DECEL (Digital Electronics Collaborative Enhanced Learning)

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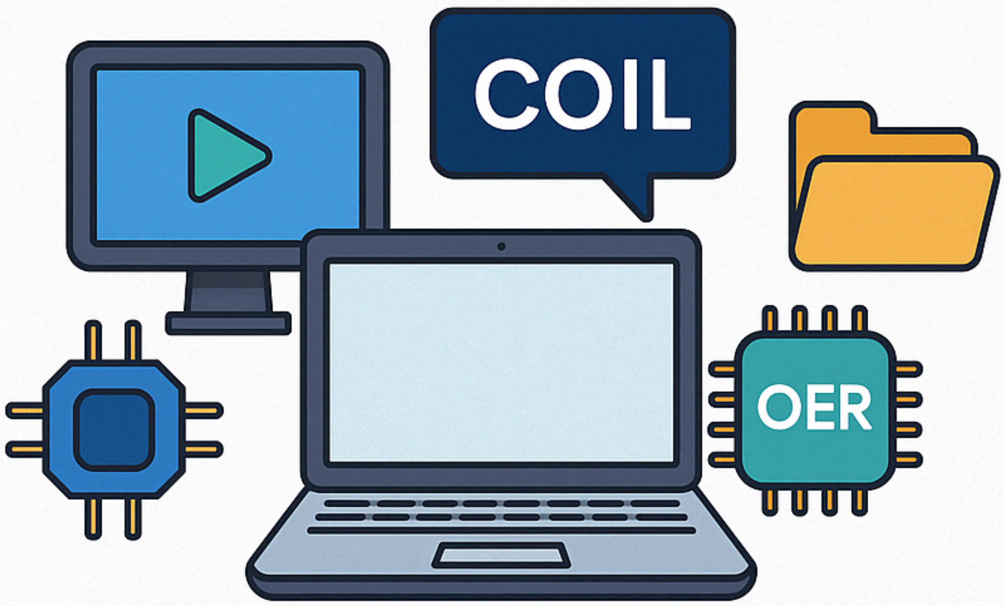
HANDBOOK

FOR MODERNISATION OF HIGH EXPERIMENTALLY-REGULAR COURSES



Project DECEL

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Contents

1. Introduction

The DECEL Handbook has been developed as a comprehensive guide to support the modernisation and internationalisation of experimental engineering courses, with a particular focus on Digital Electronic Systems. This handbook consolidates the collective experience and expertise acquired by the DECEL consortium, a partnership comprising the University of Alcalá (UAH), University of Porto (UP), University of Ferrara (UNIFE), and Université de Tours (UT), France.

DECEL was originally conceived within the context of **Electrical and Electronic Engineering** education, where the practical, “hands-on” nature of the courses presents a unique set of challenges. Traditional teaching in this field often relies heavily on face-to-face sessions and physical laboratory work, making innovation in course delivery particularly complex. However, from the outset, the project also aimed to generate results and methodologies that could be **exported and adapted** to other engineering disciplines, and more broadly to STEM fields with strong experimental components.

The ultimate goal has been to develop a **replicable and scalable model** of course modernisation—one that addresses not only the needs of Electrical and Electronic Engineering, but that can also be applied in other domains where teaching innovation remains limited, despite the growing need for flexibility, accessibility, and international collaboration.

While the European Higher Education Area (EHEA) provides a shared reference framework, significant differences persist across institutions in curricula, teaching methodologies, academic calendars, and resource availability. These variations underscore the need for adaptable strategies that respond effectively to local educational realities.

The DECEL project has tackled these challenges through a set of coordinated innovations. These include the adoption of active and collaborative learning strategies, the integration of remote laboratories, the deployment of virtual learning platforms, and the design of COIL (Collaborative Online International Learning) experiences. These approaches have been piloted and refined by all partners, ensuring relevance across diverse institutional settings.

Therefore, this handbook presents the **consolidated methodology and implementation path** derived from that collaborative process. It is intended as a practical reference for academic staff, institutional leaders, and other stakeholders engaged in curriculum design, teaching innovation, or international education initiatives.

By documenting best practices, offering tested protocols, and outlining concrete implementation steps, the DECEL Handbook aims to empower higher education institutions to **overcome common barriers** in course transformation. It also contributes to **closing the gap between education and industry**, equipping students with both technical expertise and transversal competences such as teamwork, adaptability, and intercultural collaboration—skills that are increasingly demanded across STEM-related fields.

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2. Methodological Framework

The methodological framework of the DECEL project provided the foundation for the coordinated transformation of experimental engineering education across a diverse group of institutions. While anchored in the context of Electrical and Electronic Engineering, it was developed with the clear intention of enabling adaptation and replication in other disciplines, particularly within the STEM fields where experimental, hands-on components are essential and teaching innovation often remains limited.

Figure 1 shows a short summary of the Digital Electronics Collaborative Learning (DECEL) initiative. This European effort (4 partners over 3 years) focused on enhancing engineering education through innovative, hands-on teaching, has achieved multiple outputs and notable impacts such as the development of over 20 courses, creation of 4 COILs, and training of more than 50 educators.

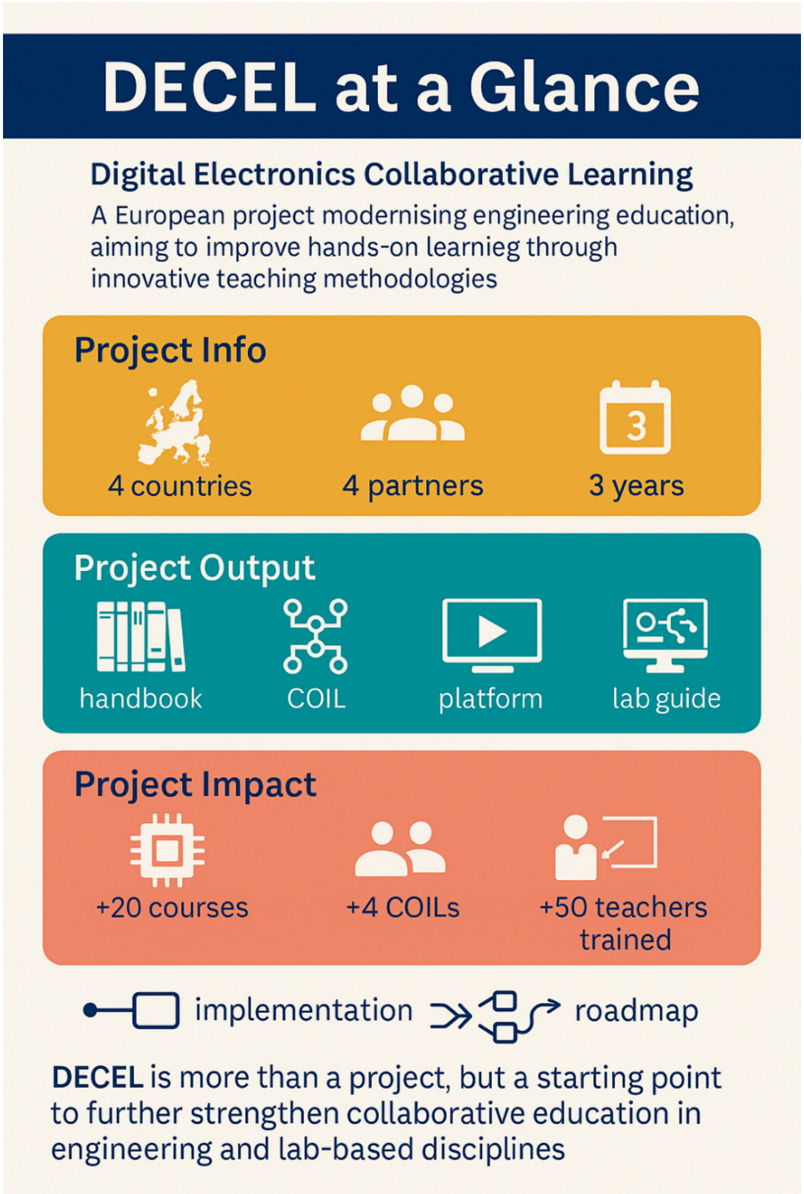

Figure 1. Overview of the DECEL project.

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The framework combined pedagogical innovation, digital integration, and international collaboration. It reflected both the shared goals of the consortium and the need to respond flexibly to the **variety of academic programmes, institutional structures, and national systems** present among the partners.

2.1 Pedagogical Orientation

From the outset, DECEL embraced the need to evolve beyond traditional lecture-centric teaching models that remain prevalent in experimental engineering education. The project promoted a shift towards **active, student-centred, and competence-based learning**, better aligned with 21st-century educational goals and labour market expectations.

Core pedagogical approaches included:

- **Collaborative project-based learning**, encouraging teamwork and peer-to-peer interaction;
- **Problem- and challenge-based activities**, closely linked to real-world engineering scenarios;
- **Blended and hybrid modalities**, combining online learning with physical experimentation;
- **Continuous and formative assessment**, promoting reflective learning and student autonomy.

These approaches were informed by contemporary didactic research and tailored to courses with a strong laboratory component. The emphasis on student engagement, problem-solving, and transversal skills (such as communication and intercultural collaboration) addressed the increasing demand for flexible, practice-oriented learning environments in STEM education.

While the pedagogical vision was unified, **its implementation had to be adapted to local conditions**, as the courses involved in the project differed across institutions. In some cases, the DECEL methodology was applied to undergraduate modules; in others, to master's-level courses. Moreover, **the content and structure of the targeted subjects were not identical** between institutions, even when dealing with broadly similar topics. These differences influenced both the pace and scope of pedagogical transformation.

Nonetheless, one of the key findings of the project was that **successful pedagogical strategies could be exported across disciplines and contexts**, provided that they are properly adjusted to fit the characteristics and needs of each course.

2.2 Institutional and National Diversity

One of the most important challenges faced during DECEL's implementation was the **heterogeneity of the academic environments** in which the project was deployed. Even though all partner institutions were part of the European Higher Education Area, they operated under different national regulations, degree structures, and internal academic cultures.

Differences emerged in areas such as:

- **Programme types**: Bachelor's vs Master's degrees;
- **Course lengths and credits**: variations in ECTS allocation and semester duration;
- **Teaching roles and responsibilities**: differences in how teaching staff engaged with course design and delivery;
- **Infrastructure and digital maturity**: uneven availability of virtual environments or lab resources.

Additionally, the **content and scope of the subjects addressed** by the DECEL pilots varied significantly. Some institutions focused on core digital systems design, while others included broader or more specialised applications. Despite these discrepancies, the project confirmed that shared objectives — such as enhancing experimental learning, internationalisation, and resource sharing — provided a **strong common ground for collaboration**.

The framework therefore promoted a **flexible and modular approach**. It allowed institutions to engage with the components that best matched their context, while preserving coherence and comparability across the consortium.

This adaptability also supported the **transferability** of DECEL outcomes. The methodologies, tools, and protocols developed through the project were not confined to the original courses or academic levels. Instead, they were conceived as **building blocks** that could be applied or reassembled to fit other subjects within engineering or STEM education more broadly.

2.3 Role of Partner Institutions

The DECEL consortium was composed of four higher education institutions, each of which brought complementary expertise to the project:

- **University of Alcalá (UAH)** – Project coordinator. UAH led the overall implementation strategy and was responsible for synthesising all contributions into a unified handbook. It ensured the coherence of the methodology across outputs and the applicability of results to external stakeholders.
- **University of Ferrara (UNIFE)** – Task leader for teaching modernisation strategies in experimental courses. UNIFE contributed its experience in redesigning hands-on, laboratory-intensive modules, particularly through the integration of active and challenge-based learning.
- **University of Porto (UP)** – Leader in the implementation of remote laboratories. UP's longstanding work with online experimentation and remote access systems provided a technological foundation for shared lab experiences across institutions.
- **University of Tours (UT), France** – Responsible for deploying virtual platforms in teaching. UT brought its expertise in blended learning and digital resource integration, and contributed to the development of virtual environments adapted to engineering education.

Despite their distinct roles, all partners engaged actively in **joint development, piloting, testing, and peer feedback**. Every institution experimented with aspects of the DECEL model beyond its assigned tasks, ensuring **horizontal learning** across the consortium.

Importantly, all partners worked within different national systems and taught students enrolled in different types of degrees. This diversity offered a unique opportunity to validate the **versatility and resilience** of the methodological framework across varied educational settings.

2.4 Integration Across Outputs

DECEL's methodology was developed in an incremental and iterative manner, with each Output (O1 to O4) contributing essential building blocks:

- **O1 – Modern teaching strategies**: Focused on identifying and adapting pedagogical approaches suitable for courses with strong experimental content. It laid the foundations for curriculum redesign and methodological change.
- **O2 – Remote laboratories**: Tackled the technical, organisational, and pedagogical dimensions of implementing remote access to laboratory experiences. It proposed protocols for effective integration within existing courses.

- **O3 – DECEL platform**: Established the project's central digital infrastructure, supporting course delivery, resource sharing, and communication. It served as both a content hub and a collaborative space.
- **O4 – COIL experiences**: Brought an international and intercultural dimension to learning through the design and implementation of Collaborative Online International Learning. This output introduced students and staff to new ways of co-creating knowledge across borders.

While each output had its own objectives, their combination allowed for a comprehensive course transformation model. The role of O5, and of this handbook, was to synthesise and articulate these innovations into a coherent, transferable methodology. Therefore this document collects an implementation guide of all the steps carried out in the DECEL project. This is really important in order to extend the scope of DECEL to other potential partners outside the DECEL consortium.

2.5 Guiding Principles

The DECEL methodological framework was built upon a set of guiding principles, developed collectively by the partner institutions. These principles informed not only the design of project activities but also the structure and content of this handbook:

- **Adaptability**: The methodology was designed to be adapted to different course types, academic levels, and institutional environments.
- **Transferability**: Outcomes and tools were made applicable beyond the initial target disciplines, especially to other STEM fields with experimental components.
- **Sustainability**: Emphasis was placed on solutions that could be maintained and scaled over time, avoiding over-reliance on external funding or specific project conditions.
- **Inclusiveness**: All partner institutions contributed equally to the development and testing of innovations, ensuring shared ownership and contextual relevance.
- **Open access and collaboration**: Materials, platforms, and knowledge were shared transparently, supporting future partnerships and community building.

These principles serve as the foundation for the practical guidance offered in the following sections. They also reflect the project's broader mission: to support a meaningful and sustainable transformation of engineering education through innovation, cooperation, and openness.

3. Teaching Methodologies and Course Redesign

The DECEL project placed methodological innovation at the centre of its strategy to modernise experimental courses in engineering. The initiative focused on improving not only the transmission of disciplinary knowledge, but also the development of broader competences needed in today's professional and academic environments. The methodological redesign applied to selected courses was informed by current educational research and tested collaboratively across the partner institutions.

While rooted in the context of Electrical and Electronic Engineering, the redesigned approaches are applicable across the STEM spectrum, particularly in programmes where practical or laboratory-based learning is central, yet pedagogical innovation is still scarce.

3.1 Shared Goals Across Diverse Curricula

The courses selected for transformation varied significantly across the institutions involved in the project. Some were part of Bachelor's degrees; others belonged to Master's programmes. Content emphasis ranged from digital system design to applied signal processing or embedded systems. Furthermore, each institution operated under different national higher education systems, with distinct expectations for student workload, assessment, and learning outcomes.

Despite these differences, several shared objectives emerged:

- Move from content transmission to competence development.
- Enhance student participation and autonomy.
- Integrate collaborative work systematically.
- Provide students with internationalised learning experiences.
- Align course design more closely with industrial and societal demands.

The diversity of the courses acted as a **validation mechanism** for the methodological model. It confirmed that meaningful innovation can take place even under very different starting conditions, and that the core pedagogical principles tested in DECEL are **robust, modular, and transferable**.

3.2 Key Pedagogical Concepts

The following teaching strategies were central to the course redesign processes carried out across the project:

<u>a) Active Learning</u>

Students were no longer passive recipients of information but were encouraged to explore, question, and apply knowledge during class. Activities included:

- Short, structured challenges to be solved in groups during sessions.
- Real-time problem-solving using digital tools.
- Pre-class materials allowing students to engage with content ahead of lectures.

This model encouraged preparation, participation, and accountability.

<u>b) Project-Based Learning (PBL)</u>

Courses were restructured around authentic projects that required design, decision-making, and problem-solving. Projects were:

- Structured progressively to match the students' growing competences.
- Often open-ended, allowing multiple valid solutions.
- Aligned with real-world applications and tools.

PBL increased student motivation and created a natural context for the integration of technical and transversal competences.

c) Collaborative Learning

Students worked in small groups to tackle tasks, both within and outside the classroom. Collaboration was supported through:

- Structured group roles (coordinator, researcher, designer, etc.).
- Peer assessment mechanisms to monitor contribution.
- Teacher facilitation focused on guiding team dynamics.

In later phases of the project, some of these collaborations extended across borders, reinforcing the value of teamwork in international settings.

d) Blended and Digital Delivery

While the physical lab remained an essential space, many courses experimented with:

- Asynchronous video lessons and demonstrations.
- Virtual simulations for circuit design or debugging.
- Shared repositories of exercises and solutions.
- Discussion forums for continuous engagement.

These formats increased flexibility, encouraged self-paced learning, and reduced dependence on fixed timetables or locations.

3.3 Methodological Adaptation and Implementation

Each partner adapted the above strategies to the local academic environment. This was done following a generalised, but flexible, process:

1. **Analysis of current course structure**: Identification of aspects requiring improvement (e.g., low engagement, assessment overload, lack of teamwork).
2. **Definition of innovation goals**: E.g., increase interactivity, integrate a final project, include remote activities.
3. **Design of new course plan**: Activities, assessment, resources, and timelines.
4. **Pilot phase**: Running the new model partially or fully with a student cohort.
5. **Review and optimisation**: Adjustments based on student and teacher feedback.

The implementation confirmed that **teaching innovation is not only desirable but feasible**, even in traditionally rigid or technically demanding courses.

3.4 Teaching Tools and Digital Resources

To support the adoption of the redesigned methodologies, several supporting materials were created or adapted:

- **Rubrics** for evaluating both individual and group contributions.
- **Activity templates** for designing challenges, labs, or flipped content.

- **Checklists** for instructors to plan and evaluate course redesign.
- **LMS-integrated modules** with forums, quizzes, and project workspaces.
- **Guides** on how to structure digital content effectively.

These tools were shared across the consortium and contributed to the DECEL platform. They remain available for future adaptation by external institutions.

3.5 Transversal Skills Development

One of the most significant outcomes of the methodological redesign was the **improvement in students' transversal competences** — skills that are essential across disciplines and increasingly demanded by employers.

The new teaching model contributed directly to the development of:

- **Teamwork and collaboration**: through structured group tasks and joint problem-solving.
- **Communication**: students presented results, wrote reports, and discussed decisions both orally and in writing.
- **Critical thinking and problem-solving**: real-world challenges demanded creativity, iteration, and analytical skills.
- **Autonomy and responsibility**: flexible, blended formats required students to manage their time and workload independently.
- **Intercultural awareness**: especially in courses involving virtual exchanges or COIL activities, where students interacted across national and linguistic boundaries.

These competences were **formally integrated into learning outcomes** and often assessed using dedicated criteria. In many cases, students were made explicitly aware of the importance of these skills, which further encouraged their development and reflection.

The inclusion of transversal competences also positioned students more strongly in the job market, aligning their profiles with industry needs across sectors like aerospace, automotive, defence, and emerging technology fields.

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4. Remote Laboratories and Hardware-as-a-Service

A central aspect of the DECEL modernisation framework was the incorporation of **Remote Laboratories (RRL)** into experimental engineering education. These remote labs enabled students to interact with physical hardware over the internet, extending hands-on learning beyond traditional spatial and temporal constraints.

This section elaborates on the rationale for their inclusion, the implementation strategies adopted, the pedagogical and institutional benefits achieved, and the technical challenges addressed. A defining feature of DECEL's approach was also the development of a **Hardware-as-a-Service (HaaS)** model, enabling shared use of laboratory infrastructures across institutions.

4.1 Why Remote Labs?

Experimental learning in engineering depends on real-time interaction with physical systems. However, traditional in-person labs often face several constraints:

- **Limited access** due to infrastructure capacity or class scheduling,
- **Geographical limitations** for students not based on campus,
- **High costs** of replicating complex hardware setups,
- Disruption during crisis scenarios, such as the COVID-19 pandemic.

DECEL addressed these challenges by introducing **remote-access physical laboratories** where students could carry out authentic experiments from any location, using real equipment hosted by the partner institutions.

The motivation extended beyond convenience. Remote labs:

- Fostered student autonomy and responsibility,
- Created opportunities for **cross-border collaboration**,
- Made advanced hardware platforms available to students at institutions lacking such resources,
- Supported **inclusion and equity** by removing physical and financial access barriers.

In the context of digital electronics and systems design, this meant giving students remote access to real programmable hardware, not mere simulators.

4.2 Design and Pedagogical Integration

The integration of RRL into curricula was not limited to technological deployment — it required careful pedagogical alignment. DECEL developed a multi-stage implementation strategy:

1. **Selection of suitable content and experiments**
   Not all lab practices can be effectively implemented remotely. DECEL focused on experiments that involved digital logic, reconfigurable devices (e.g., FPGA), and microprocessor-based systems, where meaningful interaction could be achieved through well-structured inputs and observable outputs.
2. **Instructional redesign**
   Existing lab guides were adapted for remote settings. Activities were re-sequenced to include:
   - Simulation/preparation phases,
   - Live remote interaction slots,
   - Post-experiment analysis and reflection.
3. **Interface and scheduling systems**
   Custom web interfaces or VPN access provided secure interaction with lab setups. Booking systems were established to manage concurrent access fairly and efficiently.

4. **Assessment integration**
   The remote labs were fully embedded in the course evaluation system, not considered add-ons. Student performance was assessed through submitted reports, recorded experiment sessions, and reflective tasks.

It is worth noting that **student and teacher training** on the remote lab platforms was also part of the integration process. Tutorials, walkthroughs, and live Q&A sessions ensured usability and pedagogical continuity.

4.3 Hardware-as-a-Service (HaaS) Model

A key innovation of DECEL was the development of a **Hardware-as-a-Service (HaaS)** model. This concept went beyond isolated remote access originating a **shared laboratory ecosystem** among the consortium partners.

Key features:

- **Multi-institutional access**: Students from any partner university could access equipment hosted at another partner site.
- **Standardised interfaces**: Whenever possible, tools and platforms were harmonised to simplify user experience and support interoperability.
- **Scalable architecture**: The system could grow to include new hardware or new institutional partners.
- **Resource optimisation**: Institutions with advanced equipment supported others with limited infrastructure, fostering collaborative equity.

The HaaS model proved particularly useful for institutions or departments with limited funding for high-end equipment, as it removed the need for each partner to replicate expensive lab setups.

4.4 Open Tools and Software Accessibility

From the outset, the DECEL project prioritised the use of **free and open-source tools** whenever feasible. This was essential to promote scalability, reduce dependency on proprietary systems, and support transferability of the model to other institutions — particularly in **low-resource environments**.

However, in the specific field of Digital Systems Design with reconfigurable hardware (FPGAs) and microprocessor-based platforms, the project encountered significant limitations:

- Most development environments (e.g., for FPGA design) are vendor-specific and require proprietary software (e.g., Xilinx Vivado, Intel Quartus).
- Toolchains for debugging or programming microcontrollers often depend on specific hardware vendors and include licensing constraints.

Despite this, the project proposed a **pragmatic solution**:

- Use of free academic versions or student/demo licences offered by vendors.
- Selection of development boards and platforms that are **affordable and widely available**.
- Creation of **instructional content and lab activities** that are compatible with these free tools.

This approach ensured that other institutions wishing to adopt DECEL's methods could **implement them without major cost barriers**, even if full open-source solutions were not viable. It also kept the door open for hybrid strategies: combining open pedagogical models with semi-open technical tools.

This flexibility is key to ensuring the **long-term replicability** of DECEL outcomes in other areas of STEM where similar constraints exist.

4.5 Educational Benefits and Learning Impact

The integration of RRL and HaaS had a significant impact on both teaching and learning:

For students:

- Greater access to practice-based learning, regardless of geography or timetable.
- Authentic experience with real hardware, not just simulations.
- **Improved digital fluency** through use of remote platforms and collaborative tools.
- **Exposure to international collaboration** by sharing labs with peers in other countries.

For teachers:

- Optimised use of institutional infrastructure, reducing bottlenecks in lab scheduling.
- **Opportunities to innovate** and explore hybrid and flipped teaching models.
- **Richer feedback and assessment possibilities**, with logged lab sessions and asynchronous observation.

Beyond technical outcomes, remote labs also contributed to the **development of transversal competences**, including:

- Time management and planning (booking and preparing for remote sessions),
- Technical communication (describing procedures and analysing data),
- Teamwork (coordinating remote activities across group members),
- Problem-solving in unfamiliar or asynchronous environments.

4.7 DECEL Real Remote Laboratories

In the project up to 3 different RRLs have been developed.

RRL1 (MQTT-based RRL): uses open-source hardware and software including MQTT and custom web interfaces. It supports 1 experiment focused on industrial IoT and targets courses in control systems, digital electronics, and engineering IoT. It requires minimal physical resources.

RRL2 (Digital Systems RRL): relies on commercial FPGA boards and manufacturer-specific FPGA design tools. It supports 6 digital electronics and 2 computer architecture experiments, aimed at digital electronics, computer architecture, and reconfigurable computing courses. Requires a specific FPGA board.

RRL3 (Microprocessors RRL): is based on commercial microcontroller platforms with dedicated embedded software. It includes 3 experiments on microprocessors and embedded systems, serving courses in computer architecture and embedded systems. Requires a specific microcontroller board.

Next, Figure 2 shows a comparison in different categories for the developed RRLs.

Comparison of DECEL Real Remote Laboratories (RRLs)

Categories	RRL1 MQTT-based RRL	RRL2 Digital Systems RRL	RRL3 Microprocessors RRL
Hardware	Open-source hardware platform	Commercial FPGA board	Commercial microcontroller platform
Software	MQTT protocol, custom server, web interface	Manufacturer-specific FPGA des-ign software	Manufacturer-specific embedded device softw-are
Experiments	1 targeted experiment: industrial IoT application	6 digital electronics experiments 2 computer architecture experiments	3 computer architecture microprocesssors, embedded systems
Target Courses	Control systems, digital electronics, engineering IoT	Digital electronics, computer archi-tecture, reconfigurabie computing	Computer architecture, microprocessors, embedded systems
Physical Resqurces Required	Minimal	Specific FPGA board	Specific microcontroller board

Figure 2. Comparison of DECEL RRLs

4.7 Limitations, Challenges, and Mitigation Strategies

While the overall implementation was successful, the deployment of remote laboratories required addressing several challenges:

- **Technical infrastructure**: Ensuring reliable internet connections, server uptime, and responsive interfaces was critical.
- **Security and access control**: Preventing misuse or damage to equipment necessitated robust authentication and monitoring protocols.
- **Learning curve for users**: Both students and staff needed time and support to become comfortable with the new systems.
- **Scalability issues**: Limited hardware availability could still pose bottlenecks, especially during peak periods.

The project mitigated these challenges through:

- Structured training sessions for teachers and students,
- Extensive documentation and user guides,
- Shared support networks between institutions,
- Scenarios with virtual “sandbox” labs when hardware access was saturated.

These measures ensured that remote labs remained a support to teaching, not a source of disruption or frustration.

4.8 Sustainability and Future Transferability

The model of remote labs and HaaS developed in DECEL was designed with sustainability in mind:

- The use of **existing infrastructure**, rather than developing from scratch,
- The choice of accessible hardware platforms and freely available software versions,
- A model that requires **moderate maintenance and staffing**, especially once initial deployment is complete.

This makes it suitable for future expansion in:

- Other departments or faculties within partner institutions,
- STEM areas beyond electronics (e.g., control systems, robotics, energy),
- New partnerships at European or international level.

The remote lab and HaaS framework established through DECEL stands as a **scalable, inclusive, and pedagogically sound solution** for modern experimental engineering education.

5. Virtual Learning Platforms (DECEL Platform)

The DECEL platform was conceived as a central element in supporting the pedagogical transformation of experimental engineering education. More than a simple digital repository or course organiser, it functioned as a **comprehensive virtual learning environment** that connected students, instructors, institutions, and physical resources — all within a shared educational vision.

This section explores the motivations for its development, its components and technical structure, its role in teaching and learning innovation, and the challenges faced during deployment. Special attention is paid to the **interoperability with local institutional platforms** and the tension between centralisation and decentralisation in digital learning ecosystems.

5.1 Rationale and Role in the DECEL Ecosystem

The need for a dedicated digital platform in DECEL emerged from several converging factors:

- The increasing complexity of course redesigns and digital content,
- The incorporation of **remote laboratories** that required a secure and centralised access point,
- The implementation of Collaborative Online International Learning (COIL) modules across borders,
- The necessity of **cross-institutional coordination** for collaborative teaching.

The platform was designed to serve as:

- A **central learning environment**, hosting teaching resources, activities, and assessments,
- A **collaboration space** for students and educators from different countries,
- A **gateway** to technical infrastructures such as remote labs,
- A **repository** of open and reusable teaching tools created during the project,
- A **hub** for COIL project coordination, documentation, and submission.

Its overarching aim was to provide **pedagogical continuity across institutional boundaries**, while offering enough flexibility to serve local teaching needs.

5.2 Design and Functional Components

The DECEL platform was based on **interoperable, open-access technologies** whenever possible, in line with the project's commitment to openness and sustainability. Its design was modular, allowing partners to deploy selected components within their own infrastructure or access a shared instance hosted by the coordinating institution.

Key functional components included:

<u>a) Course Modules</u>

Each course participating in the project was structured into modular sections including:

- Multimedia lecture materials (PDFs, videos, animations),
- Self-evaluation quizzes,
- Instructions and documentation for practical exercises,
- Weekly learning objectives and deadlines.

These modules were easily adaptable to different institutional programmes, allowing for content personalisation while preserving the overarching learning design.

b) Collaborative Workspaces

Integrated discussion forums, team workspaces, and chat tools allowed students and instructors to interact across institutions. These spaces supported:

- Peer review and discussion,
- Group project coordination,
- COIL preparation and debriefing.

Additional tools (e.g., shared document editors, Kanban boards) were integrated using lightweight plug-ins or external links.

c) Remote Lab Interface Layer

The platform included a user interface for remote lab access that provided:

- Real-time control of physical hardware (e.g. FPGA boards),
- Booking systems and usage logs,
- Video feedback from lab environments,
- User authentication and monitoring.

Students were able to book sessions and conduct experiments within predefined time slots, with instructors overseeing access and results.

d) COIL Project Toolkit

To facilitate the implementation of international collaborative projects, the platform hosted a dedicated COIL space including:

- Project templates and guidelines,
- Cross-institutional team assignment tools,
- Shared reflection journals and deliverable submission areas,
- Feedback mechanisms for teachers and peers.

This toolkit enabled synchronous and asynchronous collaboration, even among students in different time zones and with diverse academic calendars.

e) Instructor and Admin Dashboard

Teachers and administrators could:

- Track student participation and access logs,
- Organise and grade assignments,
- Monitor forum activity and group progress,
- Manage technical incidents and resource allocations.

This administrative backend ensured effective course management and supported data-driven reflection on teaching practices.

5.3 Integration with Local LMSs: Challenges and Lessons learnt

A major challenge encountered in DECEL was the **coexistence of multiple learning management systems** across the partner institutions. Each university had its own established LMS (e.g., Moodle, Blackboard, Chamilo), with internal policies, integration structures, and user expectations.

Combining these with a shared DECEL platform created **tensions and trade-offs**, including:

- Fragmentation of student experience: some students were required to access both their local LMS and the DECEL platform.
- Duplication of content and tasks: instructors often had to replicate materials or learning paths in multiple systems.
- Technical incompatibilities: integration of DECEL with institutional Single Sign-On (SSO) systems or APIs was not always feasible.
- Data privacy and access rights: national and institutional regulations varied regarding user data and platform hosting.

To address these challenges, DECEL adopted a **pragmatic and flexible strategy**:

- Institutions could choose to fully adopt the DECEL platform, partially integrate selected components, or mirror resources in their local LMS.
- Synchronised calendars and documentation were developed to align workflows across platforms.
- Lightweight solutions (e.g., shared drives, embedded iframes, public repositories) were used to bridge environments.

This experience highlighted an important lesson for future projects: **full platform centralisation is not always practical in cross-institutional settings**, and digital strategies must be adaptable to different technological and administrative ecosystems.

5.4 Pedagogical Contribution

The DECEL platform enabled a shift from traditional teaching to more flexible, student-centred practices. It directly supported:

- **Flipped classroom models**: with asynchronous content and in-class application.
- **Self-regulated learning**: allowing students to track their progress and revisit content.
- **Collaborative learning**: especially in group-based tasks and COIL formats.
- **Blended teaching**: with seamless transitions between physical and virtual activities.

For instructors, it provided a space for **innovation and experimentation**, offering digital tools to redesign assessments, integrate transversal skills, and personalise feedback.

It also allowed for **greater pedagogical consistency** across courses with different national contexts, helping to anchor a shared set of quality standards within DECEL.

5.5 Technical Scalability and Sustainability

The DECEL platform was built to be sustainable and replicable beyond the project's lifetime. Key technical principles included:

- Use of **open-source technologies** and modular architecture,
- Compatibility with common formats and interoperability standards (e.g., LTI, SCORM),
- Hosting flexibility: either on institutional servers or in cloud-based environments,
- Maintenance procedures that could be transferred to local IT staff post-project.

Its **scalability** allowed for future integration of:

- Additional universities or faculties,
- New course modules or technical domains,

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- Expanded lab infrastructure and booking systems.

The project also developed **deployment guides** to facilitate replication in other institutions, even those not involved in the original consortium.

5.6 Transferability to Other STEM Areas

While originally developed for courses in Digital Electronics and related fields, the DECEL platform structure is highly adaptable. It can support other areas of engineering and STEM, including:

- Robotics and automation,
- Energy systems,
- Materials science,
- Applied computing and programming.

Its features — especially the integration of remote experiments, project-based collaboration, and cross-border teamwork — are relevant to any discipline with practical, experimental, or design components.

Moreover, the platform's **modular structure** allows selective adoption of features (e.g., COIL toolkit, lab booking, assessment rubrics) in contexts with existing institutional platforms.

6. COIL Experiences and International Collaboration

One of the most distinctive features of the DECEL project was the implementation of **Collaborative Online International Learning (COIL)** activities across partner institutions. COIL provided a practical and inclusive framework to integrate **internationalisation at home (IaH)** and **internationalisation at a distance (IaD)** into engineering education, without relying on physical mobility.

In the context of Digital Electronic Systems, the incorporation of COIL represented a meaningful pedagogical innovation. It complemented technical instruction while enhancing students' **cross-cultural competences**, digital fluency, and collaborative problem-solving abilities — all essential for modern engineers operating in global environments.

6.1 The COIL Model: Foundations and Purpose

COIL is a teaching strategy that connects students and faculty from different countries through co-developed and co-facilitated online learning projects. Its structure is:

- **Curriculum-embedded**: part of credit-bearing courses,
- **Discipline-specific**: aligned with the subject matter of each partner,
- **Interculturally oriented**: fostering communication across cultural and academic backgrounds,
- **Collaborative and project-based**: focused on joint tasks, reflection, and shared outcomes.

In DECEL, COIL was not treated as an *add-on* or extra activity, but as a **core driver for internationalisation and pedagogical renewal**, especially in traditionally rigid STEM fields.

6.2 COIL in Digital Systems and Engineering Education

Engineering programmes are often seen as difficult environments for international collaborative initiatives, due to:

- Dense and tightly packed curricula,
- High dependency on physical labs and infrastructure,
- A historical focus on technical knowledge over interpersonal or intercultural competences.

DECEL demonstrated that these constraints can be overcome by designing well-scaffolded COIL activities within engineering contexts. For example:

- Students from different universities collaborated on the simulation and implementation of digital systems using shared technical platforms.
- Teams co-developed applications based on FPGA design or microprocessor logic, using remote tools and asynchronous coordination.

These projects offered not only **technical challenges**, but also **opportunities to develop transversal competences** rarely addressed in standard curricula.

6.3 Implementation in the DECEL Project

COIL experiences were implemented across the project's partner universities with shared methodological phases:

1. Course alignment and topic selection
    - Teachers from each institution selected compatible courses and agreed on technical themes.
    - Learning objectives were harmonised, though not necessarily identical.

2. Joint planning and task design
    - Projects were structured in phases, including ideation, design, implementation, and reporting.
    - Deadlines and grading criteria were co-developed.
3. Team building and facilitation
    - Mixed international student groups were formed.
    - Teachers adopted facilitative roles, guiding collaboration and monitoring progress.
4. Project execution and support
    - Students used cloud-based tools (e.g., GitHub, Google Drive, DECEL platform) to collaborate.
    - Weekly checkpoints helped ensure sustained engagement.
5. Presentation, assessment, and reflection
    - Teams submitted deliverables and gave joint presentations.
    - Debriefings focused on both technical results and intercultural collaboration experiences.

6.4 Motivation: A Critical Factor for Success

Across all implementations, a clear lesson emerged: the success of COIL depends fundamentally on the motivation of both teachers and students.

For teachers:

- COIL requires extra preparation time, pedagogical flexibility, and intercultural sensitivity.
- Teachers must be open to co-design, share control, and take on facilitative roles.
- Without **genuine interest and belief in the pedagogical value** of COIL, implementation becomes superficial.

For students:

- Working in international teams, across time zones and cultural expectations, demands effort and openness.
- Motivation must be sustained throughout the project — especially when technical or communication difficulties arise.
- When students understand the **relevance to real-world careers** and receive clear support, their engagement increases significantly.

DECEL partners found that clear project framing, visible teacher commitment, and showcasing past student experiences all helped to **boost motivation and ownership**.

6.5 Integration into Assessment Systems

One of the main implementation challenges concerned the integration of COIL activities into course evaluation frameworks.

Questions that arose included:

- Should COIL be a mandatory part of the course, or an optional component?
- How can joint work be fairly assessed, considering differing local grading systems?
- How to account for transversal competences in a system traditionally focused on technical accuracy?

Different approaches were trialled:

- In some cases, COIL was **mandatory and credit-bearing**, with clear assessment rubrics for technical and soft skills.
- In others, COIL was **optional but incentivised** (e.g., bonus marks, certification).
- Some institutions adopted a **formative assessment model**, where COIL contributed to learning but not to the final grade.

In all cases, transparent communication with students about expectations and assessment criteria was essential. DECEL recommends that **COIL be embedded formally in course design**, but with flexibility to adapt based on institutional context.

6.6 Tools, Resources, and Pedagogical Support

To ensure consistency and scalability, the project developed:

- **Shared project templates** to simplify the co-design process,
- **Assessment rubrics** aligned with both technical and transversal outcomes,
- **Student handbooks** with guidelines on intercultural communication, remote collaboration, and conflict resolution,
- **Reflection tools** including self-assessment and peer feedback forms,
- **Facilitator checklists** to support teaching teams throughout the project lifecycle.

All of these were integrated into the DECEL platform, with versions adaptable to various LMS environments.

6.7 Sustainability and Recommendations for Transfer

The DECEL experience demonstrated that COIL:

- Is feasible in technical, experimental disciplines,
- Has **strong pedagogical benefits** for both students and instructors,
- Requires institutional support and staff training for long-term adoption,
- Is **scalable** to other fields where project-based learning is present.

For future deployments, DECEL recommends:

- Embedding COIL as a recurring feature in selected courses or modules,
- Creating incentive structures for teachers (e.g., workload recognition, digital badges),
- Establishing a pool of trained facilitators across departments,
- Promoting student testimonials and visibility of international collaboration outcomes.

By addressing motivation, institutional structures, and assessment integration, COIL can move from a pilot initiative to a **mainstream practice in globalised STEM education**.

7. Implementation Guidelines

This section provides a structured set of **guidelines and recommendations** to support the implementation of DECEL-inspired methodologies in other higher education contexts. It is addressed to academic leaders, curriculum designers, teaching staff, and institutional stakeholders seeking to replicate or adapt the innovations developed throughout the project.

Figure 3 illustrates a possible journey that shows progressive and interconnected pathway for both students and teachers as they engage with digitally enhanced and internationally collaborative educational practices. It is worth noting the emphasis about how the integration of tools like COIL, RRLs, and OERs can transform the learning and teaching experience in experimental disciplines.

From the student perspective, the journey begins with participation in COIL (Collaborative Online International Learning) projects. These experiences help students expand their intercultural skills and prepare them for meaningful international collaboration. As they advance, students take part in hands-on experiments using Remote and Real Labs (RRLs), which allow them to gain practical skills from any location. The integration of Open Educational Resources (OERs) into these courses further enhances accessibility and provides students with exposure to high-quality digital lab environments. Through these structured engagements, students are ultimately better prepared for the global workforce, having developed both advanced experimental competencies and the cultural awareness needed for international settings.

Simultaneously, teachers undergo their own transformation. They begin by engaging in COIL activities, which encourage international cooperation among faculty and foster a collaborative teaching environment. Working together, educators co-develop new OERs and adopt innovative, student-centered teaching practices. As they incorporate RRLs into their curriculum, teachers facilitate interactive and engaging lessons, collaborating closely with peers to enrich the educational experience. This continuous development culminates in the modernization of experimental courses, ultimately enhancing the quality of education, promoting internationalization, and expanding the global reach of their academic programs.

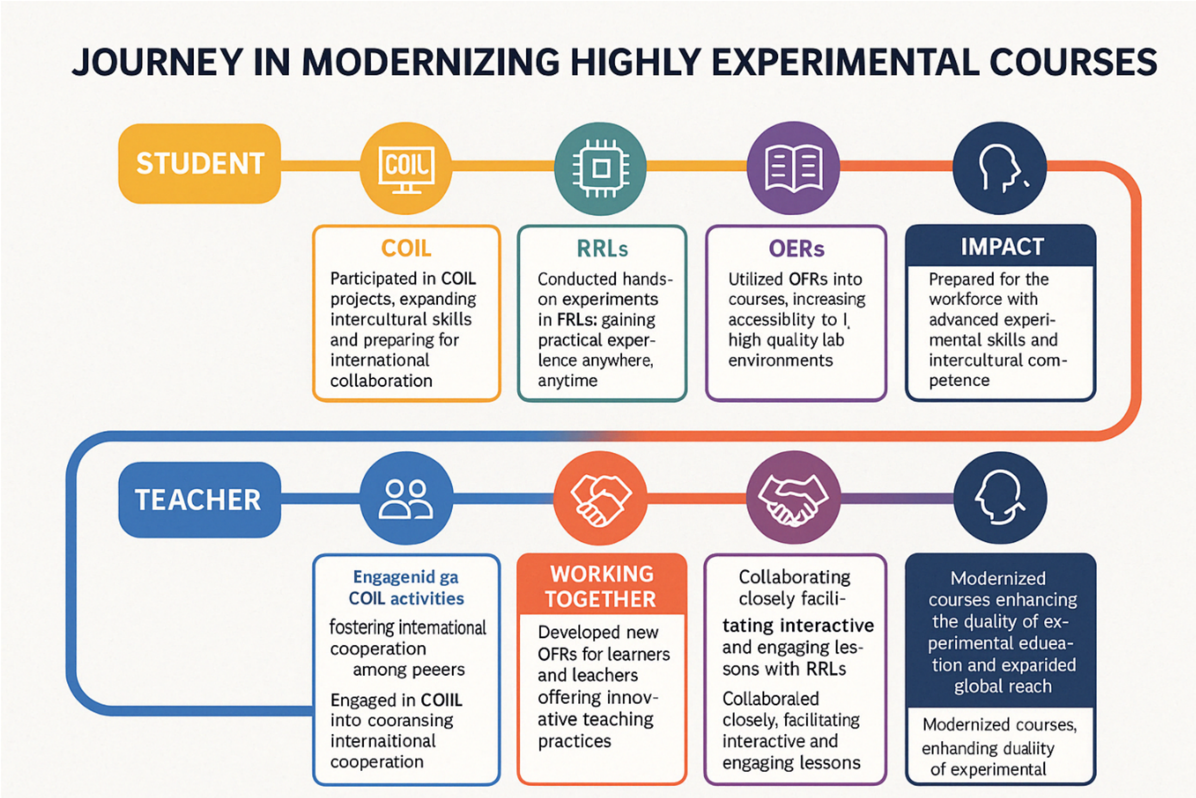

Figure 3. Journey in modernizing highly experimental courses.

Then, the following guidelines are grounded in the real experiences of the DECEL consortium, considering institutional diversity, pedagogical constraints, and infrastructure challenges. They aim to offer a clear path for transforming courses and programmes with high experimental components into modern, flexible, and internationalised learning environments.

7.1 Core Dimensions of Implementation

The DECEL model integrates four main pillars:

1. Modernised Teaching Methodologies
2. Remote Laboratories and Hardware-as-a-Service
3. Digital Platform Integration
4. International Collaboration via COIL

These components are **modular and complementary**: they can be adopted progressively or combined, depending on institutional capacity and strategic goals.

7.2 Step-by-Step Implementation Process

The following steps describe a phased implementation framework with a comprehensive and strategic transformation process aimed at modernising higher education through innovation, international collaboration, and digital integration, ensuring alignment between institutional goals, pedagogical redesign, and sustainable implementation.

Step 1: Institutional Readiness and Vision

- Define clear objectives for innovation (e.g., increasing flexibility, expanding international collaboration, modernising lab access).
- Ensure leadership support and alignment with institutional strategies.
- Establish a core implementation team, including academic, technical, and administrative profiles.

Step 2: Course and Curriculum Selection

- Choose one or more experimental or lab-intensive courses as pilots.
- Analyse current teaching practices and identify opportunities for redesign.
- Map transversal skills and internationalisation goals onto the course learning outcomes.

Step 3: Methodological Redesign

- Apply active and collaborative learning strategies.
- Introduce project-based activities and team assessments.
- Align with digital tools and remote formats (e.g., flipped classroom, asynchronous labs).

Step 4: Remote Labs and Resource Sharing

- Evaluate existing lab infrastructure and potential for remote access.
- Select suitable experiments for remote execution.
- Develop a booking and monitoring system (in-house or using HaaS principles).

Step 5: Platform Deployment or Integration

- Choose a hosting model: standalone (DECEL-like) or integrated into the local LMS.
- Install and configure modules for learning content, collaboration, assessment, and remote lab access.
- Provide training for staff and technical support structures.

Step 6: COIL Planning and Facilitation

- Identify international partners with compatible courses.
- Co-design project activities, timelines, and evaluation methods.
- Prepare students for intercultural collaboration and digital teamwork.

Step 7: Assessment and Quality Assurance

- Define how redesigned activities will be assessed:
    - Will COIL be optional or mandatory?
    - What weight will be given to transversal skills?
    - How to ensure fairness across different student groups?
- Use rubrics, peer assessments, and reflective tools to ensure transparent and meaningful evaluation.

Step 8: Feedback and Iteration

- Collect student and teacher feedback through surveys, interviews, and classroom observation.
- Document challenges and success stories.
- Refine practices and prepare for scale-up or replication in other courses or departments.

7.3 Key Enablers and Success Factors

Successful implementation of the DECEL approach depends on:

- **Teacher motivation and commitment**: without engaged staff, innovation cannot take root.

- **Student engagement**: clearly communicate the relevance and value of new methods.
- **Technical support and infrastructure**: ensure usability and reliability of remote labs and digital platforms.
- **Institutional flexibility**: allow curricular space and administrative adaptation.
- **Recognition mechanisms**: formally value the effort required to redesign courses or participate in COIL.

7.4 Potential Barriers and Mitigation Strategies

Considering the previous information, it is worth mentioning the potential barriers that institutions may encounter during the implementation of DECEL-inspired methodologies in different higher education contexts and presents corresponding strategies to effectively mitigate these challenges.

Table 1 –Potential barriers and corresponding mitigation strategies

Potential Barrier	Mitigation strategy
Lack of time or training for staff	Provide targeted workshops and team teaching opportunities
Incompatibility between partner academic calendars	Use asynchronous collaboration and flexible deadlines
Resistance to new assessment models	Pilot in low-stakes contexts and progressively scale up
Platform overload or duplication	Integrate DECEL tools selectively within existing LMSs
Dependence on proprietary tools (e.g. FPGA IDEs)	Use demo or academic licences and choose accessible platforms

7.5 Scalability and Expansion Scenarios

The DECEL model can be scaled or adapted in various ways:

- **Horizontally**: by including more courses or departments within the same institution.
- **Vertically**: by extending from undergraduate to postgraduate levels.
- **Internationally**: by establishing new COIL partnerships.
- **Transversally**: by applying the same methodology to other STEM fields (e.g., physics, biotechnology, mechanical engineering).

The model supports **partial adoption**. For instance:

- A course may only adopt remote labs, without COIL.
- Another may use the collaborative project methodology with local teams only.
- Institutions may pilot the full DECEL approach with one module before expanding.

7.6 Supporting Materials and Templates

The following materials are available as part of the DECEL toolkit:

- Course redesign templates
- COIL partnership agreement samples
- Remote lab protocol guides
- Student reflection and peer assessment tools
- Rubrics for technical and transversal competences
- Platform configuration and integration manuals

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These resources are provided under open licenses, to encourage reuse and adaptation.

Then, the next sections provide different real examples to show the DECEL results in practice.

7.7 Practical Examples from DECEL

To illustrate the flexibility of the DECEL model, here are selected case studies from the consortium, showing different institutional realities and how each partner adopted elements of the methodology:

Case A: University of Alcalá (UAH), Spain

Profile: Medium-large public university with established engineering programmes. **Focus:** Full course redesign with flipped classroom, remote labs, and COIL. **Actions:**

- Integrated asynchronous video content into Digital Systems Design course.
- Enabled students to conduct experiments remotely on reconfigurable hardware (FPGA boards).
- Implemented COIL with a partner institution using shared DECEL platform space. **Impact:** Improved student autonomy and lab availability; positive feedback on international collaboration.

Case B: University of Tours (UT), France

Profile: Technological university with a strong digital learning infrastructure. **Focus:** Digital platform and collaborative project work. **Actions:**

- Deployed DECEL platform components into their LMS ecosystem.
- Designed collaborative assignments integrating simulation tools and asynchronous labs.
- Provided additional support for students with lower digital experience. **Impact:** Teachers developed digital facilitation skills; increased student engagement in group-based challenges.

Case C: University of Ferrara (UNIFE), Italy

Profile: Traditional university with smaller class sizes in engineering. **Focus:** Incremental innovation and transversal skill development. **Actions:**

- Introduced team-based problem-solving tasks in digital logic courses.
- Used reflective journals to assess soft skills.
- Piloted COIL as an optional activity with intercultural reflection tasks. **Impact:** High student motivation; teachers reported deeper student involvement in technical topics.

Case D: University of Porto (UP), Portugal

Profile: Large research university with extensive experience in remote experimentation. **Focus:** Hardware-as-a-Service and cross-institutional access. **Actions:**

- Enabled remote control of lab equipment for local and partner students.
- Developed multi-university booking protocols.
- Co-developed project work with students in Spain and Italy. **Impact:** Reduced infrastructure redundancy; demonstrated feasibility of lab sharing in low-resource settings.

7.8 Implementation Matrix by Institutional Maturity

To support strategic decision-making, Table 2 offers a roadmap for implementation based on an institution's **maturity level** in digital infrastructure, internationalisation, and pedagogical innovation. First column represents a clear progression from Starter to Advanced in terms of digitalization and international collaboration in the centre. Then, each maturity stage outlines specific, progressively complex actions: starting with small-scale teaching innovations and advancing toward institutionalized international collaboration. The tools advance from basic instructional information to sophisticated, integrated digital platforms supporting collaboration and innovation. Finally, the required institutional support evolves from individual-level guidance to institutional coordination and strategic incentives as digital maturity grows.

Table 2 – Implementation matrix

Maturity Level	Priority Actions	Tools to Adopt	Support Needed
Starter (limited digital and international activity)	- Pilot active learning in 1 course- Introduce collaborative projects	- Templates for PBL- Reflection tools	- Teacher training- Peer mentoring
Developing (some blended learning, basic LMS usage)	- Embed remote lab in existing course- Run internal COIL trial	- DECEL platform (partial)- Lab booking system	- IT integration- Curriculum alignment
Established (hybrid learning, international links)	- Launch full COIL partnership- Share labs with a partner	- Full DECEL toolkit- Remote lab interfaces	- Timetable coordination- Institutional incentives
Advanced (experience in educational innovation and mobility)	- Scale model across departments- Connect with external networks	- COIL + HaaS + platform integration	- Interdepartmental strategy- Recognition systems

By adapting the level of ambition to the context, institutions can progress towards full implementation **step by step**, learning and scaling as they go.

8. Impact and Transferability

The DECEL project was designed not only as a pilot for modernising specific engineering courses, but as a **scalable and transferable model** for innovating teaching in higher education across Europe and beyond. Throughout its implementation, DECEL generated **tangible impact** at multiple levels: for students, teachers, institutions, and the broader academic and professional ecosystem.

This section presents the key outcomes of the project, the value created for different stakeholders, and the pathways for transferring and replicating the DECEL model in other contexts.

8.1 Impact on Students

DECEL significantly enhanced the learning experience of students enrolled in experimental courses. Key impacts included:

- **Improved technical competence** through more meaningful engagement with design tasks, digital systems, and remote experimentation.
- **Development of transversal skills**, such as teamwork, communication, problem-solving, autonomy, and intercultural awareness.
- **Greater motivation and satisfaction** resulting from active participation, responsibility in learning, and the opportunity to collaborate with peers from other countries.
- **Increased employability** by aligning learning with professional expectations, especially in sectors where remote collaboration and hardware programming are essential.

Student feedback collected during the project confirmed high levels of engagement and appreciation for the new methodologies — particularly when COIL activities and remote labs were well integrated and clearly assessed.

8.2 Impact on Teachers

DECEL created new spaces for **pedagogical innovation** among academic staff. Teachers reported:

- Enhanced awareness of active and collaborative methodologies, supported by real-world applications and peer exchange.
- **Renewed professional interest** through cross-border collaboration and co-teaching experiences.
- **Skill development in digital tools**, including platforms for blended learning, remote labs, and online project facilitation.
- **Better alignment between teaching and assessment**, particularly in the incorporation of transversal competences into grading frameworks.

Participation in DECEL also strengthened the role of teachers as **agents of curriculum transformation**, empowered to redesign their own practices with institutional backing.

8.3 Institutional Impact

At the institutional level, the project contributed to:

- **Modernising teaching practices** in engineering and STEM programmes.
- Expanding access to specialised infrastructure, through the Hardware-as-a-Service model.
- **Internationalising curricula**, even in programmes with limited mobility.
- Improving digital infrastructure and pedagogical services, particularly in support of remote and hybrid formats.

- **Building long-term partnerships** between universities across Europe.

DECEL also reinforced the institutional capacity for innovation by involving educational developers, IT services, and academic leaders in a shared change process.

8.4 Relevance for Industry and Employers

Although not directly targeted at companies, the DECEL model addressed several industry-relevant needs:

- Students with practical, hands-on experience, even in virtual and remote conditions.
- **Familiarity with real-world tools and platforms**, including design software and programmable hardware.
- Capacity to work in multicultural, distributed teams, using collaborative digital environments.
- **Agility and adaptability**, increasingly valued in engineering and technology professions.

Sectors such as aerospace, automotive, electronics, defence, and industrial automation — where reconfigurable systems are common — stand to benefit from graduates trained under this model.

8.5 Transferability Potential

The methodologies, tools, and structures developed by DECEL are **highly transferable** to other institutions, disciplines, and regions. Key factors enabling transferability include:

- **Modular design**: Institutions can adopt only those components (e.g., remote labs, COIL, flipped classroom) that suit their priorities and capacity.
- **Open-access resources**: Templates, guides, and documentation are shared under open licenses.
- **Use of scalable, accessible technologies**: Preference for free, demo-access, or low-cost tools makes adoption feasible for resource-constrained settings.
- **Applicability beyond Digital Electronics**: The model can support other experimental STEM areas such as control systems, robotics, mechatronics, chemistry, or applied physics.

Several DECEL partners have already initiated internal scaling, and discussions are ongoing with external institutions interested in piloting the approach in their own contexts.

8.6 Conditions for Effective Transfer

For successful adoption elsewhere, several conditions are recommended:

- **Institutional support and flexibility**, including openness to curriculum redesign and recognition of innovative teaching.
- **Teacher engagement and training**, to ensure understanding of new methodologies and tools.
- **Technical infrastructure**, especially for remote labs or digital platforms — though this can vary from basic to advanced.
- **Clear student communication**, particularly around expectations, assessment, and added value.
- **Monitoring and iterative improvement**, based on local feedback and adaptation.

A stepwise implementation, starting with small pilots and building gradually, is often the most sustainable strategy.

8.7 Future Prospects and Strategic Outlook

Looking forward, the DECEL model offers a **future-oriented approach to STEM education**, capable of responding to trends such as:

- Increased demand for hybrid and flexible learning environments,
- The need for green and inclusive internationalisation,
- Integration of remote access and IoT technologies into teaching,
- Growing emphasis on competence-based learning and digital skills.

With continued collaboration, updates to content and technology, and dissemination to new partners, DECEL can evolve into a **permanent reference model** for modern, international, and experimental engineering education.

9. Conclusions

This handbook shows that the DECEL project has demonstrated a viable, flexible, and replicable framework for the transformation of experimental engineering education across diverse academic environments. Through its integration of modern teaching methodologies, remote laboratory infrastructures, digital learning platforms, and international collaboration mechanisms such as COIL, the project responded effectively to contemporary challenges in higher education—ranging from institutional diversity to the growing need for digital and intercultural competences.

A central strength of the DECEL approach lies in its modularity and adaptability. Institutions with varying levels of digital maturity and pedagogical experience were able to engage with the model according to their specific contexts and capacities. This ensured not only the relevance of the methodology across borders, but also its sustainability and scalability within institutions.

The focus on active, student-centred learning, combined with real-world technical challenges and cross-cultural collaboration, proved to be especially impactful in enhancing both technical and transversal skills among students. Teachers also benefited from new avenues for innovation, professional development, and international networking.

While some barriers were encountered—such as technical constraints, platform interoperability, and institutional inertia—the project offered effective mitigation strategies and practical implementation guidelines. These ensure that the DECEL model can be adopted progressively, starting with pilot courses and scaling up based on feedback and institutional support.

Overall, it offers a forward-looking blueprint for educational transformation in STEM fields, one that is aligned with global trends in digitalisation, internationalisation, and competence-based learning. Its outcomes and resources position it as a valuable reference point for institutions seeking to modernise teaching and prepare students for increasingly complex and interconnected professional landscapes.

10. Acronyms used

Acronym	*Meaning*
COIL	Collaborative Online International Learning
DECEL	Digital Electronics Collaborative Experimental Learning
ECTS	European Credit Transfer and Accumulation System
FPGA	Field-Programmable Gate Array
EHEA	European Higher Education Area
IT	Information Technology
LMS	Learning Management System
LTI	Learning Tools Interoperability
PBL	Project-Based Learning
RRL	Remote Laboratories
SCORM	Sharable Content Object Reference Model
SSO	Single Sign-On
STEM	Science, Technology, Engineering and Mathematics
UAH	University of Alcalá
UNIFE	University of Ferrara
UP	University of Porto
UT	Université de Tours
VPN	Virtual Private Network