# Deliverable 4.2

## Report on Best Practices and Professional Training

| DISSEMINATION LEVEL | | |
|---|---|---|
| **PU** | Public | **X** |
| **CO** | Confidential, only for members of the consortium (including the Commission Services) | |

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[1] **R**=Report, **DEC**= Websites, patents filling, etc., **O**=Other
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## Consortium Information

| Institution / Design Centre (incl. address) | Role in CPSELabs |
|---|---|
| **FORTISS GMBH (FOR) GMBH**<br><br>BOLTZMANNSTRASSE 3, GARCHING 85748, Germany | The main role of **FOR** is to serve as a design centre in the network of the CPS Engineering Labs with a focus on co-simulation of virtual vehicles and cloud-based flexible production systems. **FOR** is the project coordinator of the CPSELabs. |
| **KUNGLIGA TEKNISKA HOEGSKOLAN (KTH)**<br><br>BRINELLVAGEN 8, STOCKHOLM 100 44, Sweden | The main role of **KTH** is to serve as a design centre in the network of the CPS Engineering Labs with an emphasis on autonomy (platforms and reference architectures) and on marketplaces for CPS platforms, in particular for engineering environments. In CPSELabs **KTH** leads WP4 and provides the Innovation Manager. **KTH** moreover contributes with its experiences in best practices dissemination and in industry/academia collaboration on demonstrators and training. |
| **OFFICE NATIONAL D'ETUDES ET DE RECHERCHES AEROSPATIALES (ONR)**<br><br>Avenue de la Division Leclerc 29, CHATILLON 92322, France | The role of CPSELabs is to ease exchange of technologies developed in different research contexts, to mature and to adapt them for CPS new applications. **ONR** will play this role thanks to the following assets:<br><br>**ONR** conducts multi-disciplinary researches in aeronautic, space and defence fields. In the CPS Labs, **ONR** gathers in a coherent framework research results and experimental means related to autonomous systems (developed initially for the defence) and to safety critical systems (developed initially for the aeronautic).<br><br>These results will be adapted to better address CPS needs related to autonomous dependable vehicles (e.g. civil UAV or advanced driving systems for cars) and to ease their access to companies which shall enhance their artificial intelligence and dependability culture to enter new markets.<br><br>Finally, **ONR** is strongly involved in collaborative researches with European and National academic and industrial partners. At the regional level, it has a privileged link with their regional partner CNRS-LAAS, to perform joint research projects during long periods. It also contributes actively to the scientific animation of the Aerospace Valley cluster. So **ONR** network will be widely used in the project to promote the CPSELabs approach and potentially to identify new contributors. |
| **UNIVERSITY OF NEWCASTLE UPON TYNE (UNEW)**<br><br>KINGS GATE, NEWCASTLE UPON TYNE NE1 7RU, United Kingdom | The main role of **UNEW** is to serve as a design centre in the network of the CPS Engineering Labs with a focus. **UNEW** is also primarily responsible for maintaining and executing the communications plan of the network through WP2 and for administrative issues regarding the management of the open calls (including amendments and third party agreements). |
| **OFFIS EV (OFF)**<br><br>ESCHERWEG 2, OLDENBURG 26121, Germany | The main role of **OFF** is to serve as a design centre in the network of the CPS Engineering Labs with a focus on transfer of CPS innovations from the automotive and avionic domain into the maritime domain. |

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|---|---|
| **INDRA SISTEMAS S.A. (IND)**<br><br>Avenida de Bruselas 35, ALCOBENDAS-MADRID 28108, Spain | **IND** offers its experience in previous CPS researches, providing a platform of Smart objects for intelligent applications. This platform will be used for the experiments proposed by the Spanish Lab regarding to the Smart City, but it will be also be used by the other labs that need a platform for smart data in a grid context.<br><br>The experience of **IND** in other competencies will be also available for the Labs, such as cloud computing, geographic information systems or architectures and platforms.<br><br>**IND** will also be the coordinator of the open calls, defining and executing the process according with the EU principles and the objectives of the consortium. |
| **STEINBEIS INNOVATION GGMBH (SEZ)**<br><br>WILLI BLEICHER STRASSE 19, STUTTGART 70174, Germany | Due to its experience in managing European projects, **SEZ** will take over the administrative and financial management. Furthermore, **SEZ** has invaluable experience in technology transfer and knowledge management, therefore it will strongly supporting WP2 and WP5 dealing mainly with the communication, dissemination of the project's activities and results, the exploitation of the project's results by its own networks and channels as well as networks to be established on the event management and governmental fields, as well as the IPR management and technology watch of the applications and devices to be developed.<br><br>• WP1 administrative and financial project management<br><br>• WP5 support project dissemination and exploitation |
| **CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE (CNRS)**<br><br>Rue Michel-Ange 3, PARIS 75794, France | **CNRS-LAAS** has extensive expertise in Decisional and Planning issues in robotics including learning and adaptation. It will in particular be a supplier of navigation algorithms for mobile robotic platforms. It also has extensive expertise on run-time verification of autonomous systems, whether the monitoring is integrated to the control system or is an independent safety device. **CNRS-LAAS** also has a lead position on testing methods applied to a variety of embedded systems, including both conformance and robustness testing. |
| **UNIVERSIDAD POLITECNICA DE MADRID (UPM)**<br><br>CALLE RAMIRO DE MAEZTU 7 EDIFICIO RECTORADO, MADRID 28040, Spain | The main role of **UPM**, in close cooperation with INDRA, is to serve as a design centre in the network of the CPS Engineering Labs with an emphasis on smart cities. **UPM** provides access to their Integrated Facility4Smart Cities infrastructures which are distributed among different geographical locations (Campus Sur and Campus of Montegancedo), and its background/experience in platforms and (event-driven/autonomic) architectures for Cyber Physical Systems.<br><br>**UPM** will also contribute with its experience in setting up collaboration between industry and academia, and in promoting the consolidation of experiments/ideas into products/start-ups. |

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# Table of Contents

# Executive Summary

The purpose of this deliverable is to report on the overall effort by work package 4 in the CPSELabs network to establish effective regional learning networks.

During the first year of CPSELabs this effort has primarily involved understanding the context of the CPSELabs design centres and relevant CPS eco-systems, and identifying the best way for CPSELabs to proceed with offerings to support learning. The outcome of this investigation has resulted in a) a common understanding of the relevant eco-systems, and b) the identification of a number of challenges to learning in the immediate network surrounding the design centres and in entire eco-systems dealing with Cyber-Physical Systems (CPS). **Section 2** describes the method of investigation and (a), while **Section 3** and **4** presents (b) (each identified challenge) together with 1) ways of dealing with the challenge, either through management and practice, or through policy; and 2) the implications of the challenge to the further work of CPSELabs.

A parallel investigation into the professional training available within CPSELabs is presented in **Section 5**.

The conclusions with regard to how CPSELabs should move forward to establish effective regional learning networks, presented in **Section 6**, can be summarized as the suggestions that CPSELabs:

- Interacts further with the experiments to (a) identify and support their training needs, (b) ensure the preparation and harvest of use cases and demonstrators that can be reused for training purposes, and (c) connect training opportunities across domains.
- Continues detailing the design centre eco-systems, specifically to identify CPSELabs access to large infrastructure, virtual resources, or otherwise scalable artefacts.
- Builds a course pilot in one of the areas the CPSELabs partners hold much knowledge in. In the short run for the hands-on, direct benefit of the CPS communities and feedback on how partner interactions in training can be managed best in order to maximise impact; and in the long run to handle the identified challenges to learning in CPS eco-systems by establishing a complete, evolving description of the most basic set of techniques and structures for CPS engineering.
- Capitalize on its ability to act as a neutral ground by e.g. providing a summer school for professionals, building small communities (e.g. web-based) around the output of each experiment, and organizing workshops at relevant venues.

# 1 Introduction

This deliverable details results from the efforts within CPSELabs Task 4.1 (T4.1), Task 4.2 (T4.2) and Task 4.3 (T4.3).

The common denominator between these tasks is that they rely on a solid understanding of the innovation and engineering eco-systems surrounding the CPSELabs design centres:

- T4.1 to a) establish a learning network among the design centres to exchange best practices in creating innovation eco-systems and b) carry out cross-centre opportunity scouting to identify innovation and other collaboration opportunities;
- T4.2 to establish regional learning networks; and
- T4.3 to identify existing best practices for managing networked and open innovation with regard to Cyber-Physical Systems (CPS).

To this effect T4.1, T4.2 and T4.3 have made a joint effort to interview key stakeholders that work within, or are closely aligned to, the design centres. These interviews, as described further in **Section 2**, have been transcribed and analysed to elicit a common understanding of the relevant eco-systems, and to find a way for CPSELabs to move forward with regard to the goals of the different tasks. The analysis forms the primary input and basis for **Section 2**, **3**, **4** and (by extension) **6**.

The understanding of the eco-systems forms a common basis for this deliverable and D4.3 (the Innovation Management Report), and is therefore found in both deliverables. With regard to the intention to move forward, both deliverables capitalize on a number of challenges to the goals of T4.1, T4.2 and T4.3 which were identified in the interview study. These challenges are, in this deliverable, discussed either with regard to their importance to individual design centres, or with regard to their importance to entire eco-systems. When challenges to design centres are discussed solutions involving management and practice are brought up, especially those identified through the interviews; when challenges to entire eco-systems are discussed solutions involving policy are brought up, again especially those identified through the interviews. Any related implications to the further work of CPSELabs are highlighted together with each challenge and associated solutions.

To enable a more coherent set of deliverables D4.2 (this deliverable) focuses only on challenges to **learning** (T4.2), while D4.3 focuses on all aspects related to **innovation** (T4.1 and T4.3). In other words, even though the original intention was to include also best practices on innovation management and best engineering practices for sharing within CPSELabs in D4.2, these are now found in D4.3. However, this deliverable instead includes a summary of the professional training available within CPSELabs.

The remainder of this deliverable is structured as follows. **Section 2** introduces and discusses a common understanding of the relevant eco-systems. **Section 3** focuses on challenges to learning at the design centre level, while **Section 4** takes a broad perspective and treats learning at the eco-system level. **Section 5** describes professional training within CPSELabs. **Section 6** provides conclusions that put the understanding and findings detailed throughout the text into a CPSELabs perspective: how is this analysis important, and how can CPSELabs move forward with T4.2? After this deliverable has been published CPSELabs can therefore directly move forward with identifying further industrial needs for professional training, while at the same time evaluating the best and most sustainable way to match these and already identified needs with existing competences and courses.

# 2 A Common Understanding of the Relevant Eco-systems

CPS engineering and innovation eco-systems are constituted by different organizations, communities, and individuals jointly contributing to the generation of new CPS products, processes, and businesses. These eco-systems are characterized by their multitude of stakeholders and technologies, and a resulting complexity of the undertaken development activities. Given the distributed and emergent nature of these eco-systems for knowledge creation and exploitation, they face numerous challenges in realizing effective and efficient learning and innovation. Moreover, as the changes brought about by CPS innovations are often of a disruptive and systemic nature, it is clear that these innovations depend on new and boundary-spanning interaction and that they can be expected to encounter substantial resistance and inertia.

This section outlines the most salient parts of the common understanding of these complex eco-systems that has evolved within the CPSELabs project; starting with briefly describing how we came about this understanding through our investigations.

## 2.1 The Main Method of Investigation

The first version of the CPSELabs Centre Handbook outlined a preliminary plan for how to reach a common understanding of CPS engineering and innovation eco-systems [1]. In accordance with this plan the design centres chose an eco-system they were particularly interested in, and described it in detail to the other centres. After discussions at a face-to-face meeting this exercise was redone, this time focusing on an eco-system that the design centres were directly involved in.

This was followed up by the Swedish design centre conducting interviews with about 10 key stakeholders (pointed out as such by the different design centres). The interviews were semi-structured [2] and based on an interview script with 15 open questions (of which some contained multiple sub-questions). The interviews were all recorded, and then transcribed prior to analysis. The analysis consisted of coding the material, and (if relevant) connecting the parts highlighted by the coding to the goals outlined by T4.1, T4.2 and T4.3.

By comparing the different parts of the interviews connected through the coding, or the goals of T4.1, T4.2 or T4.3, relationships and important points could be elicited. The results of the analysis forms the primary input and basis for **Section 2**, **3**, **4** and (by extension) **6**.

## 2.2 CPS and the Platform Paradox

Industrial eco-systems that develop and produce technical products have been studied extensively since the inception of research into economics. However, industries evolve and we constantly see the rise of new phenomena: such as the platforms that have entrenched firms such as Google, Apple and Microsoft into the role of market leaders, and seemingly allow them to effortlessly take that role when moving into new markets.

Still, many traditional industrial domains appear to be resistant to the flux of modern business logic, trudging on at their own pace in rather stable eco-system configurations. Can this state of affairs continue? Do we wish it to? CPS, or the increase of products bringing information and communication technology into traditional industrial domains, has been highlighted as a potentially disruptive phenomena in this regard [3], [4]. Still, is the rise of CPS as a key technology within these industrial domains a sign of these domains reaching a tipping point in which new business relationships will be established, e.g. around CPS platforms? Or will we see new relationships, new business mechanisms, appear?

Some efforts have already been made to capture why CPS are disruptive and how this disruptiveness resonates with the eco-systems in which CPS is currently noticeable as a key technology [5]. To begin to formulate an answer to the questions outlined in the previous paragraph we believe the following points are important to highlight:

- The relevant industrial domains typically require interactions across organizational boundaries, with the subsequent implications with regard to technical interoperability, law, governance and jurisdiction:
  - During development between engineering disciplines, firms supplying or integrating each other´s technology, etc.
  - During operations between nations, municipalities, firms providing complementary services, etc.
- Strict operational requirements on efficiency and flexibility favour solutions that are highly configurable, easily updatable and always responsive, which easily leads to a high degree of complexity in technical products. They are typically composed of many interconnected parts and operate with a flexibility that can make it difficult to establish cause and effect. At the same time the link to physical effects makes other considerations than the purely economic important, it might e.g. be difficult to justify a change to a more efficient technology if the implications on safety are unknown.
- Investments typically involve large sums and/or scales, if not with regard to the associated mass consumer products then with regard to the associated firm or societal infrastructure. There is the very real treat of technology, or even vendor, lock-in across a long time period and on many levels, e.g. for engineering tools, communication infrastructure on roads or factory floors, supply chains, etc.

The appeal of a technical platform that stabilizes relationships, establishes clear interfaces and supports non-technical decisions is obvious. However, at the same time it is difficult for such a platform to survive: The full end effect of legal matters often end up on system integrators, which means that these might have to spend extensive resources on ensuring the integrity of the platform. New, incompatible solutions that give an efficiency-edge appear regularly due to the parallel evolution of multiple technologies, and these solutions might be difficult to incorporate in a platform that was not originally design for them. Furthermore, customers constantly try to avoid lock-in due to its potentially harmful long-time effects, which means that a platform might be overlooked simply because choosing it obviously excludes other choices.

This essentially captures a paradox inherent in CPS eco-systems: CPS technology allows for establishing platforms that are sustainable due to a mix of software and hardware that gives high flexibility and shares the burden of complexity and non-functional properties; however, the complexity of CPS technology, the speed of innovation and the expert-dependent nature of the relevant eco-systems would at the same time indicate that these platforms might more easily reach a boundary beyond which they cannot pass.

The handling of this paradox is further aggravated by the fact that a disruptive idea might not as easily disregard technical limitations as in other domains: Currently deployed end user products might be too complex to allow for changing infrastructure without overly expensive precautions, efficiently making even gradual improvements impossible. As an example, a mobile phone can rely on mobile networks almost regardless of the significant changes they can go through or their many configurations, since the critical functionality is easy enough to test within reasonable limits; however, if the technical backbone of an intelligent transporting system changed significantly over time or location, the differences to cooperative vehicles could have severe implications that would be very difficult to spot due to the complexity of the associated safety-critical functionality.

## 2.3 Stepping Up to the Challenge

This challenge is of course met by the CPS industries in many different ways, especially when it comes to technical innovation: reconfiguration, autonomous control and self-healing are but a few of the active technical research fields in this regard. However, the setup of the CPS eco-systems also has a direct impact on how this challenge can be met by facilitating knowledge sharing or innovation:

- *Brokers of information* are very important to avoid technology lock-in, or to identify usable technology within the available window of opportunity. These brokers can include connected individuals, university-industry networks, standardization organizations, etc. Noticeable in this regard is: (a) the role of universities and research centres as "neutral ground", at which information can be shared and technical solutions influenced by requirements, demands and needs from many different sources; (b) the active effort by certain brokers, such as industrial domain organizations, to share information between different industrial domains; (c) the lack of time of many of the involved stakeholders, which leads to difficulties in reaching the common understanding required for these to understand each other.
- Among the *sources of requirements, demands and needs* one can note that both large infrastructure, like harbours and physical test beds, and firms are able to drive progress by linking relevant experts to the data required to develop CPS with the right capabilities. It seems having access to (physical) experimental platforms of a realistic scale and complexity makes certain entities key players.
- *Monetary capital* is repeatedly downplayed by stakeholders; it seems to be available to those that identify the possibility for innovation. However, while this is true for start-ups and established companies, there seems to be a lack of money available for the growth between these stages. This is also in line with the identified paradox, if one considers that a new solution needs to prove its worth by showing that (a) it will be sustainable and flexible, (b) current platforms cannot overcome a relevant boundary, and (c) that the time for change is right to get the right payoff on old and new investments. All of these are difficult to show, especially for a new CPS that has not been fielded in significant numbers.

Besides the above-mentioned prerequisites for realizing knowledge sharing and innovation in CPS industries, which are of a very generic nature, a number of other challenges for CPS learning have been identified, at the innovation eco-system level and the design centre level, respectively. These challenges will be treated in the following pages.

# 3 Challenges to Learning at the Design Centre Level

A number of challenges that were identified through the interviews, concerned learning in CPS eco-systems, e.g. (but not limited to) missing or incomplete CPS education and training. Some are not specific to the CPS domain, like industrial competition hindering the sharing of knowledge and achievements. Others have arisen from the distinctive character of the domain, like the need to embrace a wide breadth of multidisciplinary knowledge, or the difficulty in providing a realistic hands-on context during teaching. Interestingly, similar CPS-specific challenges have been identified and discussed in a report issued from a US Committee on 21st Century CPS Education [6].

Challenges that are noticeable at the design centre level are described below together with possible solutions, in terms of improved practices for learning and knowledge sharing, also identified through the interviews. After each challenge and associated solutions our analysis of their implications can be found. These are collections of possible actions that the project may, or may not, take. **Section 6** will eventually provide an elaboration, elicitation and summary of the actions that we have thought it most important to act on.

## 3.1 Challenge: Competition Keeps Organizations from Sharing Freely

### 3.1.1 Description

Competing organizations frequently strive to limit their outflow of information. By keeping critical knowledge proprietary, and often secret, competitors are unable to use the specific knowledge and gain related competitive advantages. However, the limited sharing of knowledge across organizational boundaries also has substantial negative effects. A strict focus on direct appropriation limits the potential benefits that can be gained from establishing a dominant installed base in an industry by making knowledge available to others, e.g. in terms of establishing widely used de-facto standards, and thus may exclude value creation from network externalities [7]. Moreover, a strict focus on knowledge protection may even imply that other individuals and groups, even within the same organization, might be unaware of valuable techniques and achievements.

Even academic organizations are affected by this: many universities want to see projects with the industry generating money for research, but this often means that the companies restrict how the resulting research can be disseminated and utilised.

This has direct implications on the structuring of CPS development, e.g. with regard to non-functional properties like safety and security. There is diversity of perspective on how to achieve a well-functioning structure along organizational and well-established engineering processes, including viewpoints and abstraction levels. Standards are providing structure within certain domains (such as ISO26262 within the automotive industry), but progress is slow, focused on best practice rather than the latest development techniques, and domain-specific. This is not to say that the CPS industries are actively resisting the introduction of well-functioning structures, but rather that there is a lack of understanding of what incremental improvements would provide the largest effect, with the lowest effort and interruptions. This understanding is especially difficult to achieve in a context such as CPS development, since it suffers from a large heterogeneity with regard to domains, disciplines, governance, etc.

### 3.1.2 Solutions (Management and Practice)

Seminars and short talks are frequently used within organizations to spread knowledge of efforts and achievements of different groups. Some organizations go beyond this by organizing learning networks with competence groups (focusing on specific topics, gathering people from all over the organization), and also invite experts from different research fields for presentations, courses, tutorials or longer stays. These individuals can take on roles as brokers and/or translators between different organizations, and thereby facilitate the coordination of actions that need to take place in order to align goals and strategies so that they make sense at an eco-system level. Lead firms arguably play an important role in this work, but given the disruptive nature of many CPS innovations, this may not always be a feasible approach. When CPS innovations bring about changed value functions to the involved stakeholders it may instead be necessary to exclude previously leading organizations and instead identify new stakeholders in the value network that can benefit more from the changes.

Some organizations, e.g. research centres, are viewed as more neutral and are therefore able to visit other research facilities to gain knowledge. These organizations may also play key roles in the establishment of shared projects that can develop into joint platforms supported by a multitude of different stakeholders, for their mutual benefits. Collaboration with multiple industrial partners also allows them a cross-organizational view of domains. Results from individual projects with Industry can most often be disseminated by publications, given some sanitization that removes the protected information items. A relevant example of organization, albeit with a larger scope of interest than CPS, is the French Institute of Technology Antoine de Saint Exupéry, offering training support and a collaborative development environment to major industrial and public partners in aeronautics, space and embedded systems.

However, a key competence perceived as missing in the industry is the knowledge of broader initiatives to capitalize on this neutrality, i.e. knowledge of how European initiatives for public-private partnerships work. This relates to initiatives such as the ARTEMIS Industrial Association and EU Networks of Excellence.

Online courses are another way of spreading knowledge widely, which can be pre-analysed to avoid harmful information leaks. In [6], one of the invited contributors reports on an experience with developing and teaching a CPS-related massive open online course (MOOC). The experience was quite successful, with an initial enrolment of 40,000 participants, and about 7,000 who remained active at the end of the session. However, setting the MOOC was found difficult and required three times the work of a regular class. It has been suggested elsewhere that on-line courses can be grown in a distributed fashion, allowing researchers from different organizations to cooperate to leverage on the latest sharable techniques and achievements, while distributing the effort.

Mobility between industry and academia is one possible way to facilitate knowledge creation and its application in new products and processes [8]. However, this type of cross-boundary learning is limited, with the notable exception of research institutes, where this appears to be more frequent. The mobility between subcontractors is another factor that might disseminate best practices and knowledge, even when mobility between the large companies is restricted.

Organizations controlling large testbeds, perhaps combined with the actual infrastructure of e.g. regional municipalities, can counter this challenge, both by providing a neutral ground and requiring it to be clear what can be shared. These organizations / infrastructure seem to be attracting the large players in the CPS eco-systems, which mean that their importance may grow to be even greater.

Furthermore, many important companies also in the CPS domains, traditionally wary of approaches where they share the designs of their products, have begun to see the advantage of relaxing the traditional IP and licensing protocols to distribute their products and services e.g. through open source.

### 3.1.3 Implications for Further Work within CPSELabs

As stated in the Data Management Plan (D1.1), the CPSELabs consortium has committed to ensure dissemination of the knowledge gained from experiments with third party partners. As much as possible, CPSELabs should help these partners in scoping their use cases and demonstration artefacts, in order to extract information that is sufficient to exemplify the concepts and problems, while not disclosing too much about their systems and know how. This information should be freely usable for integration in training and education material, in particular as regards hands-on work (see Subsection 3.3).

MOOCs have been identified as an attractive means for CPS training. The CPSELabs consortium should study the setting of MOOCs in a distributed scheme by at least including one MOOC among any course pilots developed. Unrelated to CPSELabs, KTH has recently started a focused effort to launch about 10 to 20 new MOOCs during the upcoming 3 years. A contact has therefore been made with the intention to find possibilities for synergy. A contact also has been taken with the French Institute of Technology Antoine de Saint Exupéry, who are about to create a MOOC on safety. The CPSELabs consortium could potentially achieve some synergy by working with them. Several providers have already established stable platforms for MOOC delivery, thus creating templates that the partners of CPSE Labs can adapt. This could allow the CPSELabs Consortium to focus on the CPS-related issues, without too much effort on the management and technical issues of developing a MOOC. When possible, the design centres should build their regional learning networks upon infrastructure/organizations that already provide an existing framework for knowledge sharing. Developing a MOOC in connection with such organizations would be in line with this strategy.

Another means for CPS training that could capitalize on the neutral ground of some CPSELabs partners is a summer school, which could provide natural boundaries for networking and knowledge exchange over techniques and knowledge already known to the public. However, such a school then needs to be profiled to avoid clashes and (too much) overlap with existing ones. One such focus might be to address PhD students and industrial participants for continued education (it seems other schools primarily targets Master students).

## 3.2 Challenge: Domain-focused Organizations and Other Domains

### 3.2.1 Description

Developing CPS end products typically requires extensive domain knowledge, for instance in airplanes, ships or the medical profession. However, designing certain parts of CPS end products can sometimes rather require an in-depth knowledge in information handling, embedded systems, networked systems, etc. It is both difficult and expensive to combine expertise from both of these worlds. It may even be difficult to find individuals with broad knowledge of (a) CPS domain(s) involved in the information handling part. This challenge is increasing due to the expanding envelope of technical and systems integration, now increasingly spanning all the way from physical, over embedded to cloud technology. In particular, there is a lack of training on CPS in general, beyond specific niches. It can be observed that the competences necessary, in order to fruitfully combine technological expertise and application knowledge, are supported neither by existing educational structures nor by professional training offerings. Whereas universities and other providers of higher education are aware of technological trends and try to continuously adapt their curricula to encompass new engineering techniques and tools, although sometimes at a somewhat slower speed than desired, domain-specific application knowledge is primarily derived from hands-on experience in professional roles. The individuals who gain knowledge about the use of technology and engineering knowledge in a specific setting play a central role in connecting the capabilities provided with the technological knowledge base with the specific needs and demands of the organizations using this knowledge in their businesses.

### 3.2.2 Solutions (Management and Practice)

Work that requires in-depth expertise in information technology is often outsourced to smaller, more agile and less domain-focused companies. By working with multiple customers and business partners, these companies directly or indirectly act as knowledge brokers within and sometimes across domains.

Individuals with a pronounced T-shaped competence profile, i.e. both depth and width, can also play fundamental roles in combining specific customer needs with new CPS technology. Universities and training providers is currently trying to find new ways of supporting T-shaped competence development, something which most likely requires new collaborations in order to move beyond traditionally established areas of responsibility (University-Industry collaboration has been identified as important to achieve this goal [9]). Research institutes ought to be well positioned to lead such initiatives, as these often have access to both the knowledge residing within academia and knowledge about the specific applications and related needs of industrial partners.

Evolving technology support has also mitigated some issues related to this challenge. One example is Polarsys [10], an environment born from a European R&D project interested in software-intensive embedded systems in the aerospace and industrial domains. The project decided to create and populate a specialized open-source repository where this type of software is uploaded, and then downloaded by interested parties wherever they may be. This allows developers to focus on the specifics of a given technology, creating modular parts that may be used in many projects. At the same time, the managers of large projects can abstract themselves from the specifics of certain technologies.

### 3.2.3 Implications for Further Work within CPSELabs

CPSELabs should be a knowledge brokering entity by trying to stimulate relationships between, or even create new, CPS communities. In particular, CPSELabs should build structures that allow organizations focused on domains to think in terms of CPS and the new requirements these imply. If CPSELabs can open the eyes of key players in this way, the resulting interest in e.g. new tools will stimulate the identification of learning and training needs.

A specific means for creating CPS communities, within the grasp of CPSELabs, is also to organize workshops at relevant venues together with industrial partners of all the experiments and the aim to demonstrate the applicability of certain techniques in several domains of CPS.

## 3.3 Challenge: Difficulty in Achieving a Realistic Context during Teaching

### 3.3.1 Description

Many CPS techniques and methods require a realistic, often large-scale, context for those studying them to really benefit from teaching. This may be difficult to achieve in small classes at universities. In order to prepare engineers for the complexity facing them in industrial development of products and processes, better opportunities need to be created for realistic use of CPS techniques. As it may not be economically feasible to invest in the necessary infrastructure in many places, better coordination of investments in this infrastructure is needed.

### 3.3.2 Solutions (Management and Practice)

The value of hands-on projects is widely acknowledged. There are examples of collaborations between industry and academia that have achieved large, realistic projects and infrastructure that can be used to teach the CPS techniques and methods. They provide a real-world context to the teaching and exemplify the interdisciplinary nature of CPS. One can see a need for more joint investments in large-scale facilities and infrastructure that can be used by both industry and academia. This can be located and coordinated by consortia of firms, by universities, or by research institutes, but an important factor is that is can be used by the different stakeholders involved without burdensome coordination. By sharing infrastructure and their related platforms, there is also a larger possibility of identifying and promoting these platforms to make them widely diffused and used.

In [6], a reported experience involved a set of problems submitted by General Electric, the solutions of which required knowledge in power technology, software and complex system design and analysis. Five interdisciplinary teams were created with students from different engineering programs.

Hands-on projects in collaboration with Industry can also be found from academic organizations in the CPSE Labs regional learning networks. For example, at ENSEEIHT (a French "Grande École" in Toulouse), a recent project concerns an agile satellite submitted by Airbus Defense & Space. The covered topics span system design, task planning, real-time kernel programming, communication systems, control theory and fault tolerance. The implementation used a mock-up.

Another solution is to use e.g. Virtual Labs based on virtual or mixed reality, which can support many of the existing CPS domains. One example of a Virtual Lab in Europe is the *European Virtual Smart Grid Laboratory*.

### 3.3.3 Implications for Further Work within CPSELabs

The experiments conducted within CPSE Labs provide examples of real-world problems, which can be used by instructors as a context for their teaching. The design centres should take actions to ensure the availability of the description of uses cases and demonstration artefacts, with possibly some modifications to preserve the IP rights.

# 4 Challenges to Learning at the Eco-System Level

Challenges that are noticeable at the level of entire CPS eco-systems are described below together with possible solutions, in terms of improved practices for learning and knowledge sharing, also identified through the interviews. After each challenge and associated solutions our analysis of their implications can be found. These are collections of possible actions that the project may, or may not, take. **Section 6** will eventually provide an elaboration, elicitation and summary of the actions that we have thought it most important to act on.

## 4.1 Challenge: Relying on the Initiative of Individual Stakeholders

### 4.1.1 Description

The transfer of knowledge between domains typically relies on individual stakeholders identifying something in one domain that might be usable in another. There is often no systematic way for knowledge to migrate between domains and/or bringing all key stakeholders to a shared understanding.

### 4.1.2 Solutions (Policy)

**Regional** councils/municipalities and large infrastructure projects, such as airports and harbours, seem to be strong stakeholders with regard to bringing together others to facilitate CPS development.

Regions can also have this effect purely by **geographical proximity**: if universities are close to industrial clusters the alumni network will stay connected (and generate interactions), and allow for at least research labs and industry to interact more easily.

**Follower groups** to large research projects, or topic-specific discussion groups/networks, also spread knowledge, and e.g. generate further interactions when consortia are restructured.

### 4.1.3 Implications for Further Work within CPSELabs

CPSELabs should ideally try to create follower groups or communities for its outputs, to ensure that these are sustainable and migrate to as many domains as possible. In concrete terms this means creating small communities tied to e.g. experiment outputs, course pilots, etc. These communities should ideally be based on interest from already existing stakeholders in the design centres´ eco-systems.

## 4.2 Challenge: Different Languages across Europe

### 4.2.1 Description

Large companies in some countries require discussions to be in the primary language of that country, which may not be known to the majority of the eco-system. The inherent linguistic diversity in Europe in this way poses a challenge to learning and diffusion of new technologies, as this is slowed down by the need for translations, and given the limited scale of some national European markets some opportunities are not even considered economically feasible. This acts against the establishment of large-scale platforms and also limits the possibilities for knowledge exchange enabled by users of such platforms, and then in particular when these are for instance of an open source character.

One may consider Spain as a particularly obvious example: while 1 in every 4 European citizens claims to be able to speak several languages, Spain is way below this figure with only 18% bilingual citizens [11]. Considering that English, as the most widespread language in Europe, has become used as a lingua franca, Spain is again at the bottom of the list [12]. In many cases, a bilingual Spaniard may be fluent not in English but in the vernacular tongue of his or her birthplace in Spain (Basque, Catalan, Galician, etc.). Particularly since Spain joined the EU in 1986, Spanish people have been found in English-speaking environments without having a great fluency in the language. A number of high managers in public and private companies have therefore had difficulties to negotiate and understand a number of important questions in and by themselves.

### 4.2.2 Solutions (Policy)

Some activities are outsourced to other eco-system entities that are fluent in relevant languages (in which relevant knowledge has been disseminated or relevant experts can easily be communicated with). This solution was e.g. used by German companies with regard to problem formulation, which research institutes performed for them (while relying on expert knowledge from other parts of Europe).

Again, using Spain as an example, Spanish companies have been known to name a specific contact point for negotiations with foreign parties. This person must not only be fluent in the language, but also in all the aspects of the problem and have enough authority to avoid having to rely on higher managers on a daily basis.

### 4.2.3 Implications for Further Work within CPSELabs

Any output by CPSELabs related to learning should ideally involve support for various languages; as an example, material for or delivery of courses should ideally be created in several languages. Failing this, output from CPSELabs should have a clear plan for how additional languages could be supported later by other parties.

# 5 Professional Training Available within CPSELabs

Partners were requested to summarise training they currently deliver in aspects of Cyber Physical systems research. They were asked to assess the level of training available and its suitability for various stakeholders via delivery methods, time taken and content.

The results produced appear to emphasise that Cyber Physical systems as a distinct discipline is not yet well enough known in Europe to act as a selling point for training courses. Therefore the current provision is patchy at best. There would be much work to do if CPSE Labs as a project was to produce a coherent training strategy covering the domain as a whole, and at the moment, it is difficult to see what the driver(s) for such an activity would be. Although many businesses and organisations throughout Europe work on problems that, to us are CPS related, the term itself is not one that is readily recognised, particularly among the SME community, so it is important first to work on having the terminology recognised more widely so that later, training in the area can be seen by the customer as a valuable tool for their business. In the meantime however, we do have some training courses being made available by partners, and as a first step in the process we summarise some examples of what is available now below.

## 5.1 Examples of Courses

### 5.1.1 fortiss

**Course:** Modelling distributed industrial process measurement and control systems with IEC 61499.

**Comments:** This is an introduction to IEC 61499 targeted at the industrial automation domain. The training gives an overview of the standard and focuses on the development of distributed control applications.

**Pre-Requisites:** There are no pre-requisites required but a basic understanding of industrial process measurement and control systems is an advantage.

**Accreditation:** There is no accreditation currently attached to this course, which is designed as a standalone dissemination of knowledge. Although not part of a recognised program, there are other courses available to build on and complement the knowledge gained.

### 5.1.2 KTH Royal Institute of Technology

**Course:** Multi processor systems on FPGA.

**Comments:** This course is aimed at people who already have some knowledge of the subject. It is designed to be delivered only as a short (1 day) course and is not suitable for accreditation. There is a strong practical element within the training with an approximate 50/50 split with theory. Other longer courses are available elsewhere. The course exploits, rather than builds knowledge.

**Pre-Requisites:** Knowledge and understanding of the topic.

**Accreditation:** No accreditation currently.

### 5.1.3 Newcastle University

**Course:** Tools training (Crescendo and VDM).

**Comments:** Newcastle aims these courses at small groups of experienced users, who ideally already have training in modelling concepts. It is designed to equip those who have not used the tools with the key concepts. This is a hands on course for experienced engineers and aims to give practical modelling experience. The maximum length the course has been spread over is 5 days, and it is categorised as dissemination of knowledge. We also use feedback from the sessions to add value to the toolset

**Pre-Requisites:** (Usually) Undergraduate Degree in CS or Engineering

**Accreditation:** No accreditation currently

### 5.1.4 OFFIS

1. **Course:** Functional Safety.

**Comments:** Basic training to address the safety lifecycle of Cyber Physical Systems as a whole, in order to provide a group-wide safety culture and to understand the basic principles of risk-driven design. The course can be 1 – 3 days long and covers basic principles of the safety lifecycle. The course exploits existing knowledge through current safety standards, but uses delivery to create knowledge through tailoring such standards for the maritime context.

**Pre-Requisites:** No pre-requisites but mainly of interest to people working in the development of safety-relevant CPS or on safety management activities for CPS.

**Accreditation:** No accreditation currently.

2. **Course:** Maritime Architecture Framework: Understanding and Using.

**Comments:** The focus is on an initial overview of the Maritime Architectural Framework (MAF). The goal is to allow attendees to use the MAF to support the development of related CPS. The course is designed to be delivered as a small workshop (5 – 10 people) and will take 2 to 4 days depending on numbers and depth of information.

**Pre-Requisites:** Attendees should have a general background in the maritime domain and enterprise architecture frameworks.

**Accreditation:** No accreditation currently

3. **Course:** Maritime Architecture Framework: Expert Workshop.

**Comments:** The training course focus on the use of the Maritime Architecture Framework (MAF). This course develops the mapping of a specific cyber-physical system (CPS) to the frameworks conceptual space. The course will be processed as an expert workshop and focus the related developer of the targeted CPS. The course lasts from a few days to three weeks depending on the scope of the targeted CPS.

**Pre-Requisites:** General understanding of the MAF and its design aspects and a maritime domain background.

**Accreditation:** No accreditation currently.

### 5.1.5 LAAS-CNRS

1. **Course:** Dependability Concepts.

**Comments:** This course is generally for systems engineers from an electronics or computer science background, but it may also be delivered to mechatronics or system modelling experts. It is a theoretical course with an introduction of dependability concepts and techniques.

**Pre-Requisites:** Masters Degree.

**Accreditation:** No accreditation currently.

2. **Course:** HAZOP-UML.

**Comments:** A course designed specifically for CPSE experiment partners and again aimed mainly at systems engineers. It is practical, rather than theoretical, and it could be delivered as a programme or a short course.

**Pre-Requisites:** Masters Degree.

**Accreditation:** No accreditation currently.

3. **Course:** GenoM.

**Comments:** This course is aimed at experts in CS and robotics and is currently used mainly for newcomers to the LAAS Labs. The GenoM tool is to specify and deploy real-time software components.

**Pre-Requisites:** Masters Degree.

**Accreditation**: No accreditation currently.

4. **Course:** Robot Safety.

**Comments:** This course can be targeted as either theoretical or practical and exploits current LAAS-CNRS knowledge. It is delivered over a day or two as a short course and aimed at people with an in depth knowledge of the area.

**Pre-Requisites:** Masters Degree.

**Accreditation:** No accreditation currently.

### 5.1.6 Indra

**Course:** Introduction to SOFIA2

**Comments:** Indra has been teaching the specifics of the SOFIA2 technology, to groups to up to forty people. This includes the attendees not only getting familiar with the methods and paradigm of the SOFIA2 framework, but they also getting to practice programming their own client software (Knowledge Processor) and connecting it to the SOFIA2's server-based Semantic Information Broker for testing purposes.

**Pre-Requisites:** There are no pre-requisites required, but an understanding of computer science and engineering is useful.

**Accreditation:** No accreditation currently.

### 5.1.7 UPM

In addition to the above**, UPM** have a suite of courses in different areas but all very similar in nature. Each can be adapted to cover the subject broadly or in more technical detail, each can be mainly theoretical or can look at the information in a more practical "hands on" style and each looks to build on existing knowledge.

These courses all may be come modules in a Masters programme but for now are not accredited.

The courses are:

- Distributed Programming for Software Systems
- Model Based Systems Engineering
- Real Time CPS Engineering
- Agile Product Modelling
- Elements of Smart Grids and Smart Cities IT

- Agile Development and Innovation

## 5.2 Collaborative Training Possibilities

During the WP4 Workshop in Stockholm, a small number of areas were identified where Partners have some expertise and could provide relevant training to interested parties. These areas would appear to define where partners have skills transferrable into the CPS domain rather than being the actual provision of CPS Training. These broad areas were as follows:

| TRAINING | PARTERS |
|---|---|
| Safety and Security | fortiss, KTH, LAAS, OFFIS, ONERA, UNEW |
| Model Based Systems Engineering | fortiss, KTH, LAAS, OFFIS, ONERA, UNEW, UPM |
| Real Time CPS Engineering | KTH, LAAS, ONERA, UPM |

## 5.3 Gaps in Current Training

Following discussions within the Consortium, two obvious gaps in our training provision have been identified:

- The CPS innovation process.
- Introductory material for CPS technologies.

During year 2 of the project we will look at possible ways to cover such gaps both externally, though training offerings from organisations outside CPSELabs, and internally, either by individual partners or, collaboratively, depending on the success of the Safety Pilot.

## 5.4 Analysis of Available Professional Training

The availability of CPS training across the consortium would at this stage best be described as patchy. Unsurprisingly, a high level of expertise amongst partners ensures that small ad hoc training courses on particular technologies, disciplines and platforms can be delivered easily. Indeed some partners are beginning to look at exploitable courses that could be embedded into Masters and other programmes but this is at an early stage. Where several partners have interests in similar areas, there will inevitably be areas of overlap and there may also still be gaps. It will be necessary to explore the areas listed (Safety and Security, Model Based Systems Engineering, Real Time CPS Engineering) more closely with named partners if we are to ascertain the breadth and depth we offer in the areas. Attempting to set up a Pilot MOOC could allow us to see more clearly how partner interactions in training can be managed best in order to maximise impact.

Indeed, we would expect the model of training courses aimed tightly at a particular technology or platform and a small audience to be the one that will be used extensively by design centres with their experiment partners. From there, it will be up to consortium members to look for opportunities to expand such offerings in terms of breadth of applicability and indeed scale.

The specific examples of training above also indicate that some Partners do have “off the shelf” training courses that can be offered to industry and academia where there is need or interest. Further work could be done here to advertise and extend such offerings. These “off the shelf” offerings, can be on similar topics indicating an overlap in effort between partners, however, for the moment, the point of difference between them is usually that they are specific to a single domain. Applicability cross domain may be something we need to explore later in the project.

# 6 Discussion and Conclusions

This section brings together implications and findings detailed in previous sections into a number of highlights, which are then elaborated on in an attempt to draw out optimal suggestions for how CPSELabs can move forward. These suggestions are then summarized in the end of the section.

## 6.1 The CPSELabs Experiments

The experiments funded through CPSELabs are an important focal point for the project, and as much as possible should be done to *optimize* and *support* their successful outcome. However, it is important to note that two calls are already finished, and the third is coming up soon. Several efforts, including the CPSELabs Strategic Innovation Agenda, have optimized the calls, and the possibilities to affect such things as project descriptions and content further is now limited. The possibilities to affect the experiments should rather be focused on active interaction with the *now* up-and-running projects.

The T4.2 investigation therefore implies three efforts with regard to the experiments and learning:

- CPSELabs needs to ensure that each design centre, as planned, interacts with the experiments to identify their training needs. When these needs can be related to an “off the shelf” course of a CPSELabs design centre, the contact between the design centre and the relevant experiment partners should be facilitated by CPSELabs. In other words, CPSELabs should act as a knowledge broker with regard to how the experiment partners can benefit from the extended CPSELabs eco-system of design centres.
- CPSELabs needs to interact with the experiments to ensure the preparation and harvest of use cases and demonstrators that can be reused for training purposes. Preparations for disseminating (as artefacts for learning) these on a broader scale should also be started.
- CPSELabs needs to start connecting training opportunities across domains, e.g. try to identify learning opportunities that can be reshaped to transfer across domains. This effort could, at least initially, be limited to new possibilities that turn up, such as those found in the output of the experiments.

UNEW is already handling the investigation into professional training at the different design centres. This investigation will continue by looking at *closing already identified gaps* (related to the CPS innovation process and introductory material for CPS technologies) *through training provided by internal* or *external organizations* (e.g. the Professional School organized by EIT Digital). Due to the close connection with the first effort outlined above, it is suggested that UNEW´s role is expanded to cover also this effort.

The second and third effort would both benefit from someone within CPSELabs acquiring an overview of what can be harvested and instructing the experiment partners in how to prepare artefacts properly. This effort is not immediately related to UNEW´s role, so the question on who should fill it is left for M14 and the work on the new version of D4.1 (the Centre Handbook).

## 6.2 Existing Infrastructure and Organizations

The infrastructure and organizations already connected to the CPSELabs eco-system of design centres are valuable assets, which we should capitalize on: they can be used to *share* knowledge, *support* CPSELabs training and even be agreeable to *change* based on our recommendations. A number of important eco-systems have already been described by the CPSELabs partners, but the details have not yet been investigated.

This suggests that the best way forward is to continue the interview effort that this deliverable is based on, further detailing and understanding the relevant eco-systems. To support future actions and deliverables, it is suggested that particular attention is then paid to:

- What external partners do the design centres have that, for learning or training purposes, provide access to large infrastructure, virtual resources, or otherwise scalable artefacts?
- What limitations are linked to said resources, i.e. how can CPSELabs exploit them or support their evolution into being more efficient for CPS learning purposes?
- Are any of the experiments likely to provide such resources as outputs, or could they benefit from access to such resources?

It would be natural for KTH to continue the effort to detail relevant eco-systems through interviews, thereby trying to answer the first two questions found above. The last question is likely best handled by the same CPSELabs partner that takes on the second effort outlined in the previous subsection.

This also suggests that CPSELabs needs to continue in its efforts to create a team of people working actively on learning within the network. It is likely that such a team can only (without difficulty) be successfully formed if there is a concrete learning task to work continuously on. It is therefore suggested that CPSELabs also builds new courses for professional training, i.e. *pilots* for both the hands-on, direct benefit of the CPS communities and feedback on how partner interactions in training can be managed best in order to maximise impact. The next delivery of D4.1 (the Centre Handbook) should therefore contain the plans for how to set up such a pilot course, and who of the design centres will be the coordinator for making it happen.

In the long run, such pilots should ideally strive to create a base for CPS Engineering. In this way, several of the major challenges outlined in the previous sections could be met: in other words, *building a complete, evolving description of the most basic set of techniques and structures for CPS engineering* would help the CPS communities avoid reinventing the wheel (see Section 3.1), and support the proliferation and transfer of domain knowledge (see Section 3.2 and 3.3). Based on this long-term vision it is suggested that:

- The best focus of such a pilot is one of the areas outlined in Subsection 5.2, since CPSELabs hold much knowledge on these. However, the pilot must contain a connection between the chosen area and the general concept of CPS Engineering, so that other areas can be connected to the first one and evolve into the base outlined above.
- The pilot is created in collaboration with *all* CPSELabs partners (thereby making it important that the choice of subject is "the right one"), and is coordinated by specified people also at the regional level.
- The pilot is created as a MOOC.
- The effort includes efforts to *grow* and *stabilize* the regional learning networks. This could e.g. be done by recruiting experts from both inside and outside the design centre eco-systems into the effort; or by setting up the pilot so that it can be continuously grown through a self-sustaining community around it.
- Even if the entire pilot cannot be created in several languages, that it is set up so that its materials and lectures could latter can be extended to other languages by internal and external stakeholders (potentially also through a self-sustaining community).

## 6.3 The CPSELabs as a Neutral Ground

CPSELabs, as cooperation between industry and academia, provides opportunities for creating neutral ground for networking and knowledge sharing within known boundaries. There are several obvious possibilities for this, i.e. CPSELabs could:

- Provide a summer school for professionals.
- Create small communities (e.g. web-based) around the output of each experiment.
- Organize workshops at relevant venues.

If these activities are realized they need to be profiled to avoid overlap with existing efforts, and should ideally draw on the interest and be realized within already existing structures in the design centre eco-systems. It is suggested that the realization of these efforts are based on the willingness to champion them by one or more design centres. If such champions exist, the next delivery of D4.1 (the Centre Handbook) should name them and outline their plans for the relevant activities.

## 6.4 Summary

This deliverable suggests that CPSELabs:

- Interacts further with the experiments to (a) identify and support their training needs, (b) ensure the preparation and harvest of use cases and demonstrators that can be reused for training purposes, and (c) connect training opportunities across domains.
- Continues detailing the design centre eco-systems, specifically to identify CPSELabs access to large infrastructure, virtual resources, or otherwise scalable artefacts.
- Builds a course pilot in one of the areas the CPSELabs partners hold much knowledge in. In the short run for the hands-on, direct benefit of the CPS communities and feedback on how partner interactions in training can be managed best in order to maximise impact; and in the long run to handle the identified challenges to learning in CPS eco-systems by establishing a complete, evolving description of the most basic set of techniques and structures for CPS engineering.
- Capitalize on its ability to act as a neutral ground by e.g. providing a summer school for professionals, building small communities (e.g. web-based) around the output of each experiment, and organizing workshops at relevant venues.

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