Co-funded by the European Union

DECEL

Benchmarking good practices for internationalization of studies in (reconfigurable) digital electronics teaching

Guideline report on best pedagogical tools

Universities of Alcalá, Ferrara, Porto, and Tours

01/11/2022

OUTLINE

Disclaimer

This project has been funded with support from the European Commission. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Acronyms

COIL	Collaborative Online International Learning
DECEL	Digital Electronics Collaborative Enhanced Learning
EU	European Union
FPGA	Field Programmable Gate Array
FSM	Finite State Machine
HaaS	Hardware as a Service
HEI	Higher Education Institutions
HW	Hardware
IaH	Internationalization at Home
IoT	Internet of Things
ICT	Information and communication technology
LMS	Learning Management System
PBL	Project-based Learning
RRL	Real Remote Labs
STEM	Science, technology, engineering and math

Introduction

This document is intended to present a benchmark of multiple good practices in the context of internationalization studies, particularly focused on digital electronics and programmable devices, yet being not limited to them. The guideline produced with this report is the result of activities of the Output Result O1 related to the DECEL project. The O1 is functional to all the other activities in the project since it is the one related to the implementation of new teaching methodologies applied to COIL and in general virtual exchange initiatives within the reconfigurable digital electronics field. The creation of a guideline as an outcome of the O1, concerning this latter topic, will start from a comprehensive paper desk analysis together with an in-depth research process that should lead to the selection of innovative tools applied to digital systems. Other EU projects and non-EU initiatives are oriented towards the increase of the quality of higher education by motivating teachers of STEM disciplines to use a multidisciplinary approach and teach with a massive support of technologies like Classroom, MS-Teams, Blackboard, etc. The central goal is to suggest and recommend a model for integrating intermediate and advanced digital electronics subjects (e.g., FPGA, microcontrollers, etc.) and ICT in international teaching approaches such as Collaborative Online International Learning (COIL), Project-based Learning (PBL) and Real Remote Labs (RRL). The main difficulty in teaching reconfigurable systems is the multidisciplinary nature of such systems. Even very simple flipped learning approaches require knowledge from multiple areas. Thus, some tools stimulating and motivating intensive learning skills must be discovered. DECEL massively seeks to exploit a multimedia approach to learning. It could be through course-oriented animated tutorials, language templates or any other type of online resources, which provide significant assistance and enable the students to succeed in learning and gaining the relevant knowledge and hands-on experience which is required for the Engineering area.

Internationalization requires a wide range of skills, both technical and interpersonal. Some of the key soft skills related to internationalization include:

- Cross-cultural competence: Understanding and adapting to cultural differences, including differences in communication styles, values, and behaviors.
- Interpersonal communication: The ability to effectively communicate with people from diverse backgrounds and cultures, including the ability to effectively negotiate and resolve conflicts.
- Adaptability: The ability to quickly adjust to new and changing environments, including the ability to work effectively in multicultural teams.
- Emotional intelligence: The ability to recognize and manage one's own emotions and those of others, including the ability to understand and empathize with others' perspectives.
- Flexibility: The ability to adjust to new circumstances and work effectively in unfamiliar situations, including the ability to work under pressure and in ambiguous situations.
- Leadership: The ability to inspire, motivate, and guide others, including the ability to effectively manage diverse teams and provide direction in a cross-cultural context.
- Problem-solving: The ability to identify and analyze complex problems, develop creative solutions, and effectively implement those solutions.
- Language proficiency: The ability to speak and understand multiple languages, including the ability to effectively communicate in both written and spoken forms.

Developing these soft skills through the different tools and techniques that will be implemented within the DECEL project, can help individuals be more successful in an international context, by enabling them to work effectively with people from diverse cultures and backgrounds, and to navigate complex and challenging situations with confidence and competence.

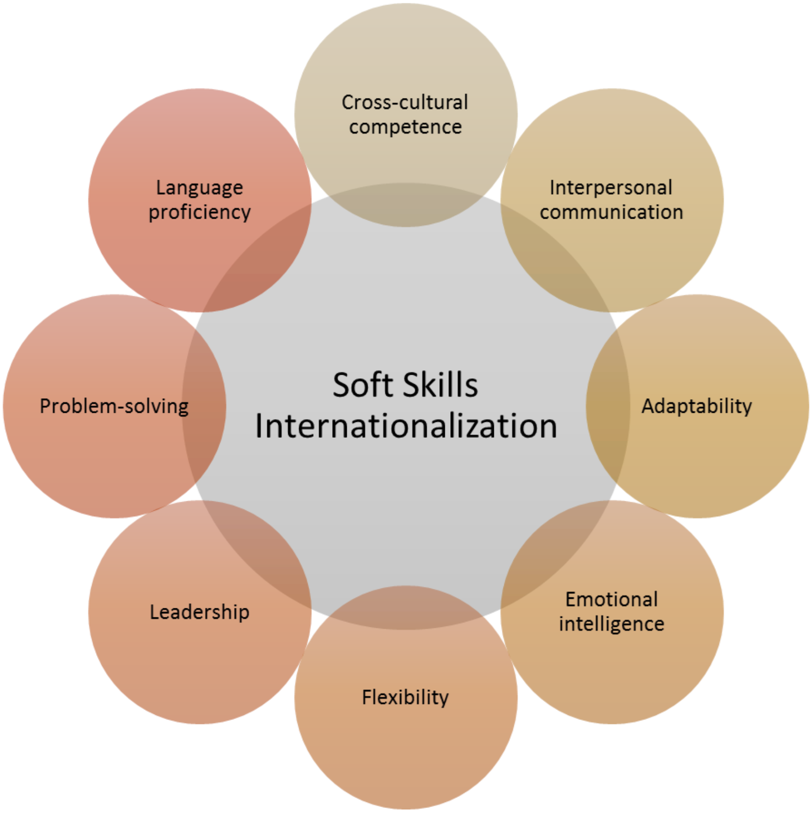

Figure 1: Soft skills related to Internationalization

Project Based Learning is a well-known teaching method that would be used by DECEL as a viable solution in which international students will gain knowledge and soft skills by working for an extended period of time to investigate and respond to an authentic, engaging, and complex question, problem, or challenge in a collaborative international environment. The teachers involved in DECEL are experienced in teaching those subjects face-to-face and are actively seeking ways to engage with digital technology tools and platforms to ease and enhance the quality of their courses. Our plan is to motivate and support them by creating a network of exchange of good practices across universities in the different partner countries. The promotion of blended learning will be achieved through remote labs and COIL initiatives that will be part of the O3 and O4 in the DECEL project. In using active learning tools to promote disciplinary sense-making, instructors of all levels of experience should take a reflective and iterative view of their instructional practice. The aim of a novel blended learning approach for HEI students is twofold: to achieve higher test scores in reconfigurable digital electronics subjects with the help of ICT technology; to foster a culture on a broader scope (even at university level) and to encourage teachers to adopt and follow the methodologies provided in this guideline. This represents a promotion of new digital skills for academic staff.

Internationalization activities for (reconfigurable) digital electronics

Understanding the concept of internationalization

The globalization process that our society is enduring allows interpreting the internationalization as the change in the flows of people, goods, information, and languages, with consequences in contemporary societies and most of all in education [1]. Higher education institutions (HEI) define the internationalization concept as "the process of integrating an international dimension into the teaching, research, and service functions of an institution of higher education" [2]. What is now called 'internationalization of higher education' is a recent phenomenon that has emerged over the last 30 years, driven by a dynamic combination of political, economic, socio-cultural, and academic rationales and stakeholders [3]. Internationalization has been expanding rapidly in the European context, thanks to the implementation of the 1999 Bologna Process, in which the autonomy of universities was challenged [4]. As this process is increasingly adopted by the majority of HEI, there is the need to code and measure the level of internationalization of a given institution: number of publications along with foreign researchers, number of international students in local campuses, number of foreign lecturers and researchers, just to name the most relevant ones [5]. However, such figures of merit have been criticised in several literature works for many reasons [6] [7]. Among them, it seems that they favour countries in which English language is used as the main medium of instruction while strongly penalizing institutions with educational programs in native languages. Further, it has been noted that academic mobility serves a small part of HEI in academic communities throughout the world, whether because of the high costs associated with it, or due to the high level of requirements for funding and transfer of credits involved in academic mobility programs [4]. On top of that, the current COVID-19 global pandemic has posed unprecedented challenges to internationalization in HEI. Most abroad programs have been cancelled, and the attempts to improve the quality of the international education suffered from the closure of campuses and the absence of international students in many institutions around the globe [8]. The context of Science, Technology, Engineering and Mathematics (STEM) University courses, especially those related to digital electronics, makes no exception. Despite the global expanding tendency of this sort of studies, and the common use of the English language as a learning vehicle, the Erasmus+ Impact Study [9] clearly evinces a deficit in the participation of students in international mobility programmes. Teaching processes in this field are still based upon traditional learning methodologies, with limited or no bilateral interaction promoted in most of them, and where the role of the teacher remains that of a mere lecturer in front of a passive cohort of students even in case of established internationalization programs. The course schedule and the potential handicap of accessing expensive laboratory equipment from anywhere when the international program is coming to an end. Although these factors seem to be an insurmountable barrier to promoting internationalization in the context of digital electronics, it must be remembered that several strategies can be imagined both from the point of view of the student and the educator to integrate the knowledge other cultural contexts in these courses [10]. HEI internationalization builds upon two essential pillars: the traditional cross-border based and the recently explored at-home paradigm [11]. The latter probably under-estimated and less-discussed aspect of internationalization is the so-called Internationalization at Home (IaH), which is one of the focuses of the DECEL project. In this chapter, we will review the definitions of the IaH paradigm with pros and cons retrieved from different experiences around the globe in several HEI. More in detail, we will explore the application of the IaH in the context of digital electronics teaching by evidencing the implementation barriers and eventually all the benefits that should be adopted as a best practice not only for the institutions involved in the

DECEL project, but also with a broad audience that could encompass different disciplines even if outside STEM community.

Internationalization at Home: definitions, pros, and cons

IaH is defined by [12] as "the purposeful integration of international and intercultural dimensions into the formal and informal curriculum for all students within domestic learning environments". The promotion of the interaction of culturally diverse peers by remaining in their own country is seen as a quality improvement factor for their future professional activities [13]. By benchmarking this concept with respect to the traditional cross-border mobility, we can experience how IaH candidates as a more versatile inclusive teaching-learning modality, since it targets students and staff personnel that are not able to participate in mobility programs. IaH is increasingly adopted by HEI in uncertain times like during the COVID-19 pandemics [8]. A search conducted on the Google Scholar engine to find the number of published articles in the time frame 2012-2021 using the query "internationalization at home" AND "higher education" lead to the results in Figure 1. There is a continuous interest in the topic in the HEIs with a surge in 2020 and 2021 with the same expected growth rate in 2022.

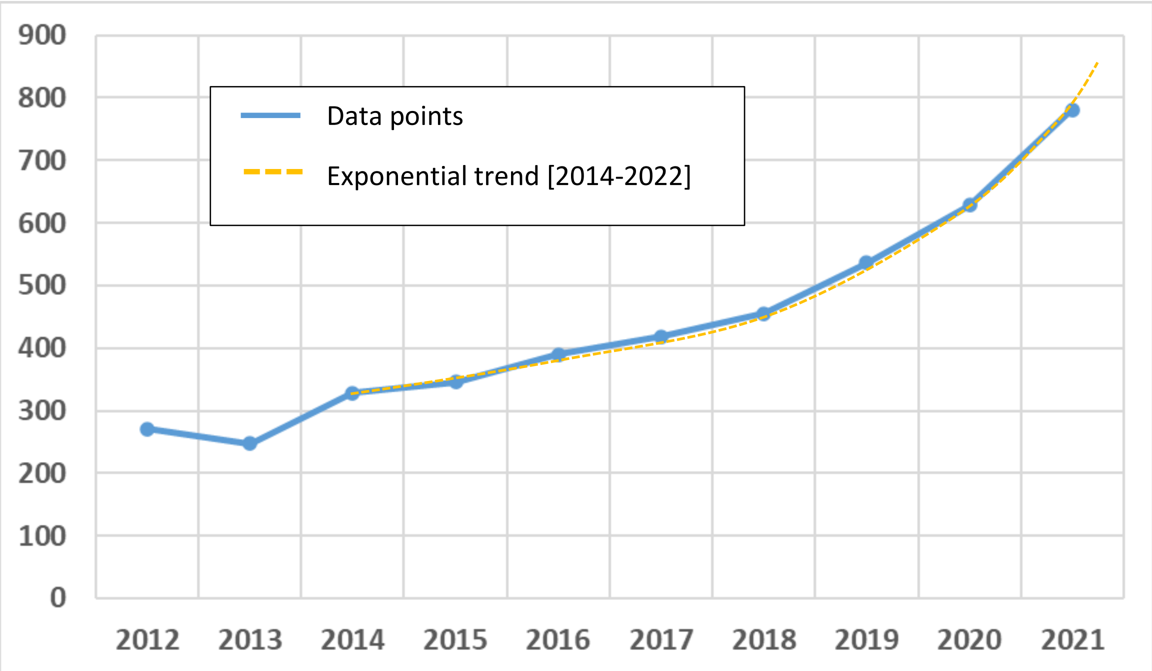

Figure 2: Number of published articles in the time interval 2012-2021 concerning IaH in HEI. Source: authors search on Google Scholar engine with terms "internationalization at home" AND "higher education"

Despite the growing tendency of IaH, these initiatives should be seen as a quality improvement rather than a goal, also in view of the criticism raised on this teaching approach [14]. In fact, the literature debates that the focusing on means rather than aims for a tendency to focus on "activity and not results as indicators of quality" [15] or pretending to be guided by high moral principles while not actively pursuing them [16] are valid concerns. To avoid the diffidence with respect to IaH and to have solid foundations to build new teaching activities upon, a Special Interest Group was formed within the European Association for International Education (EAIE) in 2001 and the first courses on the development of these initiatives were proposed in 2006, with a published guideline in 2007 [17]. International and intercultural dimensions should be integrated into teaching and learning in order to have an effect [18]. In general, IaH has been favourably received as it offers international and intercultural dimensions of teaching and learning to all students, including those who do not have the opportunity to study abroad. Still, there are misconceptions that are to be seen as obstacles to its implementation, including: teaching only using English; providing a "second best" option for students with no-mobility resources; lack of skills in the teachers and instructors in internationalizing their syllabus as well as the complexity in learning and assessment [19]. The DECEL project seeks to overcome these challenges by providing training events specifically for teachers to enable them in an IaH context and at the same time creating stimulating learning environments based on collaborative learning and on remote project experiences.

Notable case studies of IaH: learning barriers, instruments, and benefits

In this report we analysed some notable cases in literature concerning IaH activities. This study has been pursued to understand the potential learning barriers, the instruments provided by information and communication technologies (ICTs) in the implementation of the IaH paradigm, and the benefits evidenced at the end of the experience. Despite most of studies are not directly targeted to the field of digital electronics, our aim is to capture the best approaches from any discipline and adopt yet expand them in the specific context of the DECEL project. In Table 1, we summarize the following IaH activities using the work in [4] as a starting point for non-STEM oriented initiatives:

Table 1: IaH case studies used as benchmark for the DECEL activities

Ref.	Title of the study (year)	IaH activity	Instruments	Conclusions
[20]	Overcoming barriers for implementing international online collaboration assignments in Chemistry (2019)	Online collaborative tasks, pair work activities	Video conferencing software	Students were successful for overcoming barriers
[21]	Evaluation of an online IaH course on the Social Contexts of Addiction (2019)	Online interactive course about cultural differences. The final assessment was evaluating an article written by colleagues from other countries	Moodle Platform, discussions forums, lecturers from various countries	Development of awareness concerning the different social and cultural contexts. Students recognized the universality of their field of knowledge. Changes in opinions about their own cultures and societies
[22]	Nursing students' perceptions of peer learning through cross-cultural student-led webinars: a qualitative study (2019)	Presentation of online seminars. Groups of 10 students with (at	"Zoom" platform for audio and video interactions	Learning based on the interaction among students was better than expected; this

		least) two members of each country		activity created new opportunities for internationalization, without compromising individual and institutional financial resources
[23]	Trialling virtual intercultural learning with Australian and Hong Kong allied health students to improve cultural competency (2019)	Students enrolled in three different courses, in two universities. Blended learning: face-to-face and online classes	Not defined	Development of intercultural skills using experiences out of the "comfort zone", in which students learn during intercultural experiences and interactions
[24]	Internationalization at home: An international interdisciplinary experience (2021)	Students enrolled in two different universities working on two different disciplines (ICT and Marketing)	Microsoft Teams for asynchronous interaction and Zoom for real-time platform for presentations	Students improved their learning experience and developed intercultural and interdisciplinary skills
[25]	The Multidisciplinary International Virtual Design Studio (MiVDS) (2000)	Several design teams in different universities that participate in design topics for mechatronic	Mainly offline discussion using e-mail and chat	Students benefited in the engineering profession. Results of this study were extended to other institutions

What emerged from the literature analysis is that digital online capabilities are mandatory in almost all IaH. In fact, technology-based activities could promote equal access to internationalization opportunities for all students [12] and open unprecedented remote teaching experiences making use of the combination of collaborative learning environments and project-based learning tools, that can be capitalized in HEIs. Advances in ICTs created more options for IaH in the form of virtual academic mobility [4]. ICTs can promote more opportunities for all students to get involved with colleagues and lecturers who are in geographically distant areas, to produce knowledge and raise intercultural awareness and skills [26]. All the studies considered in this summary show that the IaH initiatives that exploit ICTs in their implementation have the potential to facilitate experiences for a transformative and intercultural learning experience [23], being on par with the traditional internationalization channel. Raise the question to promote "remote Erasmus" like mobility. The interactions between peers involved in IaH are foreseen to happen both through multimedia material (slide decks, audio, or video) and with common evaluation activities which promote knowledge exchange. However, one of the studies states that online interaction among students is not enough. Indeed, the "faculty presence and direct instruction has been found to be essential to depth and quality" [21]. Another important point found in this literature analysis is that most of the studies target humanities and marketing disciplines, having very few examples in the context of STEM and in particular digital electronics [25]. This has been attributed by several researchers to the fact that STEM degrees are characterized by large numbers of required classes and strict course sequences that discourage study abroad [27]. However, IaH complemented with virtually shared classes using online digital tools, can bring to students the experience of working with peers in other countries without leaving their campus and without a perceived “time loss” during studies. A notable example in the context of digital electronics has been provided in [25]. Here we must note that despite the interesting learning concept, some of the technologies used in the students and peers’ interaction are quite outdated. To this extent, the DECEL project will build on the good practices reported in literature concerning IaH, but adding new technologies for remote collaboration and learning, as we will see in the next chapters of this document.

Beyond the IaH concept in STEM: the Internationalization at Distance (IaD)

The studies in curriculum internationalization in HEIs evidenced two paradigms: traditional internationalisation and internationalistion-at-home. However, as the teaching and learning activities are increasingly supported by ICTs there are new opportunities for university internationalization that go beyond the approaches described so far. For example, students can now remain at home while using technology to study with an institution or program that is simultaneously located abroad. These activities can be envisioned in a new third category called Internationalization at a Distance (IaD), that has been formalized in [28]. The key aspect of IaD is the geographic location of the learning provider. The primary geographic location of the learning provider is expected in a different country than the location of the student. The distinctive feature of IaD is that the pedagogic perspectives and curriculum materials are developed and devised outside of the student’s home country. The “learning provider” in this case is meant to be intentionally broad, as it may refer to universities, lecturers, or peers who are geographically located in another place. ICTs are massively used as a support mechanism for the sharing of ideas, knowledge, skills, and pedagogies between the student and the learning provider across geographic distances [28]. In the formalization of IaD activities, the students are taken in consideration through both distance learning programs and blended programs with online elements connected to universities in other countries. This approach is particularly favourable for teaching STEM disciplines like digital electronics, where different platforms and learning environments can be offered by geographically distant HEIs. However, the study in [28] shown that IaD still has not reached a certain maturity level like IaH and the perspectives and implications on the staff personnel need to be thoroughly investigated. Considering the wealth of research focusing on the benefits and affordances of teaching in online and distance learning contexts, a specific focus on staff perceptions of the international and intercultural elements embedded within many programs is needed. For example, it remains unclear whether staff feel they have the appropriate training or preparation for working online with students based around the world. The DECEL project seeks to work around this limitation by providing dedicated training sessions specifically for staff and teaching personnel to avoid “lack-of-preparation” issues.

Collaborative Online International Learning (COIL)

The difference between active and cooperative learning

Over the last few years, especially after the COVID-19 pandemic, different e-learning techniques have been implemented in many universities, which can be grouped into two main categories [29]:

- ***Active learning*** is a range of teaching strategies that focus on the effective participation and involvement of learners. Thus, in active learning, the main responsibility for learning shifts from the teacher to the learner, who takes on a central role. There is empirical evidence that proves the benefits and the effectiveness of active learning compared to traditional lecturing [30]. Active learning involves students in the learning process, adapts the learner's style and provides spatial and temporal flexibility [31]. Six main types of active methodology have been found [32], namely: Flipped classroom, Game-based learning, Problem-Based Learning, Project-Based Learning, Peer instruction and Team-Based Learning. The last four would also fall under collaborative learning. Flipped classroom [33] is probably the best known and most widely implemented active learning methodology, which is why the two terms are sometimes interchangeably. In this approach, teachers provide students with learning resources, usually video lessons, and students can work, watch, or listen at home at their own pace. Later, in the classroom, students have time to apply acquired knowledge, and collaborative and participative activities can be carried out.

- ***Collaborative learning*** can be defined as the educational use of small groups of students to work together to maximize their own and others' learning in a well-defined period [34]. Collaborative learning results in a significant and positive impact on the two dimensions of relational coordination: communication and relationships, and it plays a key role in the acquisition and development of cooperative competence [29]. In facts, collaborative learning structures allow more interaction and dialogue among learners and help to create a feeling of connectedness and belonging among learners, which is crucial for learners [35]. Different experiences applying collaborative methodologies have produced successful results showing numerous benefits, including increasing knowledge retention [36], enhancing creativity [37], helping to prepare students professionally [38], enhancing results in terms of competences acquired compared to other teaching methods [39], or improving students' theoretical and practical ability, cooperative ability and autonomous learning ability [40]. Although collaborative learning has been seen as a difficult pedagogical strategy, technology can make online collaborative learning more effective and ubiquitous.

Defining COIL: a bridge for IaH

The Collaborative Online International Learning (COIL) is a pedagogical strategy that helps in the creation of an integrated intercultural environment with the use of ICTs to connect distinct geographical locations with different cultural background [41] [42] [43]. COIL can be seen as a bridge for IaH activities since it usually involves faculty members who teach similar or related courses in HEIs already engaged in cooperation frameworks. In COIL, the experiential learning tool, which can be in the form of project work, serves as the medium for student collaboration. The faculty members assume shared responsibility in mentoring the students on the collaborations [41]. The project can run from several weeks up to a semester-long project. In [43], it is prompted how COIL provides an opportunity for economically-disadvantaged students who may not be able to participate in travel abroad to also benefit from an intercultural learning environment without traveling. This is the evident link with IaH or even IaD. COIL requires investment in ICTs from the HEIs participating in the activity. COIL has unique attributes that distinguish it from synchronous and asynchronous distance learning. The work in [43] explains that distance learning could include COIL component and an experiential learning component that requires student collaborations. The inclusion of a COIL component in the syllabus of a course benefits students and faculty members through the sharing of course material. This may be done with courses that are similar in scope or complementary and apply project-based learning [41]. The literature reminds that cooperative learning or COIL overlaps with collaborative learning. Cooperative learning falls at the end of the collaborative learning continuum where the learning processes, activities, and experiences are highly organized [44]. With cooperative learning, the objective is for students to synergistically work together to maximize their own and each other's learning. Regular debriefing helps the team members in cooperative and collaborative learn to reflect on the learning process and to device ways to improve their effectiveness [44]. Thus, social, interpersonal, and academic skills are incorporated into cooperative learning and are all critical to the success of the class. To incorporate intercultural competence into cooperative learning, the environment must be created and that is one of the objectives for COIL.

Two interesting case studies explaining COIL for digital electronics

In the context of collaborative learning, an interesting experience was made involving Canadian and Japanese university students who worked together on some video game development projects. The experiment is particularly interesting as the experience gained is reflected in the objectives of the DECEL European project: to make students with different backgrounds and academic cultures collaborate in a COIL environment [45]. The project involved the formation of teams of 5 students made up of 2 Canadian students and 3 Japanese students. The duration of the projects was 3 months and involved the development of video games, based on some guidelines provided at the beginning. By nature, the video game ecosystem has long been designed for remote collaborative play, with a team working/playing together, so game development could naturally be done the same way. Each team actively worked online defining the video concepts (a summary describing what the game is about), the game theme (the game's unifying idea) and the atmosphere (how the game will look and sound). The Canadian students designed, tested, and developed the video games made in the teams. The Japanese students provided Canadian students with valuable ideas on game design, such as the type of music and graphics that the video games should have. The team members exchanged ideas and information and kept communicating on their own game development projects by using a private channel (the student from one team could read and write messages in their channel but could not read or write messages in other channels. Both the instructor from the Japanese and the Canadian universities had access to all the channels to monitor the students' progress.

Another interesting case study is the one proposed in [46]. The experiment involved 12 Spanish students studying industrial engineering and 12 Indian students studying computer engineering working together in small teams to solve projects on digital electronic systems. The objective of the study was to provide an opportunity to the students to develop interdisciplinary solutions to real-world problems and work in diverse and multisite teams. The projects were related to the smart home, smart lighting, assisting elderly people, automated car washing, remote-controlled car, and automated irrigation system. Each team had to frame a problem statement, design a solution, simulate the solution using appropriate software, implement the solution in hardware and prepare a report. The instructors and students collaborated through e-mail, cloud tools, and video conferencing during the study. The students had to complete the project in 5 weeks. They spent almost equal time on software simulation and hardware implementation. In a survey conducted at the end of the study, the students said that they had no problem in using the tools and in communicating with teammates from the other country, and they had an overall positive learning experience. This resulted in better motivation among students and a higher average grade. This experience is the closest to the paradigm we have imagined for the DECEL project (in term of study disciplines and tools used).

Lessons learned from literature about COIL that should be exploited in DECEL

Some learned lessons and suggestions from literature that lead to good practices for carrying out future COIL activities particularised in digital electronics area are summarised below.

Before running the COIL project:

- The instructors involved in COIL should carefully plan activities for themselves and the students. A Gantt chart is a project planning tool that can be used for scheduling the COIL activities in it, updating it by marking the progress on each defined task [47].
- Create a concise presentation for the students, showcasing the COIL project objectives and its process. The presentation should also include intercultural communication and awareness as suggested in the work of [48].
- Define doable and clear software or hardware development activities for the students, according to the entire COIL project duration.

During the COIL project:

- The students can use the discussion forums in the learning management system (LMS) or other online communication tools for brainstorming project/problem design ideas, and to keep communicating in the development process.
- The instructors should constantly monitor the student communications in the LMS, giving feedback to them if necessary.
- Be very clear about what students must do in COIL, explaining their tasks on the first day of COIL. Post the tasks list online to be freely accessible by the students.
- Emphasize the importance of COIL for developing cross-cultural skills. Explain how this will happen during COIL to the student’s population involved in the project.

After the COIL project is finished:

- Wrap up the COIL activities by allowing the students to present their project activities made during COIL. This can be done either synchronously via a live video conference, or asynchronously on LMS or other online platforms where the students can upload their screenshots and pre-recorded videos on their developed software or hardware.
- Ask the students to conduct a debriefing on the project that they have developed. A debriefing is an introspective exercise that analyses what went right, what went wrong and what can be possibly improved in a development project [49]. Writing a debriefing report is a self-reflection

activity on the project development process where students learn about their past mistakes and successes.

Project-based Learning (PBL)

Defining the PBL concept

Project-Based Learning (PBL) is a teaching methodology that consists in motivating the students, organized in groups, to learn actively the topics they need for solving a given problem. This is particularly important in technological engineering areas, as solving real-life problems often obligates engineers to study new matters, understand and apply them, and critically assess the results. The general paradigm of PBL can be summarized as learning by doing instead of traditional doing by learning where students learn what they need to do [a project] instead of doing [a project] with just what they were taught [50]. PBL is not a new concept and has already been used for decades in various areas of high education [50], with roots in the medical domain in the middle ‘60s. With the explosion of easily accessible information observed the last few decades, the task of the teacher in the classroom is changing. In many domains the teacher is losing his major role as the main source of information transmitted to the students and is rather gaining more and more importance as being a provider of reliable sources of information and the driver of the student’s reasoning process (learner facilitator). Thus, the focus of learning process is moving from the teacher to the student and learning is becoming the student’s major responsibility [51]. PBL is also closely related to collaborative learning as it should be implemented with groups of students. It is thus an important vehicle to promote the development of several non-technical skills such as teamwork, communication, reporting, self-organization, and critical thinking. Besides, PBL also allows for the implementation of multidisciplinary projects spanning along diverse areas and accommodating students with different styles of learning. This is particularly true in engineering where real-life projects require a multidisciplinary approach and a close cooperation of engineering teams from various areas. Some authors support that projects exploited in PBL teaching should be open-ended in some extent, to reflect what really happens in real-life situations and further motivate the students with challenging design constraints and non-trivial goals [52]. These may be set with diverse levels of demand to fulfil different accomplishment levels and corresponding assessment grades. To really engage the students and further increase their motivation, the project driving a PBL approach must be implemented and experimented in the field, at some extent. Ideally, the project activity should lead to a physical realization and allow the students to play with the system and critically assess their project outcomes against simulation results or math models. However, when true physical implementations are not viable (e.g., insufficient resources for large classes) realistic simulations environments, often called “virtual labs”, or real remote laboratory infrastructures can provide a not so rich, albeit reasonable, alternative. Although the emphasis of PBL is commonly associated to STEM disciplines and applied to high-education levels, the paradigm of the project-based learning is transversal to different areas of education and spans all levels of education [53]. Examples are the use of PBL for teaching languages, usually referred to as Project-Based Language Learning (PBLL), at the pre-school and high-school levels [54], teaching of arts disciplines [55], social studies [56] or project management [57].

Exploiting PBL in engineering studies

Project-based learning methodology is particularly appealing for various engineering domains where learning with practice is crucial for exposing the realistic challenges of engineering projects. In addition to the practical perspective, this is of utmost importance for developing many personal abilities that are not conveniently exercised by traditional lecture-based teaching schemes. This is clearly recognized by employers of engineering areas, not only for the technical and practical competences but also for strong non-technical skills such as communication, interpersonal and teamwork, ethic awareness, lifelong learning and critical thinking for problem solving [58]. Several studies have been published reporting on the application of project-based methodologies and assessment of the learning outcomes to various engineering fields, as computer programming [5], civil engineering [6], mechanical engineering [59], electrical and computer engineering [21, 4, 12], among others. Electrical and Computer Engineering and, more precisely, the target areas of the DECEL project (logic design, digital electronics, and microcontroller-based system design) are examples where the learning process can clearly be improved by adopting a PBL teaching methodology.

A PBL example for digital electronics

The following example illustrates comparatively the applications of a traditional teaching approach and a PBL methodology, to an introductory course on digital design focused on Boolean algebra and combinational circuit design. Following a traditional lecture-based teaching methodology the course would include the following 5 major sections:

- Binary number system
- Concepts and theorems of Boolean algebra
- From Boolean algebra to logic gates and logic circuits
- Equivalence and manipulation of Boolean equations, truth tables, logic circuits
- Application of the theorems of Boolean algebra for minimizing logic circuits, including the two-level circuit minimization technique based on Karnaugh maps

Although these topics are the basic building blocks to deal with the design and implementation of (simple) logic-level digital circuits, the students tend to memorize them and the associated techniques in a bottom-up fashion, show difficulties to relate them and do not gain a convenient awareness of the applications and problems they will be able to solve with these tools. When faced to a problem that do not fit in the examples exercised in the classes, many students show clear difficulties when they need to re-organize their mental scheme for solving a problem. A PBL approach for such an introductory course on digital systems could start by proposing a simple but real-life problem to be solved. Take the example of a commercial product, not cutting-edge technology but that exists: a “binary” clock that presents time in true binary format lighting on and off two or more sets of LEDs. Although having a questionable usefulness, there are many brands and models, just Google “binary watch” or “binary clock”.

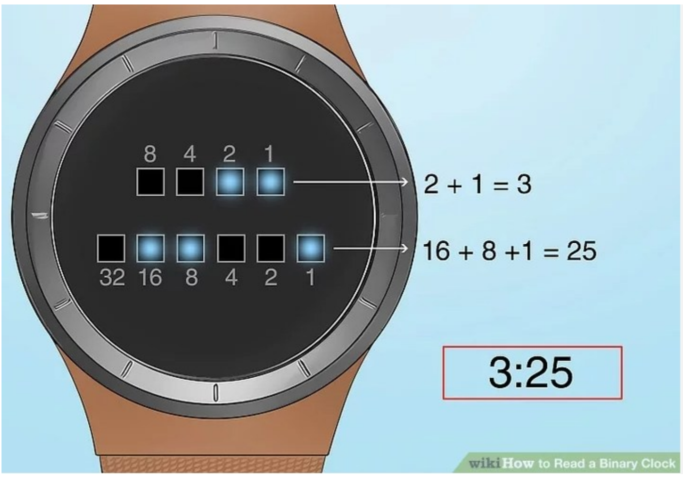

Figure 3: A binary watch (source: https://www.wikihow.com/Read-a-Binary-Clock)

To be able to read the time in these binary watches one need to know the fundamentals of the binary number system and how to convert binary numbers to decimal values. Although the instructions accompanying these clocks explain how to convert the on/off state of the LEDs to decimal numbers, this is done without any formal analysis and is just a recipe for common people. Around this example various activities may be proposed to practice with decimal-binary-decimal conversion, introduce the BCD representation and two's complement arithmetic. Then, the logic design problem would be building a logic circuit to convert the binary codes shown in the clock to conventional 7-segment displays. First, a simple BCD-7 segment decoder and then expanding it, or reusing it, to build a more complex 6-bit decoder to convert a binary number between 0 and 59 to a decimal representation in two 7-segment displays. Various goals and constraints may be proposed to create different levels of complexity and motivate the students to learn more. In a first stage this may be as simple as applying the basic two-level AND-OR / OR-AND minimization using the Karnaugh maps technique. For more complex challenges the students could be called to minimize the number of logic gates using only two-input NANDs, minimize the number of devices or sharing parts of the logic circuit among the different functions to implement. Finally, in an ideal scenario the students should be able to build and experiment their physical circuits and compare among them the different solutions.

Real Remote Labs (RRL)

Defining the RRL concept

In a high-education programs it is unquestionable that experimental skills are fundamental for gaining the competences in various engineering areas. This can only be fully achieved by doing, observing, debugging, and re-doing with feedback taken from the true interaction with real systems. Although nothing replaces the practice exercised with real hands-on experimental work, in some situations it is not possible to provide these ideal conditions to a student community due to various reasons [60]:

- The system under experimentation is at an inaccessible location or cannot be replicated for being used by all the students in a classroom, because it is unique or too expensive (e.g., an experiment onboard a ship, a large telescope, heterogeneous computing cluster, deployed IoT network).
- The system to be experimented is dangerous and require rigorous safety measures (e.g. robotic platform).
- The HEI does not have the adequate resources nor facilities for providing the necessary experimental activities to their students.
- The number of students is too large for doing the experimental works within the timeframes of their regular classes.
- The students are not physically present at the University. The whole world experienced this situation recently during the COVID19 pandemic crisis.

In these situations, remote laboratories can effectively be an asset to overcome those difficulties. However, the remote interaction with a physical experiment also has several limitations that in some cases are difficult, or even impractical, to overcome. Some examples are:

- Setting up an experiment requires some sort of construction of the system to be experimented, like for example a generic electric circuit or hydraulic piping system. For these cases, a limited number of system configurations may be achieved by means of remotely controlled relays or hydraulic valves.
- Although accessible 24/7, a remote laboratory is generally used only by one client at a time and must allocate a limited time frame for each experimentation event needing a booking system. The local and remote users can use the system but requires the use of the booking system for everyone.
- In experiments requiring real-time interaction, the latency of communications can compromise the feel of the experimentation activity.
- The remote online interface for managing the RRL might be inefficient and sometimes far from reality (eg. controlling the apparatus with the mouse instead of buttons and knobs.
- Some remote labs could include cyber security backdoors especially for logically or software programmed connected hardware by uncontrolled people.

It is common to see included under the "remote laboratories" umbrella any type of remotely accessible experimentation resources or tools, including systems based solely in simulation by software tools, usually referred as "virtual remote labs". We will only consider a strict category of remote laboratories that allow, at some extent, the interaction with real physical systems. These are called "real remote laboratories" (RRL) and must have two important characteristics:

- The system being experimented remotely actually exists as a real physical system, located at a remote site.
- The remote experimentation activity consists in building/adapting/configuring the experiment, providing some data to that system, or interacting in real-time with it, and observing/analyzing/retrieving the responses of the system under experimentation.

Simulation is naturally a necessary tool in many engineering fields, and simulation environments are getting more and more sophisticated, mimicking real physical systems with very high degrees of realism. However, running virtual laboratory environments in a local computer or a remote computer is not different, from the user point of view. However, situations exist that clearly justify accessing a simulation environment installed in a remote machine instead of using local simulators, as the availability of the tools or the limited performance of the user computers. There are many implementations of remotely accessible laboratory facilities, in a wide range of domains of knowledge. In short, a "real remote laboratory" is a system accessible by the Internet that allows remote users to do some experimental activity on a physical system. We will discuss remote laboratories in the context of the teaching activity of electronic digital systems and related matters, not considering details of other areas of engineering or physics. Additionally, we will focus not only on "logic systems", but rather on "digital electronics" which also considers the issues associated to the electric behavior of electronic digital circuits.

The case of digital electronic systems

Concentrating in real remote laboratories for teaching digital electronics (device level) and digital systems (logic-, gate-, or RTL-level) there many implementations addressing similar objectives and sharing common characteristics from their utilization point of view. On the top of the remote laboratory workbenches, all remotely accessible laboratories require a booking mechanism for managing the access to the always limited resources. For exercising with electronic digital devices and their characterization in terms of the electric and timing behavior, one category of remote laboratories makes use of network-enabled test and measurement instruments to allow the remote interaction with the physical workbench. This is the case of the VISIR system (Virtual Instruments Systems In Reality) [61], the variant Deusto-VISIR [62], the NetLab platform [63] or the iLab infrastructure [64] that are devoted to remote experimentation of analog circuits, even digital gates in some platforms. Several other systems exist that allow different levels of user interaction for setting up the circuit to be tested and controlling the remote instruments. Another category of remote laboratories for digital system design resort on FPGA platforms to allow the implementation and experimentation of digital systems from a remote location [60] [65] [66]. There are many implementations of such systems although most of such platforms do not differ too much in what concerns to the point of view of the remote user. In general, a design is uploaded to the remote laboratory platform, either as the final bitstream file used to configure the whole FPGA or a logic specification of the circuit to experiment with (HDL or schematic). Then, the circuit is physically implemented in the remote platform. This may be just loading the FPGA configuration bitstream or running remotely the design tools for the integration of the user design in a host pore-built project and performing the device-specific implementation steps (synthesis and place&route). Then, the remote user can interact with the system through a web interface that apply logic values to the inputs of the real circuit and allow to observe and analyze the circuit's behavior. This can be accomplished either by retrieving output data generated by the circuit under experimentation or watching, in real-time through a video camera, to see the state of physical devices attached to their outputs (eg. LEDs, mechanical actuators, etc).

The flexibility of FPGA-based platforms is enormous, and these types of remote experimentation facilities can address several application domains for exercising the design of digital systems. Examples are control of DC motors [67], teaching low power electronics [68], image processing [69], computer architecture [70], microprocessor design [71] or applications in the domain of the Internet of Things [72]. In this technology field we can see that the RRL is used like a hardware-as-a-service platform (HaaS).

Remote labs in a digital electronic course: where and when?

Several countries such as United States, Australia, Canada, Germany, and the United Kingdom have been early adopters of remote labs in digital electronics and have a strong history of utilizing technology in education. These countries have well-established higher education systems and a strong emphasis on technology-enhanced learning, which has driven the growth of remote labs.

In developing countries, remote labs in digital electronics are becoming increasingly popular as a means of providing students with access to laboratory experiences and hands-on learning, despite limited access to physical laboratory facilities. These countries are leveraging remote labs to overcome the challenges posed by the lack of equipment, funding, and trained personnel in traditional laboratory settings.

It is worth noting that the use of remote labs in digital electronics is growing globally, and many countries are starting to incorporate them into their educational systems.

The case of teaching electronic digital systems (how to analyze, design, build) involves different levels of know-hows for which the skills of real experimentation apply, although at different degrees. This usually requires the study of many matters that are usually spread along different courses in high-education programs. In this subsection, we now describe the sequence of matters for teaching an introductory course on digital electronic design from scratch, to identify the main stages where experimental competences should be exploited and RRL might be used. This discussion addresses the main topics and opportunities for real experimentation for an introductory course on digital electronic design based on the information from multiple HEI additionally to the four DECEL partners.

One important point at this initial stage is keeping the students aware that a logic circuit is formed by simple electronic devices performing the elementary Boolean operators. First stage aims understanding the representation and manipulation of information using the binary system: numeric representation, binary arithmetic, text encoding, etc. This is the root of knowledge to deal with the further subjects and these topics can be, and should be, exercised with simple software tools running in basic computers or even smartphones. Next comes learning the Boolean algebra abstraction, involving the symbolic manipulation of Boolean expressions, the representation of combinational functions in different forms as Boolean functions, truth tables, minterm or maxterm list, minimization of expressions (e.g., using Karnaugh maps). The path to achieve digital electronic circuits goes now through the translation of Boolean expressions to real logic gates and understanding the relationship between zeros-ones and low-high voltages. Topics to exercise are the synthesis of combinational logic circuits, minimization, and mapping to electronic gate-level devices, such as the SSI 74xxx series. Although these devices are obsolete for years, they still find a place for educational purposes, but it is more and more difficult to find these « old » components due to scarcity issues. Also, it is important to understanding the electric representation of logic values as logic standards, noise levels and input/output limitations of real devices. A first stage of experimentation with real electronic digital circuits happens here and adds physical details that do not exist when dealing with Boolean algebra and abstract logic circuits. Objective is to address and understand electric issues such as powering electronic devices, dealing with floating inputs, pull-up/pull-down inputs, outputs load. Simple projects involving a few small-scale integration ICs (e.g., 4-bit adder, 7-segment decoder) are adequate at this level and realistic simulator (including breadboard and components pinout) are becoming the perfect tool for this purpose. Following the principles of designing combinational logic, comes the concepts related to sequential logic. Focus here is on understanding the dynamic behavior of basic clocked synchronous memory devices (D-type flip-flop), finite state machines and sequential synchronous standard functions such as counters and shift-registers. This topic also introduces the analysis of timing characteristics in the behavior of sequential logic circuits, and this should be the focus of a next level of experimental works. This aims letting the students gain awareness with important characteristics of sequential devices depending on time (e.g., propagation delays, rise/fall times) and their impact in the sequential behavior. Examples are the experimental analysis of propagation delays and transition times under different loads and supply voltage conditions, and the analysis of the timing relationship of the electric signals representing the data flow along a multi-register sequential circuit (e.g., a simple shift-register). Laboratory experiments can be implemented on the top of the practical skills acquired in the previous practices, adding the utilization of basic measurement and test instrumentation, as the signal generator, oscilloscope, and logic analyzer. The construction of finite-state machines for implementing control-oriented systems is usually the next subject to be addressed. However, the logic complexity of simple, albeit realistic, finite-state machines that interact with physical sensors and actuators (e.g., the classic traffic-light controller) makes difficult to assemble such circuits using traditional prototyping platforms such as breadboards, due to the necessity of using a large number of gate-level digital integrated circuits and the increasingly complexity of building the interconnections. Programmable HW like FPGA devices is the preferred technology here to allow creating more complex sequential circuits that interface with a large variety of input and output devices. Nevertheless, it is still important at this stage to maintain a close relationship with the fundamentals of logic design and not jumping immediately to automated tools for synthesizing FSM from state-transition specifications, that hide important but real problems, as for example, state encoding or state merging/splitting. In this sense, an initial level of practical works addressing the design of FSMs can be done still at gate-level but targeting a FPGA platform and building the gate-level logic circuits in a schematic editor. This is important for the students to better understand the whole design process and the problems associated to the construction of complex control-oriented circuits. The examples of practical hand-on exercises or experiments described above are important for the students to adjust their reasoning to the real world of digital electronics.

Although nothing substitutes the real touch and feel when building and experimenting electronics in a real physical workbench, in some situations it may not be possible to provide such facilities to all the students, due to the reasons stated above.

In digital electronics, we identify 3 different types of experimental activities:

- Building (on breadboard) and experimenting basic combinational circuits using small-scale integration ICs. This is an example where a RRL is impractical do be done, as one of the competences to be exercised is the construction of the physical circuit. Simulators exist that allow the virtual construction and simulation of circuits on breadboards [25]. Although these are not “real remote labs” and do not allow dealing with the measurement and analysis of electric quantities, such simulators are the possible approach for experimenting remotely the assembly of digital circuits on breadboards.

- Characterizing electronic digital circuits, either in timing (propagation delays, rise/fall times), voltage levels at inputs and outputs, effect of output loading or power consumption. This type of remote experiment can be well implemented using test and measurement instrumentation supporting remote operation. A set of experiments can be pre-assembled with various configuration parameters such as different loads connected to digital outputs, variation of the supply voltage, clock frequency and rise/fall times or voltage levels of digital inputs.

- For the topic of sequential circuit design and finite-state machine synthesis, a remote laboratory should be able to provide the resources for: (i) implementing a FSM given a gate-level logic circuit for the basic template of Moore and Mealy FSM (at schematic level, representing the next state combinational logic and the output logic); (ii) experimenting the circuit remotely while embedded in a physical system for performing some task involving real sensors and actuators. To accomplish this the ideal platform is undoubtedly a FPGA-based system supported by a set of tools to allow the easy integration of an FSM into a more complex project for the target board. Feedback to the remote user can be supported by the most common approach of streaming video image of the real system being experimented.

Conclusions

This document is the outcome of a joint effort between Universities of Ferrara, Porto, Tours, and Alcalà in analyzing and benchmarking the best pedagogical strategies implemented in internationalization activities concerning, yet not limited to, the field of reconfigurable digital electronics. A review of the main studies about Internationalization at Home has been performed by exposing the pros and cons of such an interesting teaching methodology that brings an international dimension to the courses syllabi without the actual need to travel abroad both for staff personnel and students. Limitations, implementation barriers, and challenges have been examined in view of a critic reasoning and in attempt to apply the best solutions for the DECEL project. Then, the collaborative learning paradigm has been investigated through several case studies evidencing the benefits of the COIL approach and the active learning. A guideline of the steps to make the initiative successful has been provided and will be used as a reference for the next activities of the DECEL project. Finally, a thorough assessment of the real remote labs platforms was performed to give an overview of the new teaching techniques in the era of an enhancement of the traditional project-based learning concepts.

All these studies have been performed in the context of the O1 of the DECEL project, for which this report serves as the final document to be leveraged in the future project steps.

References

[1] K. R. Finardi e R. A. O. Rojo, «Globalization, internationalization and education: What is the connection?,» *International E-Journal of Advances in Education,* vol. 1, n. 1, pp. 18-25, 2015.

[2] J. Knight, «Updated definition of internationalization,» *International Higher Education,* vol. 33, pp. 2-3, 2015.

[3] H. de Wit, «Internationalization in higher education, a critical review,» *Simon Fraser University Educational Review,* vol. 12, n. 3, pp. 9-17, 2019.

[4] F. F. Guimarães, A. R. M. Mendes, L. M. Rodrigues, R. S. d. S. Paiva e K. R. Finardi, «Internationalization at Home, COIL and Intercomprehension: For More Inclusive Activities in the Global South,» *SFU Educational Review,* vol. 12, n. 3, pp. 90-109, 2019.

[5] S. Robson, J. Almeida e A. Schartner, «Internationalization at home: time for review and development?,» *European Journal of Higher Education,* vol. 8, n. 1, pp. 19-35, 2018.

[6] K. R. Finardi e F. F. Guimarães, «Internacionalização, rankings e publicações em inglês: A situação do Brasil na atualidade,» *Estudos Em Avaliação Educacional,* vol. 28, n. 68, pp. 600-626, 2017.

[7] F. Varvus e A. Pekol, «Critical internationalization: Moving from theory to practice,» *FIRE - Forum for International Research in Education,* vol. 2, n. 2, pp. 2-51, 2015.

[8] S. Pouromid e E. Wiasih, «EXPLORING MOBILITY OF KNOWLEDGE AS AN APPROACH TO INTERNATIONALIZATION IN HIGHER EDUCATION DURING AND BEYOND UNCERTAIN TIMES,» in *The 4th PIM International Conference*, 2021.

[9] E. Commission, «Erasmus+ higher education impact study: final report,» Pubblication Office, 2019.

[10] J. Knight, «Internationalization remodeled: Definition, approaches, and rationales,» *Journal of Studies in International Education,* vol. 8, n. 1, pp. 5-31, 2004.

[11] B. Barbosa, C. Santos e C. Prado-Meza, «There is no one way to internationalization at home: Virtual mobility and student engagement through formal and informal approaches to curricula,» *Revista Lusófona de Educação,* vol. 47, n. 10.2, pp. 85-98, 2020.

[12] J. Beelen e E. Jones, «Redefining Internationalization at Home,» in *The European Higher Education Area*, Springer, Cham, 2015, p. 69.

[13] N. Harrison, «Practice, problems and power in 'internationalisation at home': Critical reflections on recent research evidence,» *Teaching in Higher Education,* vol. 20, n. 4, pp. 412-430, 2015.

[14] H. de Wit e B. Leask, «Internationalization, the Curriculum and the Disciplines,» *International Higher Education,* vol. 83, pp. 10-12, 2015.

[15] C. Whitsed e W. Green, «Internationalisation begins with the curriculum,» University World (Issue 311), [Online]. Available: www.universityworldnews.com. [Consultato il giorno 26 January 2013].

[16] H. De Wit e J. Beelen, «Reading between the lines; Global internationalisation survey,» University World News (Issue 318), [Online]. Available: www.universityworldnews.com. [Consultato il giorno 2 May 2014].

[17] J. Beelen, Implementing internationalisation at home, Amsterdam: European Association for International Education, 2007.

[18] J. Mestenhauser, «Internationalization at home; Systems challenge to a fragmented field,» in *Internationalization at home: A global perspective*, 2006, pp. 61-77.

[19] J. Beelen e J. Elspeth, «Internationalisation at home,» in *Encyclopedia of International Higher Education Systems and Institutions*, Springer International, 2018.

[20] B. McCollum, L. Morsch, B. Shokoples e D. Skagen, «Overcoming barriers for implementing international online collaborative assignments in Chemistry,» *The Canadian Journal for the Scholarship of Teaching and Learning,* vol. 10, n. 1, 2019.

[21] B. Lee e H. Cai, «Evaluation of an online "Internationalization at Home" course on the social contexts of addiction,» *Journal of Studies in International Education,* vol. 23, n. 3, pp. 365-388, 2019.

[22] E. Carlson, M. Stenberg, T. Lai, S. Reisenhofer, B. Chan, E. Cruz, D. Leung, A. Wong e E. Chan, «Nursing students' perceptions of peer learning through cross-cultural student-led webinars: A qualitative study,» *Journal of Advanced Nursing,* vol. 75, n. 7, pp. 1518-1526, 2019.

[23] N. Hyett, K. M. Lee, R. Knevel, T. Fortune, M. K. Yau e S. Borkovic, «Trialing virtual intercultural learning with Australian and Hong Kong allied health students to improve cultural competency,» *Journal of Studies in International Education,* vol. 23, n. 3, pp. 389-406, 2019.

[24] T. Mejtoft, H. Cripps e C. Blocker, «Internationalization at home: An international interdisciplinary experience,» in *8:e Utvecklingskonferensen för Sveriges ingenjörsutbildningar: Detaljerat program*, 2021.

[25] A. Erden, A. M. Erkmen, I. Erkmen, R. B. Bucinell, C. Traver, A. Member e L. Notash, «The Multidisciplinary International Virtual Design Studio (MiVDS),» *IEEE Transactions on Education,* vol. 43, n. 3, pp. 288-295, 2000.

[26] C. Bhat e M. McMahon, «Internationalization at Home for Counseling Students: Utilizing Technology to Expand Global and Multicultural Horizons,» *Int J Adv Counselling,* vol. 38, pp. 319-329, 2016.

[27] A. Abrahamse, M. Johnson, N. Levinson, L. P. J. M. Medsker, C. Quiroga e R. Scipione, «A Virtual Educational Exchange: A North–South Virtually Shared Class on Sustainable Development,» *Journal of Studies in International Education ,* vol. 19, n. 2, pp. 140-159, 2015.

[28] J. Mittelmeier, B. Rienties, A. Gunter e P. Raghuram, «Conceptualizing Internationalization at a Distance: A "Third Category" of University Internationalization,» *Journal of Studies in International Education,* vol. 25, n. 3, pp. 266-282, 2021.

[29] R. Estriegana, J.-A. Medina-Merodio, R. Robina-Ramírez e R. Barchino, «Analysis of Cooperative Skills Development through Relational Coordination in a Gamified Online Learning Environment,» *Electronics,* vol. 10, n. 16, 2021.

[30] Prince e M., «Does active learning work? A review of the research,» *J. Eng. Educ. ,* vol. 93, pp. 223-231, 2004.

[31] Rosenberg e M.J., E-Learning: Strategies for Delivering Knowledge in the Digital Age, NY, USA: McGraw-Hill: New York, 2001.

[32] M. Ribeiro e O. Passos, «A Study on the Active Methodologies Applied to Teaching and Learning Process in the Computing Area,» *IEEE Access,* vol. 8, p. 219083–219097, 2020.

[33] A. Sams e J. Bergmann, Flip Your Classroom: Reach Every Student in Every Class Every Day, Arlington, VA, USA: ISTE: St, 2012.

[34] D. Johnson, R. Johnson e K. Smith, Active Learning: Cooperation in the College Classroom, Interaction Book Co., 1991.

[35] N. Hara, C. Bonk e C. Angeli, «Content analysis of online discussion in an applied educational psychology course,» *Instructional Science,* vol. 28, pp. 115-152, 2000.

[36] T. Bauerle e T. Park, «Experiential learning enhances student knowledge retention in the plant sciences,» *HortTechnology ,* vol. 22, pp. 715-718, 2012.

[37] A. Ayob, R. A. Majid, A. Hussain e M. M. Mustaffa, «Creativity enhancement through experiential learning,» *Advances in Natural and Applied Sciences,* vol. 6, n. 2, 2012.

[38] J. Straub, K. S. e D. Whalen, «Teaching software project management using project based learning (PBL) and group projects,» in *IEEE International Conference on Electro Information Technology (EIT)*, 2017.

[39] M. Blanco, C. Gonzalez, A. Sanchez-Lite e M. A. Sebastian, «A Practical Evaluation of a Collaborative Learning Method for Engineering Project Subjects,» *IEEE Access,* vol. 5, pp. 19363-19372, 2017.

[40] J. Wang, X. Chen e X. Gao, «Economic Management Teaching Mode Based on Mobile Learning and Collaborative Learning,» *IEEE Access,* vol. 8, pp. 200589-200596, 2020.

[41] P. Appiah-Kubi e E. Annan, «A Review of a Collaborative Online International Learning,» *International Journal of Engineering Pedagogy (iJEP),* vol. 10, n. 1, pp. 109-124, 2020.

[42] S. C. Center, *Faculty Guide for Collaborative Online International Learning Course Development,* The State University of New York Global Center, 116 E. 55th St. New York: The Center for Collaborative Online International Learning.

[43] M. Esche, «Incorporating Collaborative Online International Learning (COIL) into Study Abroad Courses: A Training Design,» Capstone Collection, 2018.

[44] B. Smith e J. MacGregor, «What is collaborative learning?,» in *Collaborative learning: A sourcebook for higher education*, PA: Pennsylvania State, University Park, 1992.

[45] M. Garcia-Ruiz, L. Gaytan-Lugo e P. Santana-Mancilla, «Cross-Cultural Experiences in Video Game Development Projects with Collaborative Online International Learning (COIL),» in *Proceedings of Society for Information Technology & Teacher Education International Conference*, San Diego, CA, USA, 2022.

[46] M. Rodriguez-Sanchez, P. Chakraborty e N. Malpica, «International collaborative projects on digital electronic systems using open source tools», *Comput Appl Eng Educ.,* vol. 28, pp. 792-802, 2020.

[47] A. Bednjanec e M. Tretinjak, «Application of Gantt charts in the educational process,» in *Application of Gantt charts in the educational process. 2013 36th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, 2013.

[48] Z. Jie e A. Pearlman, «Expanding Access to International Education through Technology Enhanced, Collaborative Online International Learning (COIL) Courses,» *International Journal of Technology inTeaching and Learning,* vol. 14, n. 1, p. 11, 2018.

[49] M. Garcia-Ruiz, S. Xu, P. Santana-Mancilla e A. Iniguez-Carrillo, «Experiences in Teaching and Learning Video Game Testing with Post-mortem Analysis in a Game Development Course,» in *Proceedings of EdMedia + Innovate Learning*, 2020.

[50] E. Montero e M. González, «Student engagement in a structured problem-based approach to learning: A first-year electronic engineering study module on heat transfer,» *IEEE Trans. Educ.,* vol. 52, n. 2, pp. 214-221, 2009.

[51] R. Hadgraft, *Integrating engineering education-key attributes of a problem-based learning environment,* Melbourne, Australia: RMIT University.

[52] R. Felder e R. Brent, «Random Thoughts: Learning by Doing,» *Chemical Engineering Education,* pp. 282-283, 2003.

[53] N. Duke, A. Halvorsen e S. Strachan, «Project-based learning not just for STEM anymore,» *Phi Delta Kappan,* vol. 98, n. 1, pp. 14-19, 2016.

[54] S. Kaldi, D. Filippatou e C. Govaris, «Project-based learning in primary schools: Effects on pupils' learning and attitudes,» *Education 3–13,* vol. 39, n. 1, pp. 35-47, 2011.

[55] A. Elfeky, S. Alharbi e E. Ahmed, «The Effect Of Project-Based Learning In Enhancing Creativity And Skills Of Arts Among Kindergarten Student Teachers,» *Journal of Positive School Psychology,* vol. 6, n. 8, pp. 2182-2191, 2022.

[56] I. lhan, «A study on the efficacy of project-based learning approach on Social Studies Education: Conceptual achievement and academic motivation,» *Educational Research and Reviews,* vol. 9, n. 15, pp. 487-497, 2014.

[57] B. Ngereja, B. Hussein e B. Andersen, «Does Project-Based Learning (PBL) promote student learning? A performance evaluation,» *Education Sciences,* vol. 10, n. 11, p. 330, 2020.

[58] A. Azmi, Y. Kamin, M. Noordin e A. Nasir, «Towards industrial revolution 4.0: employers' expectations on fresh engineering graduates,» *International Journal of Engineering & Technology,* vol. 7, n. 4.28, pp. 267-272, 2018.

[59] I. Zergout, S. Ajana, C. Adam e S. Bakkali, «Modelling Approach of an Innovation Process in Engineering Education: The Case of Mechanical Engineering,» *International Journal of Higher Education,* vol. 9, n. 2, pp. 25-39, 2020.

[60] F. Morgan, S. Cawley e D. Newell, «Remote FPGA lab for enhancing learning of digital systems,» *ACM Transactions on Reconfigurable Technology and Systems (TRETS),* vol. 5, n. 3, pp. 1-13, 2012.

[61] M. A. Marques, M. C. Viegas, M. C. Costa-Lobo, A. V. Fidalgo, G. R. Alves, J. S. Rocha e I. Gustavsson, «How remote labs impact on course outcomes: Various practices using VISIR,» *IEEE Transactions on Education,* vol. 57, n. 3, pp. 151-159, 2013.

[62] U. Hernandez-Jayo e J. Garcia-Zubia, «Remote measurement and instrumentation laboratory for training in real analog electronic experiments,» *Measurement,* vol. 82, pp. 123-134, 2016.

[63] H. Considine, M. Teng, A. Nafalski e Z. Nedić, «Recent developments in remote laboratory NetLab,» *Global Journal of Engineering Education,* vol. 18, n. 1, pp. 16-21, 2016.

[64] V. J. Harward, J. A. Del Alamo, S. R. Lerman, P. H. Bailey, J. Carpenter, K. DeLong e D. Zych, «The ilab shared architecture: A web services infrastructure to build communities of internet accessible laboratories,» *Proceedings of the IEEE,* vol. 96, n. 6, pp. 931-950, 2008.

[65] K. Henke, G. Tabunshchyk, H. D. Wuttke e T. Vietzke, «Using interactive hybrid online labs for rapid prototyping of digital systems,» in *11th International Conference on Remote Engineering and Virtual Instrumentation (REV)*, 2014.

[66] F. Morgan, S. Cawley, F. Callaly, S. Agnew, P. Rocke, M. O'Halloran e B. McGinley, «Remote FPGA lab with interactive control and visualisation interface,» in *21st International Conference on Field Programmable Logic and Applications*, 2011.

[67] E. Guzman-Ramirez, I. Garcia, E. Guerrero e C. Pacheco, «An educational tool for designing DC motor control systems through FPGA-based experimentation,» *International Journal of Electrical Engineering Education,* vol. 52, n. 1, pp. 22-38, 2015.

[68] S. AbuShanab, M. Winzker e R. Brück, «Teaching low-power design with an FPGA-based hands-on and remote lab,» in *IEEE Global Engineering Education Conference (EDUCON)*, 2015.

[69] M. Winzker e A. Schwandt, «Open education teaching unit for low-power design and FPGA image processing,» in *IEEE Frontiers in Education Conference (FIE)*, 2019.

[70] Y. Zhang, Y. Chen, X. Ma, Y. Tang, Y. Niu, S. Li e W. Liu, «Remote FPGA lab platform for computer system curriculum,» in *Proceedings of the ACM Turing 50th Celebration Conference-China*, 2017.

[71] J. S. Pastor, I. Gonzalez, J. Lopez, F. Gomez-Arribas e J. Martinez, «A remote laboratory for debugging FPGA-based microprocessor prototypes,» in *IEEE International Conference on Advanced Learning Technologies*, 2004.

[72] N. Fujii e N. Koike, «IoT remote group experiments in the cyber laboratory: A FPGA-based remote laboratory in the hybrid cloud,» in *International Conference on Cyberworlds (CW)*, 2017.