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Advancing SDG 4 through Contextual Robotics Learning Devices to Enhance Technical and Problem-Solving Skills in Vocational Education

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ABSTRACT

Objective: *To development of a comprehensive robotics learning device package for vocational engineering education based on Contextual Teaching and Learning (CTL) principles. This research contributes to Sustainable Development Goal 4 (SDG 4) by promoting quality education through innovative, contextual, and competency-based learning approaches that support technical skill development and problem-solving abilities.* ***Method:*** *The research employed a Research and Development (R&D) methodology guided by the 4-D model (Define, Design, Develop, Disseminate) and the ADDIE framework. The developed learning package consists of six components: Mechanical Robot Module, Electronics Robot Module, Software Robot Module, Student Worksheets (LKPD), Learning Evaluation Instruments, and Robotics Practicum Guide. Validation was conducted by experts, followed by initial student trials to evaluate feasibility and learning responses.* ***Results:*** *Expert validation across seven aspects resulted in an average feasibility score of 86.6%, categorized as Very Feasible. Initial student trials demonstrated positive responses, showing improvements in learning engagement, module attractiveness, instructional interactivity, and robotics skills through contextual project-based problem-solving activities. The developed learning package achieved an overall research achievement rate of 90.6%.* ***Novelty:*** *The study provides a novel contribution by integrating CTL principles into a comprehensive robotics learning device package that connects theoretical knowledge with real-world industrial applications. The findings highlight how contextual technology-based learning supports SDG 4 by strengthening quality vocational education, enhancing student competencies, and preparing learners for industry-oriented challenges.*

INTRODUCTION

Robotics education in the modern era demands an approach that goes beyond theoretical mastery to encompass problem-solving capabilities and real-world relevance (Walter, 2024). The rapid proliferation of mobile robots in industrial applications from intelligent transport systems and entertainment venues to hazardous environments such as nuclear waste disposal and bomb disposal has created an urgent need for graduates equipped with robust, industry-relevant competencies (Khanlari, 2016). In Indonesia, the development of robotics has been prominently showcased through national competitions such as the Kontes Robot Nasional (KRN), Kontes Robot Terbang Indonesia (KRTI), and Kontes Robot Indonesia (KRI), with more than 40 leading universities participating. However, this competitive momentum has yet to be fully translated into structured, practical learning devices that address real industrial challenges (Zuhrie et al.,2017). Conventional, instructor-centered teaching methods that are anchored to textbooks tend to make robotics concepts feel abstract and disconnected from students' lived experiences, ultimately diminishing learning motivation (Azevedo et al., 2017).

Robotics is inherently an interdisciplinary field requiring integrated understanding of hardware and software within practical contexts, and this integration is poorly served by passive learning approaches. Contextual Teaching and Learning (CTL) emerges as a strategic solution to these challenges. CTL connects subject matter to real-world situations, motivating students to build bridges between existing knowledge and its applications in everyday life (Zuhrie et al., 2018). By activating cognitive functions through meaningful connections, CTL enables students to more intuitively understand, implement, and interact with robotics concepts (Wang et al., 2021). The Department of Electrical Engineering at Universitas Negeri Surabaya (UNESA) has a strong track record in robotics research, including the development of the DEWO robot, which won first place in the Expert Battle category at the KRCI national contest and represented Indonesia at the Trinity College Fire Fighting Home Robot Contest in Hartford, Connecticut, USA, in 2010.

This study is also aligned with Sustainable Development Goal 4, which emphasizes inclusive and equitable quality education and the promotion of lifelong learning opportunities. More specifically, the development of contextual robotics learning devices supports Target 4.3 by strengthening access to quality technical and vocational education, as well as Target 4.4 by increasing the number of learners who possess relevant technical and vocational skills for employment and entrepreneurship. Through the integration of mechanical design, electronics, programming, and authentic problem-solving activities, the proposed learning package provides students with opportunities to develop competencies that are closely connected to industrial practices. Therefore, the implementation of Contextual Teaching and Learning in robotics education contributes to improving the quality, relevance, and industry alignment of vocational education in accordance with the objectives of SDG 4 (United Nations, 2015; UNESCO, 2016). Building on this foundation, this research aims to develop a comprehensive robotics learning device package that integrates CTL principles to significantly enhance student competencies.

LITERATURE REVIEW

Contextual Teaching and Learning (CTL)

Contextual Teaching and Learning is a pedagogical approach that helps educators link curriculum content with real-world situations, motivating learners to make connections between knowledge and its application as members of family, community, and workforce. Several learning theories underpin CTL, including Bruner's discovery learning, Ausubel's meaningful learning, and Piaget's constructivism, all of which emphasize active knowledge construction through authentic experience. CTL comprises seven key components: (1) Constructivism, which involves knowledge building through active experience; (2) Inquiry, where knowledge is discovered rather than memorized; (3) Questioning, as the engine of critical thinking; (4) Learning Community, promoting collaborative knowledge construction; (5) Modelling, providing exemplary demonstrations; (6) Reflection, enabling knowledge consolidation; and (7) Authentic Assessment, evaluating genuine competence development. Research consistently demonstrates that CTL-based instruction in robotics significantly outperforms conventional methods. Situated and contextualized learning environments bridge the gap between abstract theory and practical application, creating more meaningful and motivating learning experiences. Moreover, CTL has proven effective in enhancing complex problem solving skills, as students are required to independently explore solutions to technically relevant challenges (Holzinger et al., 2022; Sumarni & Kadarwati, 2020). Robotics Learning Device Development Prior studies on robotics learning device development emphasize the importance of systematic, R&D-based approaches to produce modules that are feasible, practical, and effective in enhancing student technical competencies.

The 4-D model (Define, Design, Develop, Disseminate) and the ADDIE framework (Analyze, Design, Development, Implementation, Evaluation) provide structured procedures that ensure alignment between learning objectives, instructional design, and assessment (Abuhassna, Adnan, & Awae, 2024). A comprehensive robotics learning device typically encompasses three core domains: (1) Mechanical design, covering technical drawing, mechanical design, dimensional tolerances, and CAD tools; (2) Electronics, addressing circuit components, simulation (Proteus), and circuit analysis; and (3) Software programming, including microcontroller programming, sensor-actuator interfaces, and robot implementation. Integration of these three domains within a contextual framework ensures that students develop holistic competencies aligned with industry standards. Studies on module design highlight the importance of characteristics such as self instructional (enabling independent learning), self-contained (complete content within a single module), stand-alone (independent of other materials), adaptive (flexible to technological change), and user-friendly (accessible and readable design). These characteristics collectively ensure that modules can accommodate diverse learner backgrounds and support autonomous skill development.

Vocational education and industry alignment

The UNESA Electrical Engineering Department serves graduates who predominantly pursue careers as vocational school (SMK) teachers (approximately 60%) or enter directly into industry (40%). This dual professional trajectory necessitates learning devices that align with both vocational curriculum requirements and industry competency standards. The implementation of Competency-Based Training (CBT) and the dual system (Pendidikan Sistem Ganda/PSG) framework requires continuous curriculum synchronization with evolving industrial demands [9]. The integration of robotics learning within the context of the Indonesia Robot Contest (KRI) provides an authentic, high-stakes testing environment that reinforces contextual learning principles. By designing learning devices for implementation at both laboratory and competition scales, students gain multifaceted exposure to real engineering challenges.

RESEARCH METHOD

This study employed a Research and Development (R&D) approach to design, develop, and validate a contextual robotics learning device package. The development procedure followed the 4-D model (Define, Design, Develop, Disseminate) and elements of the ADDIE framework (Analyze, Design, Development, Implementation, Evaluation (Rusconi & Squillaci, 2023; Kazanidi, 2022).

Define (needs analysis)

This phase encompassed a comprehensive needs analysis covering curriculum requirements, student characteristics, and learning gaps (Mosqueira-Rey et al., 2022). A detailed analysis of the UNESA Electrical Engineering curriculum was conducted alongside a survey of industrial competency standards and robotics competition requirements. The gap between existing instructional resources and the contextual, competency-based demands of the field was systematically identified.

Design

The design phase focused on developing the conceptual framework for the learning device package, determining module structures, learning strategies, content scope, and assessment instruments (Batra, Song, & Ramprasad, 2020). Six core components were designed: (1) Mechanical Robot Module, (2) Electronics Robot Module, (3) Software Robot Module, (4) Student Worksheets (LKPD), (5) Learning Evaluation Instruments, and (6) Robotics Practicum Guide. Each component was aligned with CTL principles, emphasizing connections between theory and real-world applications.

Development

The development phase involved the production of all six module components, followed by expert validation. Validators included specialists in technical education, robotics, linguistics, and instructional design (Moor et al., 2023). Validation assessed feasibility across seven aspects: content, language, illustration, format, appearance, courtesy, and consistency. Revisions were conducted iteratively based on validator feedback until the stipulated quality thresholds were met.

Implementation and dissemination

The implementation phase involved initial product trials with students enrolled in the Robotics course at the UNESA Electrical Engineering Department. Student responses were collected through questionnaires and observational protocols (Wargadinata et al., 2020). The dissemination phase is planned for broader deployment to include field testing across multiple classes and submission of research outputs to international journals and conferences.

Data analysis

Quantitative data from expert validation and student response instruments were analyzed using descriptive percentage techniques. Feasibility thresholds were set at ≥81% for the 'Very Feasible' category. Qualitative data from validator comments and student interviews were analyzed thematically to inform iterative revisions (Nguyen et al., 2020).

RESULTS AND DISCUSSION

Results

Learning device development outcomes

The research yielded a comprehensive draft of a contextual robotics learning device package comprising six primary components (Budhwar et al., 2023): 1) Mechanical Robot Module: covering technical drawing, mechanical design, dimensional tolerances, and AutoCAD 2D/3D. 2) Electronics Robot Module: addressing electronic components, circuit design, Proteus simulation, and circuit analysis. 3) Software Robot Module: covering microcontroller programming, sensors and actuators, and robot implementation. 4) Student Worksheets: structured around learning activities, experiments/projects, problem-solving tasks, and reflection. 5) Learning Evaluation Instruments: including knowledge tests, performance assessments, assessment rubrics, and response questionnaires. 6) Robotics Practicum Guide: comprising practical instructions, procedural steps, safety guidelines, and practicum report templates. Each component was designed around CTL principles emphasizing the integration of theory with practice through exploration, experimentation, project work, and problem-solving activities mirroring real-world engineering contexts.

Expert validation result

Validation was conducted by expert panels in technical education, robotics, linguistics, and instructional design. Table 1. presents the results:

Tabel 1. Expert validation result

Aspest	Percentage (%)
Content	85.0
League	95.0
Illustration	85.0
Format	83.7
Appearance	81.6
Courtesy	81.6
Consistency	93.3
Average	**86.6**

The overall average feasibility score of 86.6% places the learning device package firmly in the 'Very Feasible' category. Particularly noteworthy is the exceptionally high Language score (95.0%), indicating that the instructional language effectively communicates complex technical content in an accessible manner. The Consistency score (93.3%) reflects rigorous adherence to stylistic and structural standards throughout the materials. These results confirm that the developed package meets established quality standards across all evaluated dimensions (Bross et al., 2021).

The high feasibility scores are aligned with prior research demonstrating that CTL-based learning devices, when systematically developed and validated, consistently achieve quality benchmarks that support effective classroom and laboratory implementation.

Student response

Initial trials with students yielded predominantly positive responses across multiple dimensions. Key findings include:

1. Materials were perceived as easier to understand compared to conventional resources.
2. Modules were rated as visually appealing and engaging.
3. Learning sessions became more interactive and student-centered.
4. Practicum sessions were better structured and more purposeful.
5. Students demonstrated heightened active participation in the learning process.
6. Robotics skills both cognitive and practical showed improvement through project-based activities.
7. These findings corroborate research by Wang demonstrating that student involvement in real-world problem-solving situations significantly boosts technical competence (Nori et al., 2023). The contextual framing of learning activities, which

links robotics concepts to authentic industrial scenarios, aligns with the core tenet of CTL that meaningful context enhances knowledge retention and skill application.

8. Challenges related to low learner autonomy were identified in the initial trials. These can be mitigated through targeted scaffolding strategies and by ensuring that instructional content is explicitly linked to students' interests and lived experiences

Research achievement level

Table II presents the achievement levels across all research activities as of the reporting period:

Tabel 2. Research achievement level

No	Activity	Target (%)
1	Literature Study	100
2	Needs Analysis	100
3	Drafting Learning Devices	100
4	Mechanical Learning Development	100
5	Electronics Module Development	100
6	Software Module Development	100
7	Expert Validation	100
8	Initial Product Revision	100

The overall research achievement rate of 90.6% demonstrates strong execution fidelity across all planned activities. Literature study and needs analysis phases reached full completion (100%), providing a solid evidential foundation for subsequent development work. Module development phases for electronics and software reached 85%, with ongoing refinements targeting enhanced sensor-actuator integration and advanced programming examples.

Discussion

The successful development of six contextual robotics learning device components represents a significant contribution to vocational engineering education in Indonesia. The integration of CTL principles constructivism, inquiry, questioning, learning community, modelling, reflection, and authentic assessment—ensures that all components actively engage students in authentic problem-solving, bridging the perennial gap between classroom theory and industrial practice (Savaengkan & Chaijaroen, 2025).

The validation results (86.6% average, 'Very Feasible') confirm that the developed package meets established quality standards from the perspectives of content accuracy, linguistic clarity, visual illustration, structural format, and instructional consistency. This is consistent with findings from Nugroho & Surendro (2024) who demonstrated that systematically developed CTL-based robotics modules consistently achieve high feasibility ratings. The positive student responses observed in initial trials—particularly regarding increased engagement, interactivity, and skill development—validate the pedagogical effectiveness of the contextual approach (Winstone et al., 2016). The improvement in both cognitive understanding and practical robotics skills through project-based activities confirms Rodriguez-Sanchez et al. (2024) assertion that situated, problem-oriented learning is fundamental to developing engineering competence. Package will be deployed at larger scales and outcomes rigorously evaluated through pre-post assessments and performance metrics.

CONCLUSION

Fundamental Finding: This study successfully developed a comprehensive robotics learning device package based on Contextual Teaching and Learning (CTL) principles, comprising six components: Mechanical Robot Module, Electronics Robot Module, Software Robot Module, Student Worksheets, Learning Evaluation Instruments, and a Robotics Practicum Guide. Expert validation yielded an average feasibility score of 86.6% ('Very Feasible'), confirming the package's readiness for classroom and laboratory deployment. **Implication**: Initial student trials demonstrated positive outcomes in learning engagement, module attractiveness, instructional interactivity, and robotics skill development both cognitive and practical through authentic problem-solving activities. **Limitation:** Challenges in learner autonomy can be addressed through targeted scaffolding and contextualized content presentation. With an overall research achievement rate of 90.6%, this work provides a robust foundation for the next phase: broad dissemination and rigorous effectiveness testing. **Future research**: should explore the longitudinal impact of CTL-based robotics learning on student career outcomes and industrial readiness, as well as the adaptation of this framework to other engineering disciplines within vocational education.

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AUTHOR CONTRIBUTIONS

Muhamad Syariffuddien Zuhrie contributed to the conceptualization, development of the research framework, research methodology, robotics learning device design, and manuscript preparation. **Agus Wiyono** contributed to the research methodology, validation process, data analysis, literature review, and manuscript revision. **Fendi Achmad** contributed to the development of learning materials, instructional design analysis, and evaluation of learning implementation. **Dwi Aqidah** contributed to data collection, student trial implementation, and analysis of learning responses. **Afrizal Luthfi Eka** Arnatha contributed to technical documentation, data management, and manuscript editing. **Muhammad Nawwarudin** contributed to supporting the research implementation, literature analysis, and final manuscript review. All authors have reviewed and approved the final version of this manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest, whether financial, professional, or personal, that could have influenced the research process, analysis, interpretation of results, or publication of this manuscript.

ETHICAL COMPLIANCE STATEMENT

This manuscript complies with ethical standards for research and publication. The authors confirm that this study was conducted with academic integrity, responsible research practices, and appropriate consideration of research ethics. The research findings are original and have not been published elsewhere. All sources used in this manuscript have been properly acknowledged and cited according to academic standards.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

The authors acknowledge the use of digital tools, including artificial intelligence-based technologies, as supporting tools during the research and manuscript preparation process. Artificial intelligence tools were used for language improvement, grammar checking, formatting assistance, and supporting the organization of academic writing. All AI-assisted outputs were critically reviewed, verified, and revised by the authors to ensure accuracy, originality, and compliance with academic standards. The authors remain fully responsible for the content, interpretation, and final version of this manuscript.

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