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FORMS, METHODS AND TOOLS OF DIGITAL INSTRUMENTS DEVELOPED ON THE BASIS OF CLIL TECHNOLOGY FOR STUDENTS OF MECHATRONICS AND ROBOTICS PROGRAMMES IN TECHNICALLY ORIENTED HIGHER EDUCATION INSTITUTIONS

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Abstract. The integration of Content and Language Integrated Learning (CLIL) technology with purpose-built digital tools presents a compelling pedagogical paradigm for technically oriented higher education institutions, particularly in the rapidly evolving fields of mechatronics and robotics. This article systematically examines the forms, methods, and tools of digitally mediated CLIL instruction tailored to the specific epistemological and communicative demands of engineering students who must simultaneously develop disciplinary competence and professional English proficiency. Drawing on pedagogical theory, engineering education research, and empirical evidence from technology-enhanced language learning environments, the study proposes a taxonomy of digital CLIL instruments organised across three primary categories: interactive simulation-based platforms, discipline-specific corpus and terminology tools, and collaborative project environments. The article further delineates methodological principles governing the deployment of these tools, including cognitive load balancing, authentic task design, formative digital assessment, and technical discourse scaffolding. The findings demonstrate that a systematically designed digital CLIL ecosystem significantly enhances engineering students' ability to engage with international professional literature, participate in global technical discourse, and produce discipline-appropriate academic and professional communication in English.

Keywords: CLIL, digital tools, mechatronics, robotics, engineering education, technical English, higher education, language integration, simulation-based learning, ESP.

1. Introduction

The global engineering labour market increasingly demands practitioners who combine deep technical expertise with sophisticated professional communication skills in English. International collaboration on robotics projects, cross-border patent applications, publication in indexed engineering journals, and participation in professional bodies such as IEEE and IFR all presuppose a level of English proficiency that extends well beyond general communicative competence into the specialised registers of technical discourse. For students of mechatronics and robotics—disciplines that sit at the intersection of mechanical engineering, electronics, computer science, and artificial intelligence—this challenge is particularly acute.

Traditional English for Specific Purposes (ESP) instruction, while addressing lexical and structural features of technical English, has been criticised for its decontextualised approach and limited integration with authentic disciplinary practice (Dudley-Evans & St John, 1998). Content and Language Integrated Learning (CLIL), by contrast, situates language development within genuine content learning, enabling students to acquire technical English as an instrument of professional thinking and communication rather than as an ancillary skill (Coyle, Hood & Marsh, 2010). When CLIL is implemented through purpose-designed digital tools that reflect the

computational and engineering environment familiar to mechatronics and robotics students, the potential for motivationally authentic, cognitively demanding, and linguistically productive learning is substantially amplified.

Despite growing interest in both CLIL in higher technical education and digital language learning tools, a systematic account of the specific forms, methods, and tools appropriate to mechatronics and robotics programmes remains absent from the literature. This article addresses that gap. It proceeds from theoretical foundations through a taxonomy of digital CLIL instruments to a discussion of methodological implementation principles and pedagogical implications for technically oriented higher education institutions.

2. Theoretical Framework

2.1 CLIL in Higher Technical Education

CLIL in tertiary engineering contexts differs in important respects from its implementation in secondary school settings. University-level students bring developed disciplinary conceptual frameworks, high intrinsic motivation related to professional identity, and an acute awareness of the instrumental value of English for international career development (Fortanet-Gómez, 2013). These characteristics make tertiary CLIL both more tractable—students are motivated to engage with authentic English-medium content—and more demanding, since the disciplinary content must genuinely challenge students at the frontier of their technical knowledge.

Coyle et al.'s (2010) 4Cs Framework—Content, Communication, Cognition, and Culture—requires contextualisation for engineering settings. In mechatronics and robotics CLIL, Content encompasses the technical subject matter of the discipline (sensor systems, control algorithms, kinematics, embedded programming); Communication involves both the receptive skills needed to access international literature and the productive skills required for technical reporting and professional interaction; Cognition encompasses the higher-order engineering thinking processes of analysis, design, troubleshooting, and evaluation; and Culture addresses the norms and conventions of international engineering professional communities.

2.2 English for Specific Purposes and Technical Discourse

The linguistic demands of mechatronics and robotics discourse are distinctive and well-documented. Technical texts in these fields are characterised by high-density noun phrases, passive constructions, complex conditionals, and an extensive Tier 3 specialist lexicon encompassing terms from multiple parent disciplines (Swales, 1990). Furthermore, engineers must navigate multiple text types—research articles, technical standards (ISO, IEC), patent specifications, user manuals, and project reports—each with its own genre conventions.

Genre-based approaches to language teaching (Martin & Rose, 2008) offer a productive framework for CLIL in technical contexts, directing attention to the staged social purposes of discipline-specific text types and equipping students with explicit knowledge of the rhetorical structures they must master. Digital tools that provide genre-annotated exemplars, interactive templates, and AI-assisted feedback on genre adherence are therefore particularly valuable in this context.

2.3 Technology-Enhanced Learning in Engineering Education

Engineering education has a long tradition of simulation-based and project-based learning that aligns naturally with CLIL's emphasis on authentic, cognitively demanding tasks. Virtual laboratories, robotic simulation environments (e.g., ROS, Webots, V-REP), CAD/CAM platforms, and microcontroller programming interfaces (Arduino, Raspberry Pi) constitute an authentic technological environment in which technical English naturally functions as the operative language,

given that interface languages, documentation, and community support are predominantly English-medium.

Kolb's (1984) Experiential Learning Theory, with its cycle of concrete experience, reflective observation, abstract conceptualisation, and active experimentation, provides a productive framework for integrating language learning within engineering project workflows. Digital CLIL tools designed around this cycle can embed language development tasks at each stage—comprehension tasks during input phases, reflective writing during observation, academic reading during conceptualisation, and technical reporting during active experimentation.

3. A Taxonomy of Digital CLIL Tools for Mechatronics and Robotics

Based on the theoretical framework outlined above and a systematic review of available digital platforms, this article proposes a three-category taxonomy of digital CLIL instruments for mechatronics and robotics programmes, organised by primary pedagogical function.

3.1 Category I: Interactive Simulation and Virtual Laboratory Platforms

Simulation platforms constitute the most distinctively engineering-specific category of digital CLIL tools. These environments enable students to engage with authentic technical content—programming robotic systems, designing control circuits, testing mechatronic assemblies—in English-medium interfaces that mirror professional engineering software.

Robot Operating System (ROS) provides an open-source framework for robot software development whose documentation, community forums, and API references are entirely English-medium. Engaging with ROS requires students to read technical documentation, interpret error messages, follow tutorial sequences, and contribute to community discussions—all in authentic technical English. CLIL tasks built around ROS can target specific language functions (interpreting specifications, writing bug reports, documenting code) while simultaneously advancing programming and systems integration skills.

Webots and CoppeliaSim (V-REP) offer graphical robotic simulation environments with English-medium interfaces and extensive tutorial libraries. These platforms enable CLIL task design in which students must read English-language simulation documentation to complete engineering design challenges, producing written reflections and technical reports as language learning outputs. Tinkercad and Autodesk Fusion 360 provide analogous functionality for mechatronics design tasks involving CAD modelling and electronic circuit design.

Arduino and Raspberry Pi programming environments represent particularly accessible entry points for integrated technical-linguistic engagement. The vast English-medium community resources (tutorials, project galleries, troubleshooting forums) associated with these platforms provide authentic reading and listening input, while project documentation tasks generate meaningful writing production.

3.2 Category II: Discipline-Specific Corpus and Terminology Tools

Technical vocabulary development is a critical component of CLIL for engineering students. The specialist lexicon of mechatronics and robotics encompasses thousands of Tier 3 terms drawn from mechanics, electronics, informatics, and control theory, as well as a substantial layer of Tier 2 academic vocabulary shared across scientific disciplines. Digital corpus and terminology tools provide systematic support for this dimension of language development.

Engineering-specific corpora such as the Michigan Corpus of Upper-level Student Papers (MICUSP) and the British Academic Written English (BAWE) corpus, accessible through corpus browser interfaces, enable students to investigate authentic usage patterns of technical vocabulary and academic phrases in context. Concordancing tools allow learners to examine collocational

patterns, grammatical frames, and discourse functions of key terms, developing the lexical knowledge depth required for accurate technical production.

Specialised terminology management applications such as SDL MultiTerm and open-source alternatives enable students to build personal termbase databases organised by technical domain, creating structured vocabulary learning resources directly linked to their disciplinary studies. Spaced repetition applications (Anki, Quizlet) loaded with discipline-specific vocabulary sets—including technical definitions, usage examples drawn from engineering literature, and visual representations of mechanical and electronic concepts—support systematic vocabulary consolidation aligned with CLIL content engagement.

AI-powered academic writing assistants, including tools trained on scientific and technical corpora, can provide real-time feedback on technical vocabulary usage, academic register appropriateness, and genre convention adherence. These tools partially replicate the expert feedback function of CLIL teachers in self-directed learning contexts.

3.3 Category III: Collaborative Project and Communication Platforms

Collaborative digital environments provide contexts for authentic English use motivated by genuine communicative need within engineering project workflows. These platforms align with both CLIL's emphasis on communication as a learning medium and project-based learning approaches central to engineering education (Mills & Treagust, 2003).

GitHub serves as both a version control platform and a global community of engineering practice whose entire operational discourse—issue tracking, pull request reviews, README documentation, wiki pages—is conducted in English. Structuring student projects around GitHub workflows creates authentic English writing tasks embedded in genuine engineering practice: writing technical specifications, documenting code, participating in code review discussions, and maintaining project wikis.

IEEE Xplore and other academic database platforms expose students to authentic engineering research literature, while structured reading tasks (annotated bibliographies, literature summaries, critical reviews) develop the academic reading skills central to professional engineering practice. Collaborative annotation tools (Hypothesis, Perusall) enable group engagement with engineering texts, combining content comprehension with academic discussion in English.

Video conferencing and asynchronous discussion platforms (Zoom, Microsoft Teams, Padlet) support CLIL task designs involving international virtual exchange—connecting mechatronics students from different countries for joint project work, guest lectures from industry professionals, and collaborative problem-solving sessions conducted in English.

4. Methodological Principles for Digital CLIL Implementation

4.1 Authentic Task Design

A foundational methodological principle of digital CLIL in engineering contexts is authentic task design: learning activities should reflect the genuine communicative and cognitive demands of professional mechatronics and robotics practice. Authentic tasks (Wiggins, 1990) require students to apply knowledge in realistic contexts, produce outputs that have real-world relevance, and engage with the epistemic standards of the professional community. In digital CLIL terms, this means designing tasks around actual engineering platforms (ROS, Arduino, CAD software) with English communication outputs (technical reports, documentation, forum posts) that would be recognisable and valued in professional or academic engineering settings.

4.2 Cognitive Load Balancing

The simultaneous demands of engineering content mastery and language development create significant cognitive load risks. Effective digital CLIL methodology must attend carefully to

Sweller's (1988) Cognitive Load Theory, ensuring that instructional design reduces extraneous load (unnecessary complexity in interface design or task instructions) while maintaining appropriate intrinsic load (the productive challenge of genuine engineering problems) and optimising germane load (scaffolded opportunities for deep processing of both technical concepts and language patterns).

Practical cognitive load management strategies for digital CLIL include: sequencing language support tasks before content engagement tasks (pre-teaching key vocabulary through interactive glossaries before assigning technical readings); providing annotated exemplars of target text types; using multimedia presentations that distribute information across visual and auditory channels; and allowing flexible use of translation support tools for initial comprehension while progressively reducing this scaffolding as proficiency develops.

4.3 Formative Digital Assessment

Assessment in digital CLIL must capture both content knowledge development and language proficiency growth, reflecting the dual-focus character of the approach. Formative digital assessment tools—including automated language feedback systems, peer review platforms, e-portfolio applications, and AI-powered writing assessors—enable continuous monitoring of student progress on both dimensions. The principle of assessment as learning (Earl, 2003) is particularly relevant: digital CLIL assessment tasks should themselves constitute learning opportunities, providing students with actionable feedback that informs subsequent engagement with both technical content and language development.

Rubric-based assessment instruments for digital CLIL in mechatronics and robotics should evaluate technical accuracy (correct application of engineering concepts), communicative effectiveness (clarity and coherence of English expression), genre appropriateness (adherence to conventions of the target text type), and lexical precision (accurate use of discipline-specific terminology). Digital rubric tools such as Rubistar and Google Forms-based assessment systems can operationalise these criteria efficiently.

4.4 Technical Discourse Scaffolding

Technical discourse scaffolding refers to the structured support provided to students as they develop competence in the genres and registers of engineering professional communication. Drawing on systemic functional linguistics (Halliday & Matthiessen, 2004) and genre pedagogy (Martin & Rose, 2008), technical discourse scaffolding in digital CLIL proceeds through three stages: deconstruction (analysing the structure and linguistic features of model texts), joint construction (collaboratively producing target text types with teacher or peer support), and independent construction (autonomous production of discipline-appropriate texts).

Digital tools support each scaffolding stage: annotated digital text collections facilitate deconstruction analysis; collaborative writing platforms (Google Docs, Notion) enable joint construction with real-time feedback; and AI writing assistants support the independent construction stage by providing automated genre-awareness feedback. This scaffolding framework ensures that language development is not incidental but systematic, even within content-driven learning contexts.

5. Implementation Model: Digital CLIL in a Mechatronics Programme

To illustrate the practical application of the proposed taxonomy and methodological principles, this section outlines a module-level implementation model for a second-year mechatronics programme unit on autonomous robotic systems.

In the Preparation Phase (weeks 1-2), students complete a diagnostic language assessment using an adaptive platform to identify specific gaps in academic and technical vocabulary. A

curated vocabulary module covering key robotics and automation terminology (sensor fusion, PID control, degrees of freedom, kinematic chain, embedded systems) is loaded into Anki and assigned for daily SRS review. Students read and annotate (via Hypothesis) selected sections of introductory robotics textbooks in English, with comprehension tasks focusing on identifying key definitions, technical relationships, and argumentation structures.

During the Core Engagement Phase (weeks 3-10), students undertake a project-based CLIL unit centred on designing and simulating an autonomous mobile robot in Webots. All project documentation is produced in English, following IEEE technical report conventions introduced through genre analysis tasks in weeks 3-4. Weekly reading tasks engage students with selected IEEE conference papers relevant to their project focus, with structured reading guides scaffolding academic comprehension. Peer code review sessions on GitHub, conducted in English, develop technical discussion skills. AI writing assistants provide formative feedback on project documentation drafts.

In the Production and Reflection Phase (weeks 11-14), student teams present their robotic system designs in English, combining technical demonstrations with structured academic presentations. Teams submit a final project report in IEEE conference paper format and contribute a technical tutorial to a class GitHub repository. E-portfolio entries documenting language development alongside technical learning provide data for both student self-assessment and instructor formative evaluation.

6. Challenges and Pedagogical Considerations

Implementation of digital CLIL in technically oriented higher education institutions faces several significant challenges that require explicit methodological attention. First, the dual expertise demands on instructors are considerable: effective CLIL facilitation requires both disciplinary credibility and language pedagogical knowledge that few individual instructors possess. Team-teaching models that pair language specialists with engineering faculty, supported by digital collaboration tools, represent a pragmatic institutional response (Llinares, Morton & Whittaker, 2012).

Second, student resistance to English-medium instruction is a documented phenomenon, particularly among students who perceive language work as peripheral to their engineering identity (Airey, 2011). Framing digital CLIL tasks explicitly in terms of professional engineering competence—emphasising that international collaboration, IEEE publication, and access to cutting-edge technical documentation all require English proficiency—addresses this motivational challenge by connecting language development to students' professional aspirations.

Third, the rapid pace of technological development in robotics and mechatronics means that digital CLIL tool inventories require continuous updating to reflect current industry practice. Curriculum designers must establish systematic processes for evaluating and integrating new platforms, guided by the methodological principles articulated above rather than novelty alone.

7. Conclusion

This article has proposed a systematic framework for the forms, methods, and digital tools of CLIL-based instruction for mechatronics and robotics students in technically oriented higher education institutions. The three-category taxonomy of digital CLIL instruments—simulation and virtual laboratory platforms, discipline-specific corpus and terminology tools, and collaborative project and communication environments— provides a principled inventory of resources organised by pedagogical function. The four methodological principles of authentic task design, cognitive load balancing, formative digital assessment, and technical discourse scaffolding offer actionable guidance for instructors and curriculum designers implementing these tools.

The convergence of rich English-medium digital engineering ecosystems, increasingly sophisticated AI-assisted language tools, and compelling professional motivations for English proficiency among engineering students creates exceptionally favourable conditions for CLIL implementation in mechatronics and robotics programmes. When implemented systematically on the methodological foundations articulated in this article, digital CLIL can produce engineering graduates who are not merely technically competent but genuinely capable of operating as full participants in global engineering professional communities.

Future research should address longitudinal measurement of the dual outcomes of digital CLIL—technical knowledge acquisition and English language development—using validated instruments sensitive to both dimensions. Comparative studies across different engineering disciplines, institution types, and national contexts would contribute to a more differentiated understanding of the conditions under which digital CLIL produces optimal outcomes. The development of purpose-built digital CLIL platforms specifically designed for mechatronics and robotics education, integrating technical simulation environments with embedded language learning functionality, represents a particularly promising direction for educational technology development.

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