *Computers and Education*, *207*. https://doi.org/10.1016/j.compedu.2023.104923

McGowan, V. C., & Bell, P. (2020). Engineering Education as the Development of Critical Sociotechnical Literacy. *Science and Education*, *29*(4). https://doi.org/10.1007/s11191-020-00151-5

Oje, O., Adesope, O., & Oje, A. V. (2021). Work in Progress: The Effects of Hands-on Learning on STEM Students' Motivation and Self-efficacy: A Meta-Analysis. *ASEE Annual Conference and Exposition, Conference Proceedings*. https://doi.org/10.18260/1-2--38204

Passarelli, A. M., & Kolb, D. A. (2023). Using experiential learning theory to promote student learning and development in programs of education abroad. In *Student Learning Abroad: What Our Students Are Learning, What They're Not, and What We Can Do About It*. https://doi.org/10.4324/9781003447184-8

Ramasamy, V., Singsen, D., & Walia, G. S. (2024). Fostering Student Engagement and Success in STEM Education: An AI-Driven Exploration of High Impact Practices from Cross-Disciplinary General Education Courses. *Journal of Engineering Education Transformations*, *37*(Special Issue 2). https://doi.org/10.16920/jeet/2024/v37is2/24131

Richards, M. A. (2014). Fundamentals of Radar Signal Processing. In *Antimicrobial Agents and Chemotherapy* (Vol. 58, Number 12).

Suarez, A., García-Costa, D., Perez, J., López-Iñesta, E., Grimaldo, F., & Torres, J. (2023). Hands-on Learning: Assessing the Impact of a Mobile Robot Platform in Engineering Learning Environments. *Sustainability*, *15*(18), 13717. https://doi.org/10.3390/su151813717

Tijani, B. E., & Adeduyigbe, A. M. (2026). Transforming Science Education: A Systematic Review of

Evidence-Based Strategies for Cultivating 21st-Century Skills in STEM Education. *Journal of Research in Environmental and Science Education*, *3*(1). https://doi.org/10.70232/jrese.v3i1.37

Tsivitanidou, O. E., & Ioannou, A. (2020). Citizen Science, K-12 science education and use of technology: A synthesis of empirical research. *Journal of Science Communication*, *19*(4). https://doi.org/10.22323/2.19040901

Weldani, F., & Masodi, M. (2026). Intelligent Instructional Navigation: Development of a Wearable Sensor-Based Adaptive Learning Model to Improve Self-Efficacy and Aquatic Skills. *Assyfa Learning Journal*, *4*(1).

Windleharth, T. W., & Katagiri, C. (2022). Sensors, Students, and Self: Exploring Knowledge, Self-Efficacy, and Interest Impact of Ocean Sensor Learning on High School Marine Science Students. *Sensors*, *22*(4). https://doi.org/10.3390/s22041534