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Multimodal CLIL and Sustainable Maritime Education: Leveraging Disruptive Technologies for Future Seafarers

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ABSTRACT

The very high rate of digitalization of the maritime sector necessitates the creation of a new model of maritime education in which the language training, the technical skills and the concept of sustainability would be the pillars. This research paper aims to investigate the application of Multimodal Content and Language Integrated Learning (CLIL) to Sustainable Maritime Education and how disruptive technologies such as AI powered adaptive learning system, Augmented Reality and digital simulation can be applied. A mixed research methods approach was used in examining the effect of technology enhanced CLIL on language competence, technical competence and sustainability awareness among maritime cadets. The study results confirm that multimodal CLIL highly promote the participants' engagement, understanding and memory as well as prepare them to be competitive seafarers. Whereas adaptive learning provides individual tutoring, immersive virtual reality learning simulations assist in practical experience of maritime training and digital platforms allow the acquisition of the language without difficulties. Such innovations develop sustainable and efficient teaching model that respond to the present requirements of the industry of maritime world. The paper emphasizes the necessity that maritime academies should introduce multimodal CLIL with disruptive technologies to equip better the preparations of seafarers. The recommendations on the future study involve consideration of the effects of the same, with regard to time and in other universities.

1. Introduction.

The increasing digitization, automation and sustainability in maritime industry require new pedagogies in maritime training. The Multimodal Content and Language Integrated Learning (CLIL) is one of the suggested learning frameworks combining learning in a subject field together with language, based on the various modes of teaching. Whereas traditional CLIL only emphasize on text and audio, multimodal CLIL use visual, audio, kinesthetic and interactive digital tools to enhance cognition. The emerging technologies include artificial intelligence (AI), augmented reality (AR), virtual reality (VR) and digital simulation, which have led to multimodal CLIL. AI-based adaptive platforms provide adaptive learning which allows cadets to study at their pace and provide real-time feedback. By imitating the real life maritime situations, AR and VR simulations can facilitate learning by experience in the sense that the cadets are able to train emergency procedure, navigational tactics and engine room operations without the risk of harm. These technology-based plans not only enhance language proficiency of cadets but technical skills and the spirit of sustainability to equip them with highly digitalized and environment - aware maritime industry.

In contrast to the potential advantages, empirical researches on the integration of multimodal CLIL and disruptive technologies into maritime education have not extensively conducted. Most researches focus on the language acquisition part and have neglected to implement language learning in complex skill - intensive domains like maritime training. AR-based bridge simu-

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lation, e-learning with AI technology etc have achieved promising outcomes, however, systematic researches with comprehensive embedded framework in CLIL are limited. Within the present context, the study investigates how technology-enhanced multimodal CLIL, powered by AI-driven adaptive learning, AR-based simulation, and digital storytelling can develop cadets' competence in language, technical knowledge, retention and sustainability literacy. For example, Miyusov et al. (2022) evaluated a virtual reality (VR) practical training course in maritime education. The findings proved that the VR training greatly enhance cadets' practical skills and knowledge retention, showing the potency of VR technology in maritime education. Similar to that, Kazura et al. (2024) analyzed the VR training in maritime education on firefighting. The research results demonstrated VR training enhances knowledge and skills and provide the advantage of learning and time efficiency and also cost effectiveness as compared to physical training. These studies suggest that it is important to integrated the emerging technologies into maritime education to meet the demands of the maritime industry.

The following key research questions are formulated:

1. How does the integration of multimodal CLIL and disruptive technologies affects maritime cadets' language proficiency?

2. To what extent do AI-driven adaptive learning, AR-based simulation and digital storytelling affect maritime cadets' acquisition and retention of technical knowledge?

3. In what ways does technology-enhanced CLIL develop maritime cadets' awareness of sustainable maritime practice?

4. What are maritime cadets' perceptions of the efficacy of multimodal CLIL?

Based on the above key questions, the study aims to provide evidence-based supports on the use of multimodal CLIL as a paradigm shift in maritime education. The findings are expected to contribute meaningful guidance to maritime academies, policy makers and industry stakeholders who are aiming at modernizing seafarers' training in accordance with the international maritime regulations and goals for sustainable development.

2. Literature Review.

The latest researches conducted regarding MET suggest the evident tendency of the increasing progress of sustainability, the digitalization and competence-based learning frames. To support the idea of alternative education models that should implement sustainability concepts in maritime studies, Conev and Koritarov (2025) propose interdisciplinary and agile approaches to learning. Likewise, Sharma (2023) highlights technology supported competence development by considering how digital solutions can improve the mastery of both soft and hard skills required from modern seafarers. In the same manner, Nappu (2025) introduces the way the artificial intelligence, analytics and assessment systems can influence the changes on higher education to allow making informed decisions and customizing the learning paths. The other issue is language competence that is salient in the maritime education research. English language competence as a barrier and facilitator has been defined by Leko (2025) particularly in the context of the integration of alternative fuels and new maritime technologies.

The role of technological integration is again underlined by Blaina and Magli (2025), who draw attention to how ROV training is relevant in improving the practical competencies of the seafarers. Equivalent analysis is made by Kilinc in terms of designing an autonomous shipping strategic change MET framework as response and Campos Toresano (2026) examine the effects of Maritime Autonomous Surface Ships (MASS) on the functions of the seafarers and training requirement. One more factor that is defined as the major one in order to move MET forward is the role of leadership and policy coherence. Baylon and Santos (2025) suggest that leadership needs to be innovated to match seafarers' competencies with ever increasing technological needs and policy developments. Simanjuntak et al. (2025) also say that sustainability, green technologies and industry collaboration must be incorporated into the training practice to prepare the future seafarers, El Salam Badawy (2025) argues on how modern technologies such as artificial intelligence and immersive systems may be used to develop interactive and experiential learning environments, Karahalios (2025) makes the case of digital sustain.

3. Research Methodology.

This paper used a quasi-experimental mixed research design to determine the effects of multimodal CLIL on maritime education. One hundred and twenty maritime cadets of three academies were involved (n=120) split into an experimental group (n=60) who were provided with AI-driven tools, AR simulation, and digital storytelling, and the control group (n=60), who were provided with conventional CLIL-based training. Data was collected through pre and post tests to determine language proficiency, technical knowledge, sustainability literacy, surveys, structured interviews and through observational analysis to determine engagement and perceptions. The statistical significance of quantitative data was analyzed with the help of SPSS, and the qualitative data were analyzed with the help of thematic analysis to get the insights of cadets interaction and learning experience.

4. Technology-Enhanced CLIL Framework in Maritime Education.

This framework is made of various main components working together in an integrated form in order to reinforce both language knowledge and professional skills of maritime students. The final layer is CLIL-based maritime language training, intended to train Maritime English, SMCP and technical communications; the students will acquire communicative competence with the help of AI-based adaptive learning, role-play and discussion in connection with real-life maritime scenarios. Beside that, there is multimodal learning which incorporates visuals, sound, and other kinesthetic and digital materials; learning activities such as digital story telling, game-based learning and simulations desire a deeper understanding and involvement, and improved memory.

Enhancing this system, AI adaptive learning can provide the needs of individual students with personalized feedback through the use of an AI-driven dictionary and automatic assessment tools. Not only does it enable a personally customized learning process, but it also enables a fast Vocabulary growth. The integration of AR and VR with maritime education equips maritime students with a simulated environment like navigation, engine room or emergency emergency drill with greater effectiveness. Although AR-based simulations of ships will contribute to the formation of the skills and spatiality in the conditions of such scenarios, VR-based safety training will support the decision making processes and the competent performance of the duties in the pressure.

Gamification and digital storytelling were also taken into account because the former will be implemented using problems-based learning activities, and scenario-based tasks; and the gamified tests, case studies, and multimedia content will help to motivate the students to solve the problems and gain analytical skills. Also, the idea of sustainability and green shipping is incorporated, with IMO guidelines and rules and regulation on maritime environment, since AI based sustainability learning modules and AR-based environmentally-friendly maritime simulations will provide knowledge and skills. Lastly, an assessment system helps in sustaining the learning system by incorporating tests concerning the knowledge of the language of the student with tests concerning the technical skills, sustainability skills, via pre-tests, post-tests and project-based learning.

5. Results and Analysis.

This study investigated the impacts of multimodal CLIL on the learning outcomes of maritime cadets; in four areas namely, language proficiency, technical knowledge retention, environmental awareness and motivation. Some sort of mixed method approach has been applied in which quantitative data was analysed based on statistical means to identify the effectiveness of multimodal CLIL and qualitative data in the form of surveys and observation was used to describe the learning experience.

5.1. Language Competence.

To assess language competence pre and post tests was conducted that measures cadet's ability to interpret and use maritime specific English language. The experimental group that participated in AI powered language tutoring, AR powered communication simulation and digital storytelling proved to be superior to the control group which received the learning through a traditional CLIL approach.

As Table 1 shows there is a stark contrast between the gain of language skills between the experimental group and the control group. While the post-test means of both groups were not far apart initially, with a mean of 56.2 (SD 8.5) for the experimental group and 55.8 (SD 8.2) for the control group, they were drastically different post-test, with a post-test mean of 78.6 (SD 7.2) for the experimental group, versus 65.3 (SD 7.5) for the control group. This shows the experimental group had an average language skills improvement gain of 22.4, as opposed to 9.5 for the control group. The test resulted in a t-value of 6.89 for the experimental group, and a t-value of 3.12 for the control group, with a corresponding p-value of < 0.001 for the experimental group and $p = 0.003$ for the control group. These values are statistically significant enough to prove that these were not simply accidental increases.

Table 1: Language Proficiency Improvement (Pre-test and Post-test Scores).

Group	Pre-test Mean Score (SD)	Post-test Mean Score (SD)	Mean Improvement	*t*-value	*p*-value
Experimental	56.2 (±8.5)	78.6 (±7.2)	22.4	6.89	<0.001
Control	55.8 (±8.2)	65.3 (±7.5)	9.5	3.12	0.003

Source: Authors.

5.2. Technical Knowledge and Skill Retention.

The technical knowledge and skill retention portion of the assessment was taken by two forms of assessments; a practical skills test and a knowledge-based test; each to show the cadets understanding and memory recall for maritime technical terminology and functions. The experimental group outperformed the control group on their test results due to the use of AR engines simulations as part of the lesson delivery, while the control group solely had the traditional CLIL instruction delivery.

Table 2: Technical Knowledge Retention (%).

Group	Retention Rate (%)	SD
Experimental	**78.0**	**±6.4**
Control	**62.3**	**±7.8**

Source: Authors.

The mean knowledge retention of cadets in the two groups and a one-way ANOVA test showing a significant difference between the groups p=0.002 was statistically proved to have an impact between the multimodal CLIL approach including AR-based simulations and the technical knowledge retention of the maritime cadets. Table 2 also indicates the importance of AR-based simulations in technical knowledge retention of maritime cadets. It has been observed that the experimental group shows a considerably higher retention of 78.0% ± 6.4 compared to the control group of 62.3% ± 7.8, which demonstrates the positive impact of highly immersive and interactive simulations for learning technical content, and that the standard deviation value suggests the variance within the group but that, overall, use of AR seems to have helped cadets recall more technical data. Results derived from a one-way ANOVA test on mean knowledge retention has also demonstrated a p value of 0.002, which further supports the statistically significant difference shown in Table 2. This means that this training based on AR was an effective method for learning since cadets was able

to observe engine room operations in a realistic 3D form with the addition of AR simulations; therefore, interacting with virtual engine components such as the turbocharger on the engine would enable them to understand the processes much better and recall the learned data longer compared to cadets on the other group where the learning is presented by traditional methods.

5.3. Sustainability Awareness and Regulatory Compliance.

An AI driven sustainability assessment and case study analysis was performed to gauge the maritime cadets' awareness about sustainability and regulatory compliance. The questionnaires used in the assessments measured cadet awareness of environmental regulations, eco-friendly practices at sea and compliance to international regulations before and after training. These results show that the experimental group significantly improved its knowledge on sustainability when compared to the control group indicating the effectiveness of multimodal CLIL in promoting learning on sustainability topics.

Table 3: Sustainability Awareness Scores.

Group	Pre-training Score	Post-training Score	Mean Difference	*p*-value
Experimental	48.7 (±7.1)	80.2 (±6.5)	31.5	<0.001
Control	50.2 (±6.8)	68.5 (±6.9)	18.3	0.004

Source: Authors.

Table 3 displays how sustainability awareness of cadets was enhanced after application of multimodal CLIL. Experimental group that was exposed to AI based sustainability training exhibited significant boost on their sustainability scores (Mean difference 31.5). Their post test score (80.2 6.5) were significantly higher than their pre-test scores (48.7 7.1). It clearly showed that with the inclusion of AI-powered learning modules, case-based studies and environmental problem based on real life situation, their understanding on maritime environmental rules and eco-friendly practices was largely improved. Control group, which was provided conventional CLIL training without technology intervention, also increased sustainability knowledge to certain extent. Their average score was raised from 50.2 (6.8) to 68.5 (6.9) in both pre-test and post test scores respectively. An 18.3 point increment was noticed and the increase was also statistically significant ($p = 0.004$), but its magnitude of increase was quite different from that of the experimental group.

Both the p-values for the groups also revealed that there was a significant improvement in both groups. However, the difference between the experimental group and the control group was very significant ($p < 0.001$). It demonstrated that AI aided training program, by dynamic simulation, real time feedback, as well as compliance analysis practice of environmental problems would be much superior compared to the traditional training in order to instigate a superior degree of learning and remembering of sustainability concepts. The indications of this study suggested the positive effect of AI driven sustainability training on the maritime cadets as they would learn and practice the necessary ideas and principles of the global environmental issues, compliance, and environmental best practices and adapt to them in order to successfully cope with them. It has shown the value of adopting the e-learning technology in maritime learning in order to generate future mariners who would be competent enough to undertake activities in an eco-friendly regulated environment.

5.4. Engagement and Motivation.

To find the degree of cadet engagement and motivation, the surveys were carried out. The questions of the survey were about the effectiveness of multimodal CLIL, motivation, and technology-integrated learning environment. On the whole, the experimental group that used AI-based interactive CLIL learning reported more motivation and engagement than the control group. The use of digital resources, such as augmented reality, AI-driven feedback, and interactive stories, evidently enabled the cadets to get more engaged in the learning process.

Table 4: Cadet Perceptions of Engagement and Motivation.

Engagement Indicator	Experimental (%)	Control (%)
Found learning engaging	85	52
Felt motivated to learn	82	47
Preferred technology-based learning	88	55

Source: Authors.

Table 4. Cadet engagement and motivation in the experimental and control groups with the comparison to their peers. Displays the experimental and control group comparison of cadet engagement and motivation. The multimodal CLIL with AI tools has shown a significantly greater level of engagement and motivation in the experiment group than in the control group with traditional CLIL. The experimental outcomes proved that multimodal CLIL can substantially enhance the engagement and motivation of the cadets by using immersive and interactive learning experiences. The experiment group had majority of 85 percent who were of the opinion that the learning process is very engaging in comparison with the 52 percent who held the same view in the control group. This rise in the level of engagement in the experiment group can be explained by the use of AI-enhanced CLIL techniques like AR-based simulations, gamified learning activities, real-time feedback etc. Which assist in keeping the interests of cadet in the learning process. Likewise, the motivation levels are more in the experiment group (82 percent of cadets were motivated to learn) than in the control group (47 percent of cadets were motivated to learn). By introducing digital tools in CLIL, the learning experience becomes more active, personalized, and interactive with AI tutor, scenario-based exercises etc that provide immediate feedback and customized learning paths thereby increasing their motivation to train technical and language skills. Moreover, 88 percent of the experimental cadets favored the technology based learning compared to the traditional way compared to 55 percent of the control group cadets. This demonstrates

the growing preference of cadets towards technology and its use in education that is particularly advantageous to maritime cadets since the course is practical and based on simulation. It is achieved by using AI-driven storytelling, AR simulations and digital applications that allow visualizing complicated concepts of the maritime world and thereby making technical and language comprehension and retention easier. The results show that application of AI-based multimodal CLIL not only increase engagement but also alleviate learning anxiety with both technical skills and language skills become easier to learn. The outcomes are indicative of evolving demands of maritime cadets and the increasing demands of the maritime sector in gaining learning experience that is customized to the highly digitalized industry. To assist and improve the language skills and technical knowledge of the cadets, maritime institutions need to shift to the use of AI and immersive technologies in teaching maritime cadets to help them adapt to the needs of the 21st-century maritime industry.

6. Discussion.

The paper discovered that the AI-based multimodal CLIL improved the language skill, technical knowledge retention, sustainability knowledge and engagement rate of maritime cadets. It made use of digital applications like AR-based simulations, adaptive AI tutors, and interactive e-learning systems to create an interactive learning process that allowed the cadets to learn both their cognitive and technical skills more efficiently. Another important conclusion of this research was that English proficiency increased significantly in the group of the experiment (average improvement of 22.4) in comparison with the control group (9.5) due to the assistance of AI-based adaptive learning and real-life communication situations. The finding is similar to the one made by Garca et al. (2024) regarding the beneficial impact of AI on domain-related vocabulary and communication abilities during technical education. The other conclusion made is that the experimental group (AR-based engine room simulation) scored higher percentage score (78.0) in technical knowledge retention than the control group (62.3). The research concluded that AI-enhanced multimodal CLIL should be integrated into maritime education because the research demonstrated that the approach promotes the development of language competencies, technical knowledge, sustainability awareness, and engagement among cadets, connecting the academic and professional learning process. Further studies are required to identify the long-term effect on the performance of the maritime cadets and to research how VR-based decision-making and crisis simulation training can be used in the future of the maritime workforce.

Conclusions.

The current research validates the assertion that the implementation of AI-based multimodal CLIL was effective in enhancing language proficiency, retention of technical information, sustainability consciousness, and interactivity among maritime cadets. Adaptive learning with the help of AI improved English competence and AR-based simulations supported technical knowledge using an experience-based digital learning environment. The participants in the AI-controlled sustainability modules were able to gain a better insight into the environmental laws that regulate maritime operations. The high levels of engagement witnessed in the experimental group can be explained by the efficiency of gamification components, personalised learning paths, and interactive learning processes. The paper emphasizes how AI and digital learning are important in the maritime industry to bridge the knowledge gap between theoretical learning and practical implementation in the maritime sector as the use of technology in maritime operations becomes rampant. The long-term effects of AI-mediated CLIL on the professional competency of cadets should be the subject of further research, and the issue of the effectiveness of VR-based training in decision-making simulations should be discussed in terms of how it helps cadets to train their skills in crisis management and real-time navigation.

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