International Journal of Advance Social Sciences and Education (IJASSE)
Vol. 4, No. 4, 2026: 465-482

Development of a STEM-Based Applied Physics E-Module Aligned with IMO Model Course 7.04 to Improve Concept Mastery and Self-Regulated Learning among Maritime Vocational Students

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A R T I C L E I N F O

Keywords: E-Module, Applied Physics, STEM, IMO Model Course 7.04, Self-Regulated Learning

Received: 19, June
Revised: 20, July
Accepted: 30, August

A B S T R A C T

This study developed a Science, Technology, Engineering, and Mathematics (STEM) based applied physics e-module intended to be feasible, practical, and effective for maritime vocational instruction at Banten Maritime Polytechnic, with its content aligned to the Officer in Charge of an Engineering Watch competencies specified in IMO Model Course 7.04. A Research and Development design was employed using the ADDIE model, comprising the analysis, design, development, implementation, and evaluation stages. Participants comprised 54 first-year students of the Marine Engineering study programme and six lecturers. Expert validation placed the e-module in the Feasible to Highly Feasible category, with mean scores of 3.58 from subject-matter experts and 3.67 from media experts. Practicality testing yielded means of 3.62 from students and 3.71 from lecturers, both within the Very Practical category. The effectiveness test recorded an increase in mean achievement from 60.11 at pre-test to 83.94 at post-test, corresponding to a normalised gain of 0.60 in the Moderate category. At the same time, self-regulated learning scores ranged from 3.59 to 3.78. The findings indicate that a contextualised STEM-based applied physics e-module aligned with an international competency standard constitutes a viable instructional alternative for maritime vocational education, and that the gain observed is attributable less to digitisation as such than to the explicit anchoring of physical concepts in shipboard engineering systems.

DOI: https://doi.org/10.59890/ijasse.v4i4.20
ISSN-E: 2988-2133
https://journalijasse.my.id/index.php/ijasse

INTRODUCTION

Technological development in the era of the Fourth Industrial Revolution requires that vocational education move beyond the conventional transmission of subject matter and cultivate twenty-first century capabilities, notably critical thinking, creativity, collaboration and communication. One strategy widely regarded as responsive to this requirement is the Science, Technology, Engineering, and Mathematics (STEM) approach, which integrates four disciplines within the context of authentic problem solving so that learners acquire a more comprehensive and applicable learning experience (Breiner et al., 2012). Recent empirical evidence strengthens this position. A meta-analysis of 79 effect sizes drawn from 40 studies involving 15,577 learners found that instruction delivered through STEM integration significantly outperformed conventional instruction on academic achievement, with g = 0.661 (Zhou et al., 2025). Comparable findings were reported by Chen et al. (2026), whose synthesis of 124 studies indicated a moderate effect on knowledge acquisition and a large effect on cognitive skills.

Within maritime vocational education, and specifically within the Marine Engineering study programme at Banten Maritime Polytechnic, this requirement assumes particular weight. Graduates are expected to understand and operate shipboard machinery systems to a professional standard and to satisfy international requirements. Through IMO Model Course 7.04, Officer in Charge of an Engineering Watch, the International Maritime Organization specifies the competencies an engineering watchkeeping officer must possess, including a working grasp of applied physical principles in mechanics, fluids, heat transfer, electricity and automatic control (International Maritime Organization, 2014). Such conceptual command is necessary in order to analyse and manage shipboard systems including refrigeration, piping and propulsion. These competency requirements derive in turn from the STCW Convention, which functions as the global reference for the conduct of maritime education and training (Kandemir et al., 2018).

The teaching of applied physics in vocational institutions nevertheless encounters recurrent difficulties. Material tends to be delivered abstractly and is insufficiently connected to the working context aboard ship. The scarcity of interactive digital learning media leaves students unable to perceive the relation between physical theory and its practical application within shipboard machinery. The consequence is weak conceptual understanding and a limited capacity to transfer knowledge to operational situations. Research within maritime education confirms that the limited availability of instructional facilities replicating actual shipboard conditions constitutes a structural problem, which is why maritime training institutions rely upon simulators and digital media as a bridge between theory and practice (Kim et al., 2021; Dewan et al., 2023).

One potential remedy is the use of digital teaching material in the form of an e-module, that is, an electronic learning module employing text, images, video, animation and interactive features in support of independent study. The flexibility, interactivity and accessibility characteristic of e-modules make them appropriate to the learning preferences of vocational students, who require contextual and practice-oriented instruction. The theoretical warrant for the advantages of such media is supplied by the cognitive theory of multimedia learning, which holds that learning proceeds more effectively when information is presented through the integrated combination of visual and verbal channels (Mayer & Moreno, 2003; Mayer, 2017).

A number of development studies have demonstrated the potential of STEM-based e-modules in physics instruction. Nazifah and Asrizal (2022) produced a STEM-integrated physics e-module judged valid and practical for the improvement of twenty-first century skills, while Yulkifli et al. (2022) developed a project-based e-module employing an Ethno-STEM approach which satisfied criteria of validity, practicality and effectiveness. In the context of laboratory instruction, Sari (2021) demonstrated that a basic physics practicum e-module using a STEM approach proved feasible and practical and was capable of fostering independent learning.

Research developing STEM-based applied physics e-modules for maritime vocational education, and in particular research referring directly to the competency structure of IMO Model Course 7.04, nevertheless remains scarce. Most e-modules in the maritime field remain general in character, are not contextualised to shipboard working systems, and do not implement the STEM approach in its entirety. This constitutes the research gap the present study addresses. Accordingly, the study set out to develop a STEM-based applied physics e-module referring to IMO Model Course 7.04, to establish its feasibility through expert validation, to analyse its practicality for users, and to test its effectiveness in improving concept mastery and self-regulated learning among students at Banten Maritime Polytechnic.

LITERATURE REVIEW

E-Modules in Digital Learning

An e-module is an electronic learning module presented in digital format, systematically designed and furnished with multimedia elements in support of independent or guided study. As instructional material, it possesses four principal characteristics. It is self-instructional, permitting learners to study independently at their own pace; it is self-contained, incorporating objectives, content, exercises and assessment within a single package; it is stand-alone, in that it does not depend upon other media; and it affords interaction through quizzes, video, animation or dynamic links.

From a pedagogical perspective, the e-module facilitates learning through the use of varied media including text, image, audio and video, which together improve the quality of information processing. A meta-meta-analytic synthesis of 29 reviews encompassing 1,189 studies and 78,177 participants identified eleven multimedia design principles with meta-analytically demonstrated positive effects upon learning, the largest benefits accruing to the temporal-spatial contiguity and signalling principles (Noetel et al., 2022). Mayer (2017) reported that the multimedia principle alone yields a median effect size of $d = 1.67$, followed by temporal contiguity ($d = 1.30$) and redundancy ($d =$

0.87). These findings place the e-module at an advantage relative to the traditional printed module, which relies upon text and static illustration alone.

Cognitive load considerations are likewise central to e-module design. Castro-Alonso et al. (2021) set out five strategies for optimising instructional materials, namely the multimedia, spatial contiguity, redundancy, signalling and segmentation principles, which may be managed either by the designer or by the learner. Their application is pertinent to an applied physics e-module because the content carries technical diagrams, formulae and illustrations of machinery systems which may impose excessive cognitive load if presented without appropriate structuring.

The STEM Approach in Vocational Education

The STEM approach integrates science, technology, engineering and mathematics into a holistic whole in response to twenty-first century demands emphasising problem solving, critical thinking, creativity and collaboration. Conceptually, STEM-based instruction does not teach the disciplines in isolation but combines their concepts within a single authentic problem context relevant to the world of work (Breiner et al., 2012). In studying fluids, for example, students not only grasp Bernoulli's principle theoretically but apply it in analysing piping systems, pumps and fluid flow aboard ship.

Empirical evidence concerning the effectiveness of STEM is reasonably consistent, albeit with varying effect magnitudes. Zhou et al. (2025) found that the effect size of STEM integration was largest for context integration, smaller for content integration, and smallest for tool integration; considering the instructional model, the largest effect was obtained for inquiry-based learning. Chang et al. (2024), through a meta-analysis of 23 articles representing 9,797 participants, reported a weighted mean effect size of 0.38, which is small to moderate, and found the magnitude to be moderated by educational level, subject domain, and instructional hours. Le et al. (2023), through a systematic review of 47 studies, established that the learning outcomes obtained differ according to the mode of STEM integration employed.

Margot and Kettler (2019), in a systematic literature review, found that educators regard STEM as raising learner interest and motivation by virtue of its applied character, although they frequently encounter constraints of curricular support, time and resources. Within educational technology, Wang et al. (2022) reported that digital game-based STEM learning produced a moderate effect size of 0.667 upon learning achievement. Taken together, these findings indicate that the success of STEM depends substantially upon the quality of its design and supporting media rather than upon the label of the approach itself.

Applied Physics and the Competency Standard of IMO Model Course 7.04

Applied physics is the branch of physics concerned with the application of fundamental physical principles to the solution of real problems across engineering fields. In maritime education, it constitutes an essential foundation for understanding the operation of machinery, electrical, piping, control and occupational safety systems aboard ship. Topics such as quantities and units, motion, force, work and energy, fluid statics, fluid dynamics, vibration and waves bear directly upon the physical phenomena of ship operation. An understanding of fluid pressure and Pascal's law, for instance, is essential to the operation of hydraulic systems, while Bernoulli's principle underlies the analysis of fluid flow in pipes, pumps and engine cooling systems.

IMO Model Course 7.04 sets out the minimum competencies to be commanded by an Officer in Charge of an Engineering Watch and is constructed upon the provisions of the STCW Convention and its amendments. These competencies encompass four principal functions at the operational level: marine engineering; electrical, electronic and control engineering; maintenance and repair; and controlling the operation of the ship and care for persons on board (International Maritime Organization, 2014). All four require command of applied physical concepts in mechanics, fluids, energy and electricity.

Research within Maritime Education and Training indicates that the implementation of STCW standards varies across countries and institutions owing to differences in national regulation, resources, culture and instructor perspective, generating heterogeneous teaching practice (Karahalil et al., 2024). Kandemir et al. (2018) argue that learning outcomes in marine engineering education depend substantially upon an assessment system aligned to the knowledge, understanding and proficiency required. Dewan et al. (2023), in a systematic review of 27 articles, mapped the use of immersive and non-immersive simulators in maritime education and training and concluded that an evaluation model framed from the learner's perspective is needed. Kim et al. (2021) add that the COVID-19 pandemic accelerated the adoption of digital technology in the field, including virtual reality and cloud-based simulation. This context reinforces the case for developing digital teaching material aligned to IMO competencies.

Concept Mastery and Self-Regulated Learning

Concept mastery denotes the learner's capacity to command and restate a scientific concept correctly and to apply it across varied situations. Within the revised cognitive taxonomy, understanding is evidenced through the capacity to interpret, explain, classify, and relate concepts (Anderson & Krathwohl, 2001). In physics instruction, concept mastery is of particular importance because the discipline requires that theory, mathematical analysis, and real application be held together. Students possessing sound concept mastery are able to connect verbal, mathematical, graphical and phenomenal representations simultaneously.

Self-regulated learning denotes the learner's capacity to govern their own learning process through goal setting, strategy selection, progress monitoring and reflection upon outcomes. Zimmerman (2002) describes self-regulated learning as comprising three principal cyclical phases, namely forethought, performance and self-reflection. Meta-analytic evidence indicates that self-regulated learning interventions exert a positive and moderate effect of 0.69 upon academic achievement in online and blended environments (Xu et al., 2023), while training programmes for university students yield an overall effect size of $g = 0.36$, with the largest effects upon metacognitive strategy and motivation (Theobald, 2021).

In online settings, Broadbent and Poon (2015) found that time management, metacognition, effort regulation and critical thinking strategies correlate positively with academic achievement. Cheng et al. (2025) reported a small positive correlation between self-regulated learning strategies overall and online academic performance (r = 0.21), with the highest correlation for behavioural strategies (r = 0.23). Doo and Zhu (2024), analysing 152 samples from 43 studies, obtained a moderate effect size of 0.508 for the influence of self-directed learning upon online learning outcomes. The review by Luo and Zhou (2024) of 15 SSCI articles found that 14 reported a positive effect of self-regulated learning strategies upon learning outcomes in blended environments.

Edisherashvili et al. (2022), in a systematic review of 38 studies, mapped interventions supporting all areas of self-regulated learning but noted an uneven distribution: metacognitive regulation and the performance phase are widely researched, whereas emotion regulation and the preparatory and appraisal phases remain comparatively unexplored. Anthonysamy et al. (2020) add that self-regulated learning strategies correlate positively with non-academic outcomes bearing upon student progression. These findings collectively suggest that digital media affording latitude in the management of time, pace and learning strategy hold potential for fostering self-regulated learning, as Sari (2021) demonstrated in the context of STEM-based basic physics laboratory work.

Conceptual Framework

On the basis of the theoretical and empirical considerations set out above, the present study proceeds from the premise that applied physics instruction in maritime vocational education confronts a gap between international competency requirements and the availability of contextualised learning media. A STEM-based e-module designed in accordance with multimedia design principles and aligned to the competencies of IMO Model Course 7.04 is accordingly positioned as an intervention expected to improve concept mastery while fostering self-regulated learning. The development sequence and its outputs are visualised in Figure 1.

METHODOLOGY

Research Type and Design

The study is a Research and Development study directed at producing an educational product in the form of a STEM-based applied physics e-module referring to the competencies of IMO Model Course 7.04. The developmental approach was selected because its principal focus lies not solely in testing the effectiveness of a product but in generating, validating, and refining instructional material fit for use. The development model employed is ADDIE, comprising five principal stages: analysis, design, development, implementation and evaluation. ADDIE was selected on account of its systematic character, its flexibility, and its widespread use in the development of digital learning media. The complete development sequence is presented in Figure 1.

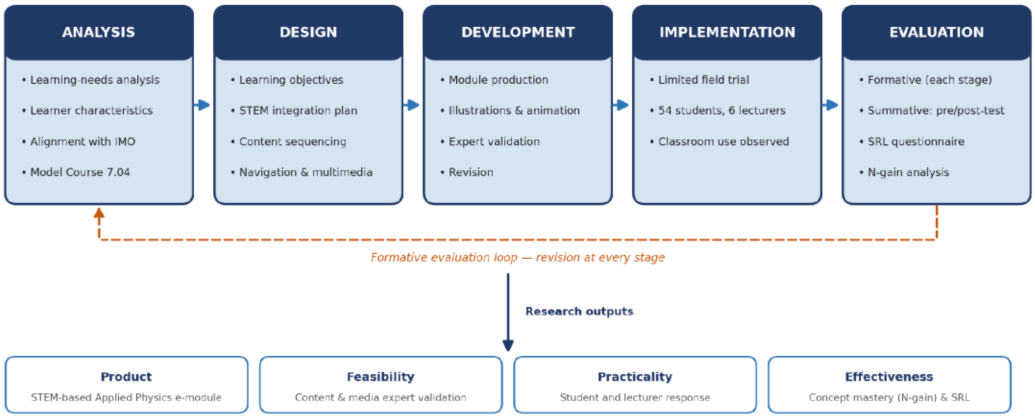

Figure 1. Development sequence of the STEM-based applied physics e-module using the ADDIE model, with formative evaluation loop and research outputs.

Participants and Setting

Participants comprised expert and user groups selected by purposive sampling. The expert group comprised subject-matter experts holding backgrounds in physics education or engineering with an understanding of applied physical concepts and experience of teaching in maritime vocational education; media experts, being educational technology practitioners experienced in developing digital instructional multimedia; and instructional experts with a command of teaching strategy including the STEM approach and instructional design. The user group comprised 54 first-year students of the Marine Engineering study programme at Banten Maritime Polytechnic enrolled in the Applied Physics course, together with six teaching lecturers. The study was conducted at Banten Maritime Polytechnic, in classrooms and computer laboratories supporting the use of digital devices.

Development Procedure

The analysis stage comprised an analysis of instructional needs, of learner characteristics, and of the correspondence between applied physics content and the Officer in Charge of an Engineering Watch competencies set out in IMO Model Course 7.04. The design stage established the structure and content of the e-module, encompassing the formulation of learning objectives, the selection of the STEM approach, the sequencing of content, the construction of project-based activities, and the design of navigation and multimedia elements. The development stage produced the e-module in accordance with the design, furnished with illustrations, animations, and simple simulations relevant to the shipboard machinery context, which was then validated by the experts and revised in the light of their comments.

The implementation stage applied the e-module in a limited field trial to gauge acceptability and practicality while observing its use in an authentic instructional setting. The evaluation stage was conducted both formatively and summatively; formative evaluation took place at each stage to ensure that the product developed in conformity with the intended standard, while summative evaluation followed implementation in order to measure effectiveness through pre-test and post-test administration together with a self-regulated learning questionnaire.

Content and Scope of the Product

The e-module covers eight applied physics topics relevant to the technical competencies of an engineering officer: quantities and units, including measurement and dimensional analysis; rectilinear motion, encompassing velocity, acceleration and graphical representation; force and Newton's laws together with their application to shipboard mechanical systems; work, energy and power, including the energy efficiency of engine systems; fluid statics, addressing hydrostatic pressure, Pascal's law and hydraulic system applications; fluid dynamics, encompassing continuity and Bernoulli's principle and their application to flow in shipboard piping; vibration and waves, including the simple oscillation relevant to machinery; and sound, encompassing its characteristics, intensity and relevance to shipboard acoustic systems and occupational safety. Each sub-section embeds the STEM elements, namely Science as physical concept, Technology as shipboard instrument and equipment, Engineering as technical process and working mechanism, and Mathematics as calculation and analysis.

Instruments and Data Collection

Four instruments were employed. The first was an expert validation sheet addressing conceptual accuracy, depth of content, coherence of presentation and correspondence with the competencies of IMO Model Course 7.04 for subject-matter experts; display, navigation, use of colour, clarity of illustration and interface quality for media experts; and correspondence with instructional design principles and the implementation of the STEM approach for instructional experts. The second comprised student and lecturer response questionnaires assessing practicality and acceptability, encompassing ease of use, visual appeal, clarity of content, usefulness of interactive features and relevance of subject matter. The third was a concept mastery test administered as a pre-test and a post-test, the items of which were constructed from indicators of conceptual understanding and reviewed for consistency with the vocational context and the technical application of shipboard machinery. The fourth was a self-regulated learning questionnaire addressing learning planning, strategy regulation, self-monitoring and evaluation of the learning process, constructed with reference to the self-regulated learning framework.

Data Analysis

Qualitative data obtained from expert review and student comments were analysed by a qualitative descriptive technique, grouping comments, suggestions and observations into categories serving as the basis for product revision. Quantitative questionnaire data were analysed by descriptive statistics, computing total scores, mean scores and feasibility percentages using a four-point Likert scale. Effectiveness was assessed by analysing pre-test and post-test results through the normalised gain, categorised as high where g exceeds 0.7, moderate where g falls between 0.3 and 0.7, and low where g is below 0.3.

RESULTS AND DISCUSSION

Needs Analysis

The needs analysis was conducted in order to obtain an accurate picture of the conditions of applied physics instruction and of student and lecturer requirements in relation to the development of a STEM-based e-module. Data were obtained through student and lecturer needs questionnaires, interviews, and observation of classroom instruction. The questionnaire administered to 54 students established a very high requirement for interactive and readily accessible digital learning media. Most students judged the applied physics material used hitherto to be difficult to understand, principally because its presentation is abstract and insufficiently furnished with illustrations and applied examples. The questionnaire administered to six lecturers indicated that the requirement for STEM integration and for cross-device accessibility both attracted the highest score, at 3.83. A summary of the needs analysis is presented in Table 1.

Table 1. Summary of the Student and Lecturer Needs Analysis

Data source	Aspect analysed	Principal finding	Mean (category)
Students (N=54)	Need for an e-module	Interactive and readily accessible e-module required	3.68 (Strongly needed)
Students (N=54)	Completeness of content	Illustrations, images and applied examples required	3.65 (Strongly needed)
Students (N=54)	Interactive features	Video, simulation and automated assessment required	3.58 (Needed)
Students (N=54)	Accessibility	E-module must be accessible by smartphone	3.82 (Strongly needed)
Students (N=54)	Self-regulated learning	E-module must support independent study	3.78 (Strongly needed)
Lecturers (N=6)	Updating of content	Content requires updating to the maritime vocational context	3.50 (Needed)
Lecturers (N=6)	STEM integration	E-module must employ the STEM approach	3.83 (Strongly needed)
Lecturers (N=6)	Digital assessment	Automated assessment feature required	3.50 (Needed)
Lecturers (N=6)	Cross-device accessibility	Compatible across a range of devices	3.83 (Strongly needed)

Interviews with lecturers and students disclosed that the limited instructional time available in class leaves students with an insufficient grasp of fundamental physical concepts. Lecturers judged that students comprehend material more rapidly when supplied with visualisation in the form of images of shipboard equipment, simple simulations, or illustrations of the application of concepts in the maritime workplace. Classroom observation likewise indicated that instruction remains dominated by oral explanation supported by static slides, without interactive media or supporting simulation, with the consequence that students participate little in discussion for want of visual reference and authentic case material.

Expert Validation

Validation was undertaken in order to establish that the e-module satisfies criteria of feasibility in respect of both content and media. Subject-matter experts returned a mean score of 3.58, placing the product in the Feasible category, and judged that the presentation of content conforms to the competency structure, that the integration of STEM elements is appropriate, and that the examples of the application of physical concepts in maritime practice are relevant. Media experts returned a mean score of 3.67, within the Highly Feasible category, and judged the display of the e-module to be attractive, proportionate and comfortable to view, with navigation that is clear and responsive, particularly when accessed by mobile device. The detailed validation results are presented in Table 2.

Table 2. Results of Subject-Matter and Media Expert Validation

Validator	Assessment indicators	Mean	Category
Subject-matter expert	Correspondence of content with learning outcomes and curriculum; conceptual accuracy and scientific correctness; relevance of examples to the maritime context; integration of STEM components; language and clarity of explanation	3.58	Feasible
Media expert	Display design and aesthetics; navigation and ease of use; legibility of type, colour and layout; appropriateness of illustration and visual material; design consistency and interactivity	3.67	Highly feasible
Overall conclusion	The e-module satisfies the criteria of content and media feasibility and may be implemented following minor revision	3.63	Feasible to highly feasible

The corrective observations offered by the validators were minor and were accommodated in full at the revision stage. They comprised the addition of more detailed applied calculation examples within the shipboard engine context, an increase in the number of technical illustrations, improvement to the sequence of explanation in several sub-sections, adjustment of page layout for greater consistency, and the addition of standard navigation icons to clarify button function for new users.

Product Development

The development stage produced a STEM-based applied physics e-module structured to comprise an introduction, statement of learning outcomes, systematically ordered content, examples of the application of concepts within the maritime domain, graded exercises, and automated assessment. Visually, the e-module was developed using a responsive design permitting access by laptop or by smartphone, the latter being the students' principal device. The display was constructed with attention to legibility, colour consistency, type size and layout in order to facilitate navigation. The e-module is further furnished with illustrations of shipboard equipment, diagrams, conceptual visualisations, links to instructional video, and simple simulations intended to consolidate understanding of physical concepts within the maritime working context.

Practicality Testing

Practicality testing was conducted in order to establish ease of use, comprehensibility and usefulness from the user's perspective. Response questionnaires returned by 54 students yielded an overall mean of 3.62, within the Very Practical category. Students judged the e-module easy to use, well accessible by mobile device, and visually attractive. The automated assessment feature was judged of considerable assistance in gauging their own level of understanding without awaiting the lecturer's explanation. The lecturer questionnaire returned a mean score of 3.71, likewise within the Very Practical category. Results by aspect are presented in Table 3.

Table 3. Summary of E-Module Practicality Testing

Respondent	Aspect assessed	Mean	Category
Students (N=54)	Ease of use (access, navigation, responsiveness)	3.64	Very practical
Students (N=54)	Clarity of content (explanation, illustration, worked steps)	3.60	Very practical
Students (N=54)	Self-regulated learning (motivation, direction of independent study)	3.59	Very practical
Students (N=54)	Display and navigation (visual design, legibility)	3.65	Very practical
Students (N=54)	User satisfaction (learning experience, usefulness)	3.63	Very practical
Student mean	-	3.62	Very practical
Lecturers (N=6)	Ease of use (efficiency, device compatibility)	3.72	Very practical
Lecturers (N=6)	Presentation of content (systematic, concise, integrated with STEM)	3.70	Very practical
Lecturers (N=6)	Media design (display quality, illustration, legibility)	3.73	Very practical
Lecturers (N=6)	Instructional usefulness (assistance in explaining concepts)	3.70	Very practical
Lecturer mean	-	3.71	Very practical
Overall conclusion	The e-module is very practical in use for students and lecturers alike	3.66	Very practical

Effectiveness Testing

Effectiveness was assessed on the basis of the improvement in student achievement before and after use of the e-module. Pre-test scores fell within a range of 40 to 70 with a mean of 60.11, indicating that most students had yet to command the fundamental concepts of applied physics adequately. Following use of the e-module, post-test scores rose to a range of 70 to 95 with a mean of 83.94. The mean improvement of 23.83 points indicates that the e-module exerted a positive influence upon student understanding. The normalised gain computation returned a mean of 0.60, within the Moderate category. A summary of the effectiveness results is presented in Table 4.

Table 4. Summary of E-Module Effectiveness Testing

Component	Result	Remarks
Number of students	54	Limited field trial
Mean pre-test	60.11	Range 40-70; low to moderate initial understanding
Mean post-test	83.94	Range 70-95; majority attained mastery
Mean improvement	+23.83 points	Marked improvement following use of the e-module
Mean normalised gain	0.60	Moderate category ($0.3 < g < 0.7$)
Self-regulated learning score	3.59-3.78	Supports independent study and self-regulation
Effectiveness category	Effective	The e-module improves student concept mastery

Students with lower initial scores exhibited higher normalised gains than those with higher initial scores. This pattern is unremarkable in educational research, since learners of lower initial attainment possess greater room for improvement, whereas those with high pre-test scores approach the ceiling of the scale, so that their normalised gain tends to fall within the moderate to low range. The self-regulated learning questionnaire returned student response scores ranging from 3.59 to 3.78, indicating that the e-module supports independent study and self-regulation.

The needs analysis confirms that students and lecturers alike require learning media connecting abstract physical concepts to their concrete application in the maritime domain. This finding accords with the proposition that STEM instruction is effective precisely because it situates concepts within authentic problem contexts (Breiner et al., 2012), and is reinforced by the meta-analytic evidence of Zhou et al. (2025), who found the effect size of STEM integration to be largest for context integration relative to content or tool integration. The advantage of the e-module developed here accordingly lies not in the digitisation of teaching material as such but in the explicit anchoring of physical concepts within actual shipboard working systems.

The Feasible to Highly Feasible categorisation returned by expert validation confirms that the e-module satisfies requirements of content correspondence and display quality alike. This accords with the multimedia design principles shown meta-analytically to improve learning outcomes, particularly the signalling, spatial contiguity and segmentation principles (Noetel et al., 2022; Mayer, 2017). The high scores awarded by media experts for consistency of layout, use of colour and clarity of illustration indicate that the design of the e-module succeeds in managing extraneous cognitive load as Castro-Alonso et al. (2021) recommend, so that students' cognitive capacity may be allocated to the processing of essential material.

The Very Practical categorisation returned by students and lecturers alike confirms that the e-module is easy to use and supportive of independent study. This finding is consistent with Sari (2021), who demonstrated that a STEM-based physics practicum e-module fosters independent learning, and with Nazifah and Asrizal (2022) and Yulkifli et al. (2022), who obtained valid and practical categorisations for STEM-integrated physics e-modules. The high score attracted by accessibility through mobile devices is likewise pertinent to the characteristics of vocational learners, who require repeated access to material outside class hours.

The significant improvement from pre-test to post-test, with a normalised gain in the Moderate category, confirms the effectiveness of the e-module in improving concept mastery. The magnitude is comparable to that obtained in cognate studies and may be explained through the cognitive theory of multimedia learning, which holds that the integration of text, visual material and interaction improves comprehension and retention (Mayer & Moreno, 2003; Mayer, 2017). Considered within the framework of the cognitive taxonomy, the improvement in concept mastery scores indicates a shift in students' cognitive activity from mere recall towards understanding and application (Anderson & Krathwohl, 2001).

The self-regulated learning scores, ranging from 3.59 to 3.78, support the proposition that digital media affording latitude in the management of time, pace and learning strategy may strengthen self-regulation. This finding is consistent with Zimmerman's (2002) cycle of self-regulated learning and is supported by meta-analytic evidence that such interventions exert a positive influence upon academic achievement in online and blended environments (Xu et al., 2023; Theobald, 2021). The positive correlation between self-regulated learning strategy and online academic performance reported by Cheng et al. (2025), together with the moderate effect size for self-directed learning obtained by Doo and Zhu (2024), situates the effect observed here within the range to be expected of a media-based intervention.

From the standpoint of maritime education, the present findings complement a Maritime Education and Training literature hitherto dominated by simulator-based research. Kim et al. (2021) and Dewan et al. (2023) emphasise the importance of media replicating actual shipboard conditions, while Karahalil et al. (2024) show that variation in the interpretation of STCW standards across institutions produces heterogeneous teaching practice. The e-module developed here offers a complementary and considerably more affordable route than simulation, while remaining bound to the competency structure of IMO Model Course 7.04 and thereby supporting consistency of learning outcomes across institutions.

Several limitations warrant record. The effectiveness test was conducted at limited scale using a one-group pre-test and post-test design without a control group, so that the improvement observed cannot be attributed to the e-module alone. Measurement of self-regulated learning moreover rests upon self-report and is therefore susceptible to response bias. Chang et al. (2024) caution that the effect size of STEM is moderated by educational level, subject domain and instructional duration, so that generalisation of the present findings to other contexts should proceed with care.

CONCLUSIONS AND RECOMMENDATIONS

The STEM-based applied physics e-module developed using the ADDIE model and aligned to the competencies of IMO Model Course 7.04 satisfies three criteria of instructional product quality. In respect of feasibility, the e-module falls within the Feasible to Highly Feasible category, with scores of 3.58 from subject-matter experts and 3.67 from media experts. In respect of practicality, it attains the Very Practical category, with scores of 3.62 from students and 3.71 from lecturers. In respect of effectiveness, its use raised mean student achievement from 60.11 at pre-test to 83.94 at post-test, corresponding to a normalised gain of 0.60 in the Moderate category, while self-regulated learning scores ranged from 3.59 to 3.78.

On the basis of these findings, maritime education institutions are advised to support the continuing development of digital learning media and to provide facilities and training for lecturers in the design of technology-based instruction. Lecturers are advised to employ the e-module to full advantage both within class and as independent study material, developing instructional scenarios that exploit its interactive features. Students are encouraged to make consistent use of the exercise and automated assessment sections in order to deepen their command of concepts.

ADVANCED RESEARCH

The limitations of the present study open several avenues for further work. First, the effectiveness design lacking a control group may be strengthened through a quasi-experimental design incorporating a comparison group in order to reinforce causal inference. Second, the sample, confined to a single study programme within a single institution, may be extended through a multi-institutional study across several maritime polytechnics in order to test the generalisability of the findings. Third, the multimedia features may be enriched with three-dimensional simulation or interactive animation replicating shipboard machinery systems, the effectiveness of which may then be tested comparatively against simulator-based training as mapped by Dewan et al. (2023). Fourth, the measurement of self-regulated learning may be supplemented with process data drawn from learning analytics in order to reduce reliance upon self-report.

ACKNOWLEDGMENT

The authors express their gratitude to the Director of Banten Maritime Polytechnic and the institutional leadership, to the Centre for Research and Community Service, to the expert validators, and to all students and lecturers of the Marine Engineering study programme who participated in and supported the conduct of this research.

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