A Model Driven Method to Design Educational Cyber Physical Systems

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Abstract: Instructional design is a major concern in TELE (Technology Enhanced Learning Environments) research, especially since the beginning of the Covid-19 health crisis. Since the beginning of this crisis, emergency remote teaching has been widely used. Accordingly, the primary objective in these circumstances is not to re-create a robust educational ecosystem, but rather to provide adapted access to instructional support, learning materials, services and objects. However, design connectedness in such environments is still required regarding the emergence of IoT (Internet of things) and CPS (Cyber Physical Systems) in everyday life and thus in educational environments. In this paper, we propose a model-driven engineering method for the design of Educational Cyber Physical Systems (ECPS). Our method deals with the separation of concerns when it comes to considering a Platform Independent Model (educational aspect) and a Platform Description Model (connected aspect). This practice could then be adopted in order to design further environments by adapting the required models.

1 INTRODUCTION

IoT (Internet of Things) and CPS (Cyber Physical Systems) have overwhelmed several domains and are gaining increasing attention. Research on connected environments often focus on specific domains which may result in a gap in the development between particular domains and others. For instance, interests in Industry 4.0 exist because of the mass consumption society we live in. For that reason, the industrial field has expeditiously moved through several revolutions to attend the industry 4.0 (Hermann et al., 2016).

The buzzword IoE (Internet of Everything) has, over the last years, registered a tremendous increase in use. The connected world does not only mean connected things, it also includes services, humans and data. In our research work, we investigate the next revolution at an educational level by exploring the core technologies of Industry 4.0 (IoT/E, CPS) for University 4.0. Although several research papers in the literature have had the interest of connected pedagogical environments, many challenges with regard to educational system policies remain, in particular at a university level.

The purpose of this paper is to define and model Educational Cyber Physical Systems (ECPS) based on a model driven engineering (MDE) method through meta-modeling. A meta model describes a specific domain model through a modeling language (Bézivin, 2005). To do so, we first start by defining the meta-model of CPS within a PDM (Platform Dependent Model) perspective, then, we define the meta-model of the educational environment from a PIM (Platform Independent Model) perspective and finally, we implement a model fusion through ATL rules (Atlas Transformation Language) which will result in an ECPS model.

The remainder of this paper is structured as follows. Section 2 presents the related works covering the proposed DSLs (Domain Specific Languages) by describing IoT, CPS environments and IoT in education. Section 3 presents our contribution regarding both the definition and the design method of ECPS. In order to clarify our work, an illustrative case study will highlight the different concepts, in section 4. Conclusions and future works will resume the paper.

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2 RELATED WORKS

To the best of our knowledge, ECPS are not addressed in the literature. Only the use of connected things in education are provided in the research field but without any modeling perspective. The corresponding related works will be presented later. As a result, we rely on IoT and CPS related works. In the literature, one may find several definitions of IoT and CPS to such a degree that they could be considered as look-alike concepts, however, they are not. More notably, it was stated in (Guth et al., 2016) that CPS can be used as a synonym of IoT since both terms have recently been mentioned coincidentally. Nonetheless, they are technically highly linked. In this section, we clarify both definitions and give a glance of their proposed models in Software Architecture (SA).

2.1 Internet of Things (IoT)

Various definitions of IoT can be reviewed in (Muccini and Moghaddam, 2018). For each definition, a specific view point or perspective is considered. In fact, some research works (e.g (Khan et al., 2012), (Tyagi, 2016)) highlight the *machine-to-machine interactions* when qualifying this paradigm. Others focus on *the real-time collaboration and interaction* (Syed et al., 2016).

More generic definitions are also given in (Roman et al., 2013) where the authors consider IoT as *a worldwide network of interconnected entities*. In (Navani et al., 2017), IoT is seen as *the ability to connect, communicate with, and remotely manage an incalculable number of networked and automated devices*. It is transforming our physical world into a giant information system (Fortino et al., 2017). Also, a definition given in (Nunes et al., 2017) characterizes IoT as *an ecosystem that interconnects physical objects with telecommunication networks, joining the real world with the cyber space and enabling the development of new kinds of services and applications*. We notice that this latter represents IoT as Cyber Physical Systems (the next section specifies more what CPS are).

In our work, we consider that IoT is getting an expanded dimension of its things. Currently, we deal with Everything. And so, IoE includes not only smart machines (things), but also humans, data and Services (CISCO, 2013). Interactions are then established between all these pillars of the IoE. Thus, IoE could be defined as an infrastructure of a smart world where CPS could carry out high-performing computational capacities.

Regarding IoT modeling in SA, a review (Muccini and Moghaddam, 2018) about IoT architectural styles notes that the layered style was dominant in the different research works. Cloud-based and service-oriented styles also have an important presence. We believe that data-oriented architecture is not sufficiently developed in the literature. Object-oriented architecture (in the sense of smart-object) could also be considered as a way to IoT architecture.

For instance, the work of (Fortino et al., 2017) focuses on designing IoT service models which, according to the authors, are the real IoT drivers. Each IoT Service is designed as a composition of the Service Model (details about attributes and relationships describing the IoT Service itself) and the Service Profile (details about the process implementing the service). The LAURA architecture (Teixeira et al., 2020) is yet another service-oriented architecture for IoT. Its aim is to implement changes in business models by taking into account numerous contextual elements. Meanwhile, various research works are in the pursuit of standardising IoT reference Architecture (e.g. (Bauer et al., 2013), (Guth et al., 2016), etc).

Accordingly, an IoT Reference Model (IoT ARM) widely provides the concepts and definitions on which IoT architectures can be built (Bauer et al., 2013). IoT ARM could be considered as a mature and well-defined reference model that provides a common structure and guidelines to deal with the core aspects of developing, using and analysing IoT systems. However, the emphasis is laid on service and thing (device) modeling. Some research works have adopted this reference model in order to design and analyze IoT applications. For example, a SysML profile was proposed in (Costa et al., 2016) to be used by IoT application engineers where a verification of QoS properties is presented. This work itself was followed by (Hussein et al., 2017) to propose model driven development adaptive IoT systems.

Towards an open architecture, authors in (Vogel and Gkouskos, 2017) pointed out some design principles (flexibility, customizability, and extensibility) that should be taken into account in order to control and guarantee the system evolution over time.

The trend in IoT architecting is highly directed towards service modeling. However, we are facing new paradigm such as *aaT (Everything-as-a-Thing) (Maamar et al., 2018) or IoE. In our work, we are interested in a "four-oriented" architecture for IoE. In the next section, we explore CPS. Then, we define our proposed CPS modeling language to build upon ideas from some related works.

2.2 Cyber Physical Systems (CPS)

CPS are defined as transformative technologies for managing interconnected systems between its physical assets and computational capabilities (Baheti and Gill, 2011). They monitor, analyse and control the physical processes and act accordingly. They are considered as System of Systems (SoS).

So far, architecting CPS is still in its enfancy. There are presently no standardized or reference models for such a system. But, SA is currently gaining important attention of researchers. Looking through the last 5-years proceedings of the most recognised conference on Software Architecture (ECSA (European conference on Software Architecture), ICSA (International Conference on Software Architecure), Models (International Conference on Model Driven Engineering Languages and Systems), etc.) has allowed us to select a small number of interesting works gathering both SA and CPS modeling.

For instance, (Muccini and Sharaf, 2017) propose CAPS architecture framework for modeling and simulation of situational-aware CPS which deals with different architectural views of CPS in order to model the software, hardware and physical space views. These three proposed modeling views are linked by two auxiliary views. Modeling the hardware as well as the physical space is a low-level specification of the concepts we may find in the IoT environment models. The structural aspect in CAPS SA could also be considered in this way. The Behavioral aspect is globally defined as a set of actions and events which are highly related to the domain model application.

A proposed framework was also published in (Group et al., 2016) in order to develop a CPS analysis methodology and vocabulary to describe it. One of the various addressed issues mentioned by the authors was data exchange that is considered as a prominent dimension of a CPS operation. In a recent study (Kirchhof et al., 2020), further related works on modeling CPS are also presented (e.g ThingML, MontiArc).

The difference between IoT and CPS is conspicuously clear now. The former is highly linked to environmental issues (hard devices, networking, etc) as a paradigm. The latter concerns systems in a software and digital level (digital twins (Kirchhof et al., 2020),computational capabilities, control, decision-making). Yet, both subjects are thoroughly connected in order to construct a smarter world.

Figure 1 shows the borders among this plethora of concepts in the composition of CPS.

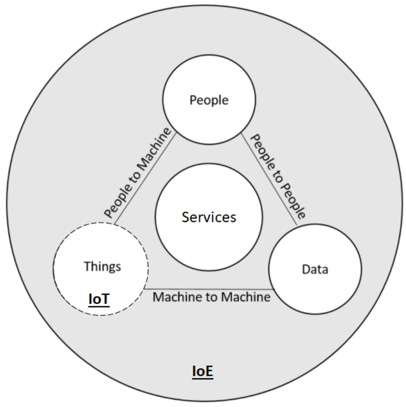

Figure 1: Main components of Cyber Physical Systems (revised from (de Amorim Silva and Braga, 2018)).

2.3 Educational Connected Environments

As far as connected environments are concerned, many research works have had the interest of the added values of IoT in education. Related works about educational modeling languages are presented later in this paper. Several value propositions (Bagheri and Movahed, 2016) are empowering, directly or not, students' achievements. Interesting efforts have been conducted to improve the educational ecosystem based on this paradigm. We classify them according to the way IoT are used. We opt for the following classification :

- Learning/Teaching **of** Internet of Things: this classification concerns the teaching and learning of IoT as a learning subject. The aim is to teach/learn the different core knowledge of the subject like in (Sackey et al., 2017). Education 4.0 could be classified in this type of IoT use. It focuses on teaching/learning IoT to prepare future professionals who will have the required competences and skills of the subject and then will be able to work on an IoT equipped environment like Industry 4.0.
- Learning/Teaching **by** Internet of Things: this classification concerns the use of Internet of Things as an artifact to acquire other knowledge. (Yuqiao and Kanhua, 2016) is an example of research works which focus on such an aspect. Experiment based Learning is one of the conducted pedagogies that could be viewed as a way to serve knowledge through the bias of smart object manipulation.
- Learning/Teaching **based on** Internet of Things: This perspective is addressed in some research works regarding the monitoring of students'

healthcare or in classroom access control, like in (Palma et al., 2014). Learning analytic techniques are adopted as a means to provide feedback to the different stakeholders.

- Another category could be drawn according to further uses of IoT in the educational context, which are not directly linked to learning and teaching. These applications focus on energy management, enhancing safety, improving comfort, etc. (Bagheri and Movahed, 2016).

According to this classification, we consider that there is still a great deal of work to do in order to directly improve educational processes **based on** IoT. Modeling an educational connected environment is still needed. We thus adopt the positioning of our work on the third categorisation of IoT application (Learning/teaching **based on** IoT). This does not exclude the possible association with the other purposes of IoT applications.

3 EDUCATIONAL CYBER PHYSICAL SYSTEMS

3.1 Definition

Domains and applications of CPS were identified in previous studied works (robotics domain, electric vehicles, supervisory system, federal embedded system, sensor and actuator network, and smart grid). We thus consider that such an educational application could also be viewed as a supervisory system aiming at gathering real-time data from connected educational systems in order to constantly monitor and make decisions about not only the adaptation of curriculum for students but also other educational oriented decisions.

We define what we call Educational Cyber Physical Systems (ECPS) as Cyber Physical Systems applied to the world of Education. An ECPS is a set of objects, services, data and humans, that collaborate to carry out a teaching and learning scenario in a short/medium/long term context (Classroom, Course, and Curriculum). For the best of our knowledge, Educational Cyber Physical System are not yet emerging in the scientific community.

We consider that ECPS consists in the instructional design to occur in a connected environment gathering learners, teachers, admin, learning object (physical and virtual), technological object, data, etc in order to collect, analyse data and make decision according to the learning and teaching context, in other words, educational purpose in IoE environment. Based on (Lee et al., 2015), we published, in a previous work, a generic architecture of ECPS (Bachir et al., 2019). In this paper, we detail the modeling of pedagogical situations in IoE environment.

3.2 Method

(Costa et al., 2016) identified some design challenges related to IoT system. We believe that they remain the same for IoE system. They concern (i) the heterogeneity of hardware devices and software components; (ii) the lack of mechanisms to address multiple stakeholders' concerns; and, (iii) lack of a method to design IoT applications. In our work, we provide a method for the design ECPS. As stated in (Ramsin and Paige, 2008) and according to the (OMG, 2000), a method, in software engineering, consists of : (1) a modeling language : a set of modeling conventions (syntax and semantics); and (2) a process.

Our aim is to propose a method to define and model ECPS based on MDE. MDE is a software development method that uses its core models not only as inputs but also as outputs in order to reduce the gap between problem domain and solution domain. It is more general than the set of standards and practices recommended by the OMG's MDA proposal (Kurtev et al., 2006). It handles separation and combination of various kinds of concerns (such as platform models and code generation) in software engineering in order to bridge the gap between design and implementation.

Domain Specific Languages (DSLs) are the complementary part of MDE which is considered as the main means to define models. DSLs are languages tailored for a specific application domain. In contrast to general-purpose languages, they offer substantial gains in expressiveness and ease of use (Mernik et al., 2005). We will also define DSLs to explore their different parts (concrete syntax, abstract syntax, and semantics) and benefit from model generation features.

We adopt the classical "Y development cycle" from MDA as the process of our method, as illustrated in Figure 2. The objective of this process, according to (Bézivin, 2005), is to enable the generation of Platform Specific Models (PSMs) from Platform Independent Models (PIMs) (specific to the business model) and Platform Description Models (PDMs).

Aiming a higher flexibility, the goal is also to produce software assets that are resilient to changes in technologies. MDA stresses on the importance of PIMs since they are supposed to survive the constant changes in software technologies that are transformed into new PSMs (Kurtev et al., 2006). In contrast, PDM are highly linked to the kind of platforms (connected in our case). In an educational purpose, we

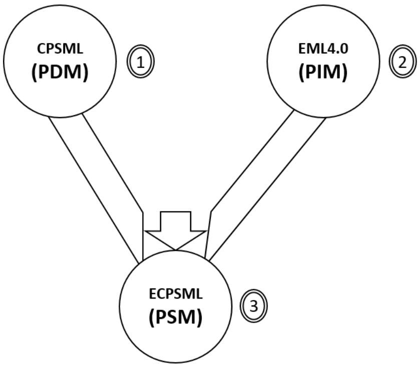

Figure 2: Modeling process.

can deploy the same pedagogical scenario in different platforms (something we have noticed during lockdowns). In this case, the Y development cycle is a real advantage, allowing us to redefine only the PDM model, with no change in the educational one (PIM). Furthermore, several pedagogical situations can be modeled in the same environment, only by changing the PIM model.

In this section, we present different meta models according to these different perspectives. In the interest of simplicity, the concepts are depicted without cardinalities. Examples will be provided for further elucidation of the proposed models.

3.3 CPSML

We begin by presenting the PDM perspective as mentioned in Figure 2 (1). We propose a specific modeling language, called CPSML (Cyber Physical System Modeling Language) in order to design a connected environment regardless the domain model. CPSML is a SysML profile. According to OMG, SysML is a general-purpose modeling language for systems engineering. In turn, it is considered as a UML profile where the former (e.g Block diagram) is an extended customization of the latter (Class diagram).

SysML is a highly referenced modeling language among the scientific community. It handles both structural and behavioral perspectives in the modeling of specific system features. It has proved its efficiency and re-usability. CPS is a system of systems where the components within a system interact between each other or with other systems. So it is crucial that our proposal takes into account both view points.

We extend the block diagram by specifying the *block* concept through different stereotypes, as specified in Figure 3. According to OMG, *blocks are modular units of system description. Each block defines a collection of features to describe a system or other element of interest*. A stereotype is a generalization or specification of a predefined metaclass. To do so, we implemented our CPSML profile, in the Papyrus modeling tool, in order to customize SysML in the Eclipse Modeling Framework (EMF). The idea is to allow the designer to specify the nature of the used blocks (object, service, human, data) which refer to the main components of CPS illustrated in Figure 1, thus representing all the aspects in a connected environment. For instance, in an educational context, the proposed stereotypes are:

- ”*Human*” refers to the students, teachers, administrators or other stakeholders who are involved in the learning/teaching processes. This knowledge about user profile is essential to create personal and professional linkages by incentivizing collaboration and cooperation. As it is stated, people themselves will become nodes on the Internet, with both static information and a constantly emitting activity system.
- ”*Object*” refers not only to physical devices that can establish connection with the Internet and utilize sensors to capture environment information (as it is presented in (de Amorim Silva and Braga, 2018)) or actuators to act on the environment, but also to smart learning resources that can establish connection with the Internet (e.g computer, telepresence-robot, etc.).
- ”*Service*” refers to how people and objects must interact to generate data that can be transformed into usable knowledge through service invocation. According to (Fortino et al., 2017), each IoT Service is designed as a composition of the Service Model (details about attributes and relationships describing the IoT Service itself) and the Service Profile (details about the process implementing the service).
- ”*Data*” refers to all the different data flows coming from the different elements of the connected system. Cloud computing and learning analytics are examples of technologies for data management and its transformation into information. Data could be a structured, semi-structured, or non-structured in a connected environment.

Likewise, we extend the activity diagram to add Autonomic Computing (AC) (IBM, 2006) features and specify action types regarding CPS control, analysis and computational capabilities. AC covers different aspects of self-management that implement MAPE control loops (Monitor, Analyse, Plan and Execute) which collect details from the system and act accordingly. More precisely, we extend the *Action* concept (which represents the behavior of the system) in SysML by adding both *Analyzing Action* and *Monitoring Action* stereotypes. We believe that they play

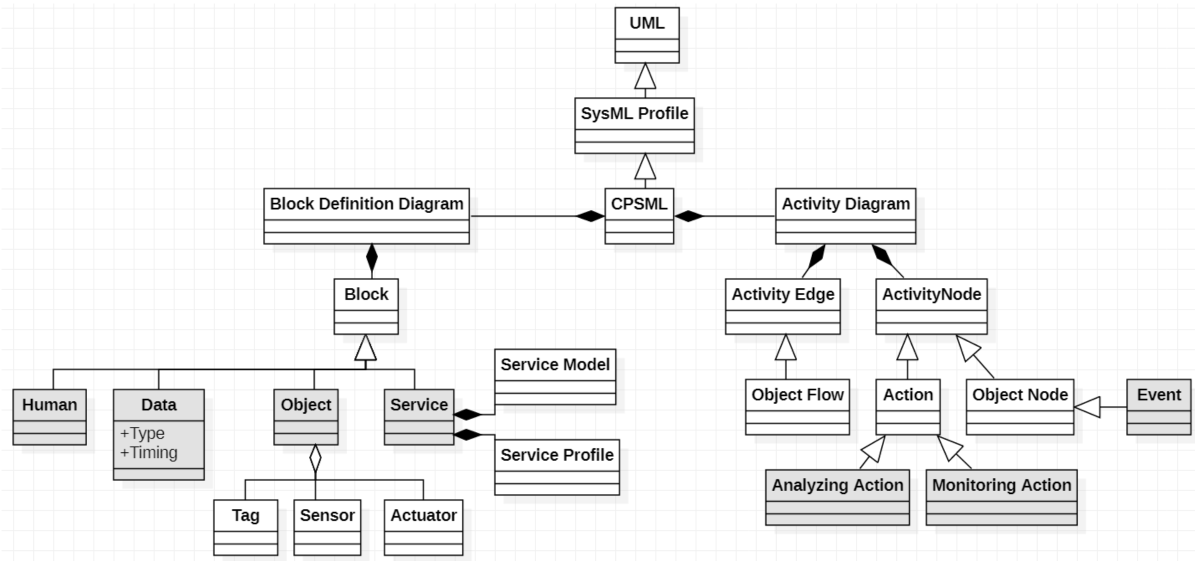

Figure 3: CPS Modeling Language.

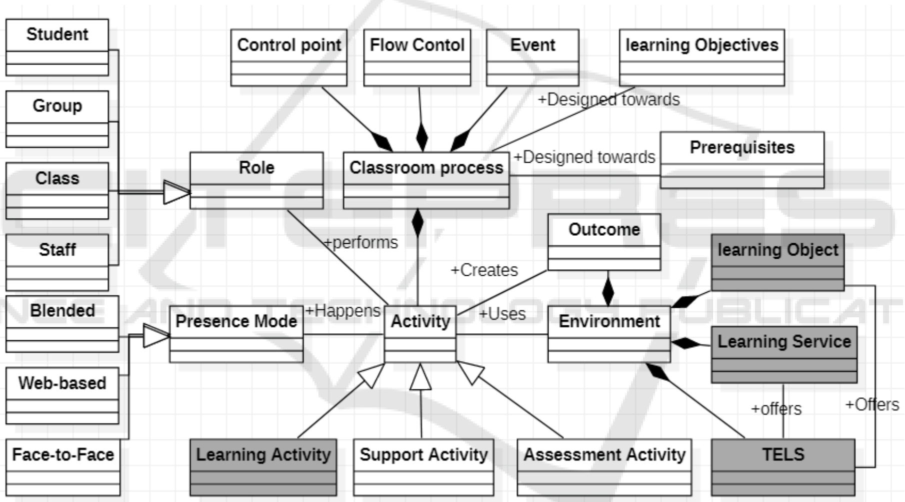

Figure 4: Educational Modeling Language for University 4.0.

an important role throughout the design process of the connected environment such as to represent the autonomic properties of the CPS. Other types of actions like 'decision-making' could be simply designed as *Action* with the SysML concept. In such systems, we also deal with events. For this purpose, it is also important to explicitly model them. In CPSML, Event is modeled as a stereotype of the *Object Node*.

3.4 EML4.0

In the literature, modeling education has taken several dimensions. Various research works have been conducted since the early 2000s especially with the emergence of online learning via, for instance, Moodle platforms. One may consider an educational modeling language according to a particular perspective. There are some research works that design learning through Activity Modeling Language (e.g. E2ML (Botturi, 2003), ColeML (Martel et al., 2006)). Others design learning through Content Structuring Language (e.g. PoEML (Caeiro-Rodríguez, 2008), (SCORM, 2003)). Some others focus on both perspectives, Activity and Content Structuring Languages, (e.g. IMS LD (Koper and Olivier, 2004), CoUML (Derntl and Motschnig-Pitrik, 2008)). Furthermore, there are modeling languages which concern rather evaluation modeling (e.g (QTI, 2005)).

In our work, we build upon ideas from Activity and Content Structuring Language, in order to ensure

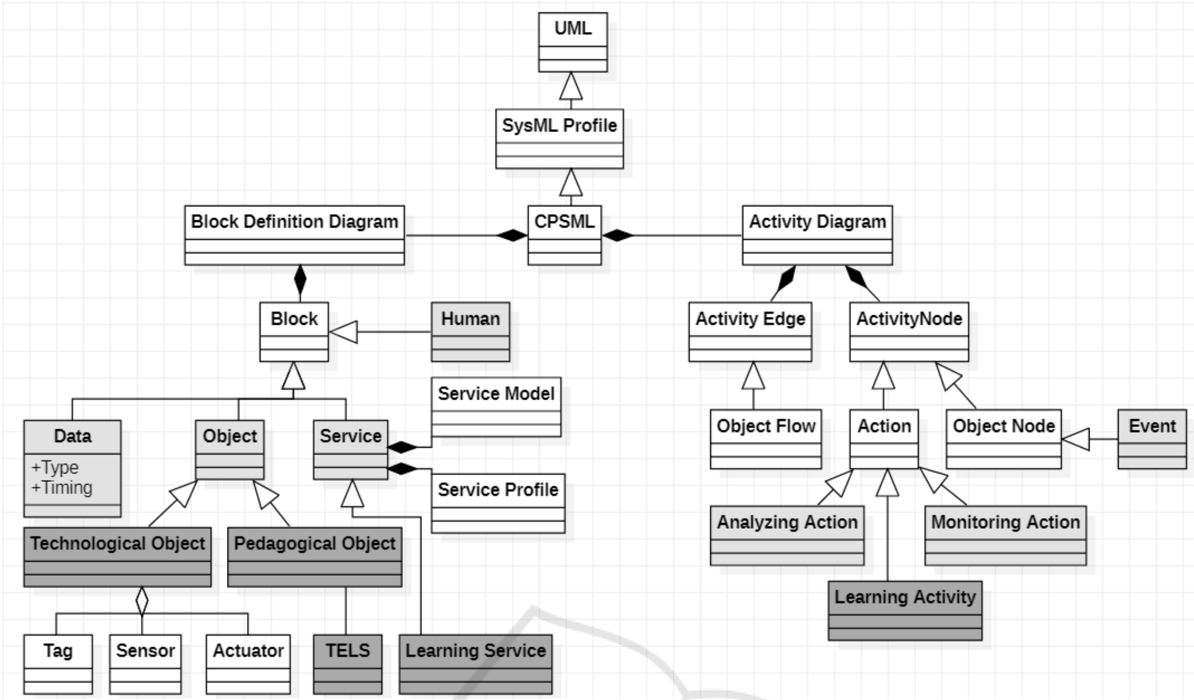

Figure 5: ECPS Modeling Language.

both structural and behavioral aspects of educational modeling in a learning process. For this purpose, we adopt IMS-LD (Instructional Modeling System - Learning Design) as it is an IMS standard. As presented in Figure 4, we extend IMS-LD with further concepts. Some of the latters are inspired from (Ruiz et al., 2018) regarding presence mode and user role in a learning activity. We also upgrade the ”Environment” concept in order to support any type of *TELS* (ITS, MOOC, Moodle, CSCL, etc.).

EML4.0 corresponds to (2) in Figure 2. IMS-LD is a specification implementation based on an XML Schema. To the best of our knowledge, there is no standardised tool for it. Many attemps have been conducted in order to offer a required tool to design learning according to the IMS specification. But, they are not open-source and cannot support extensions. As we are in a model driven approach implemented with EMF, we realized an EML4.0 modeling tool from scratch in this framework.

3.5 ECPSML

In our research, we adopt a MDE method in order to design ECPS. The latter is defined and build based on both CPS and EML4.0 meta models. We propose ECPS as a SysML profile too, as shown in Figure 5. ECPS integrates structural concepts coming from both CPS and pedagogical meta-models. For

```
-- @path CPSMM=/CPSML_v2/model.profile.di
-- @path EMLMM=/ECPS-v2/MetaMordels/EML4_MetaModel.ecore
-- @path ECPSMM=/ECPS-profile/model.profile.di

module MyRules;
create OUT : ECPSMM from IN : CPSMM, IN1 : EMLMM;
rule Obj2tObj {
    from
        s1 : CPSMM!Object
    to
        t : ECPSMM!TechnologicalObject (
            name <- s1.name
            )
}
rule Obj2pObj {
    from
        s11 : EMLMM!LearningObject
    to
        t1 : ECPSMM!PedagogicalObject (
            name <- s11.name

        )
}
```

Figure 6: ATL transformation rules.

instance, Object could be either technological (from (1)) or pedagogical (from (2)). From a behavioral perspective, learning activity is a type of action in a SysML profile.

The generation of our ECPS model will be automatically handled by the ATL module. ATL is a model transformation language (Allilaire and Idrissi, 2004). It is integrated in EMF which, in addition to its modeling framework features, provides facility model generation building tools and other applications based on the different XMI (XML Metadata Interchange) models.

Rules are the heart of ATL transformations.

They describe how output elements (ECPS) are produced from input elements based on the input meta-model(s). Input models could be multiple which is the case of this work (CPSML, EML4.0). Each rule expresses a mapping between a multiple input element and an output element. Figure 6 presents parts of our ATL rules.

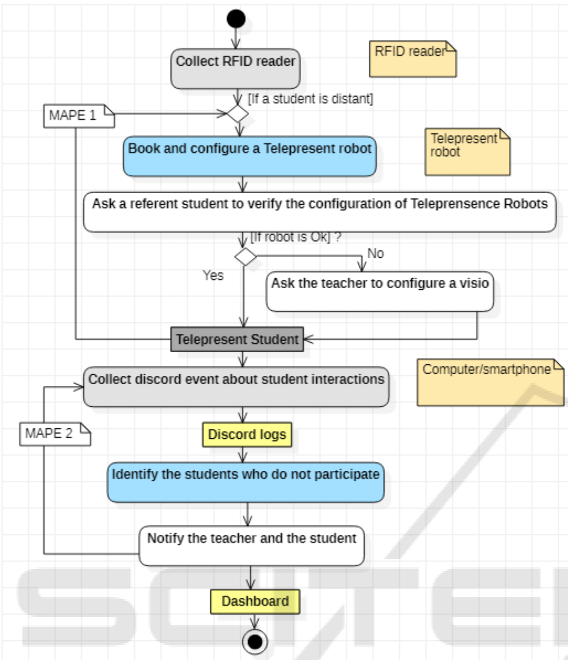

Figure 7: Parts of the CPS model elements within a connected learning environment (Monitoring Action (light grey), Analyzing Action (blue), Object (orange)), Data (yellow), Human (dark grey), other activities regarding decision making (white)).

4 CASE STUDY

The aim of this section is not to represent a full study case, but rather to illustrate the generation of the ECPS model from both CPS and EML4.0 models through transformation rules. Also, due to limited space, the above will be simply presented through activity diagrams illustrating the different elements. The case study was implemented and tested in EMF by defining input models as dynamic instances.

We present both structured and behavioral aspects of the different scenarios inspired from observations conducted during the first lockdown (March - April 2020) at our university with bachelor students, in a ”Cyber Security initiation” subject, in order to collect and analyse their logs. In the CPS model, monitoring and analyzing activities are highlighted (Figure 7). Two control loops (MAPE) were implemented, each of which is linked to some parts of the pedagogical scenario presented in the Figure 8.

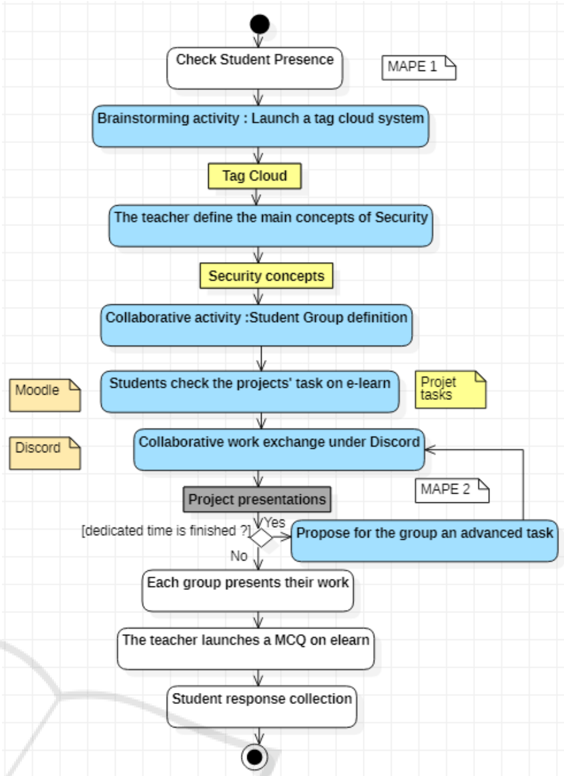

Figure 8: Parts of the EML4.0 model elements within a learning scenario (Learning Activity (blue), Learning Object (yellow), Outcome (dark grey), TELS (orange),other activities regarding the pedagogical scenario (white)).

The first MAPE control loop aims at configuring the CPS by detecting the telepresent students and deploying a telepresent robot or a visio in order to ensure their involvement. The presence of the other students is controlled by reading their student card with the RFID reader. The second one monitors the CPS during the collaborative activity, by collecting and analyzing students discord logs. Time was noted between both control loops.

Regarding this, we focus on the domain model scenario of some learning activities of the ”Cyber Security” knowledge-to-be-taught. This example is built upon teaching strategies adopted during the lockdown. Figure 8 presents the pedagogical scenario which starts by checking students’ presence (handled by the MAPE 1). Then a brainstorming activity is followed in order to introduce ”Cyber Security” concepts for students. After this, the students are asked to work collaboratively on different projects (handled by the MAPE 2) to finally present them and move to an evaluation activity.

Figure 10 shows the ECPS model, obtained by fusioning the two previous models, using the transfor-

ECPS-Model-E...

```
<?xml version="1.0" encoding="ISO-8859-1"?>
<xmi:XMI xmi:version="2.0"
    xmlns:xmi="http://www.omg.org/XMI"
     xmlns:ecps="http:///ecps.ecore">
  <ecps:TechnologicalObject name="Telepresent Robot"/>
  <ecps:TechnologicalObject name="RFID reader"/>
  <ecps:TechnologicalObject name="Computer"/>
  <ecps:TechnologicalObject name="Smartphone"/>
  <ecps:PedagogicalObject name="Tag cloud"/>
  <ecps:PedagogicalObject name="Security concepts"/>
  <ecps:PedagogicalObject name="Project tasks"/>
  <ecps:PedagogicalObject name="Project presentations"/>
</xmi:XMI>
```

Figure 9: Parts of the ECPS model generated through the transformation rules given in Figure 6.

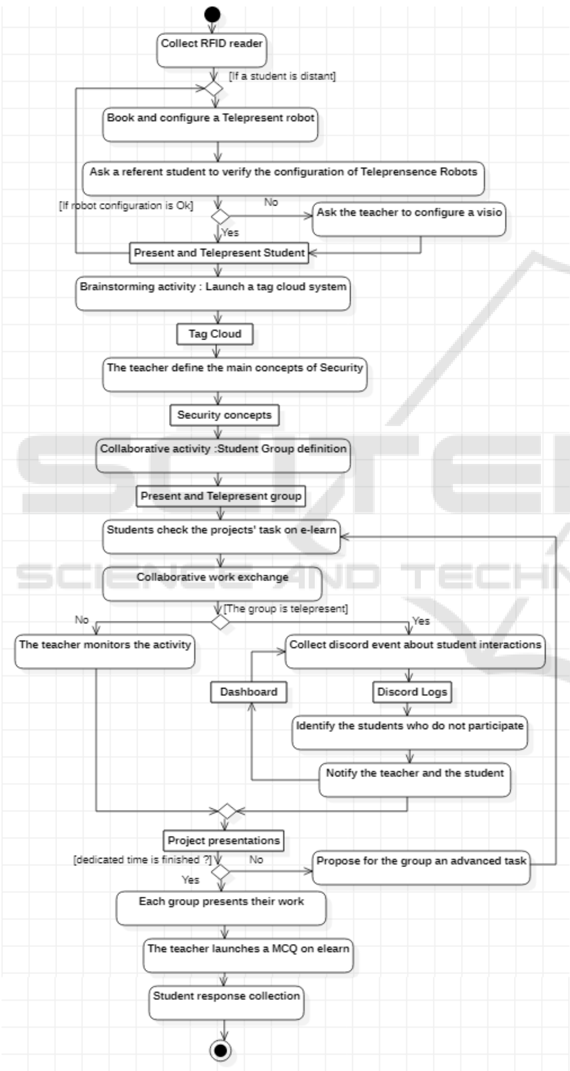

Figure 10: ECPS model.

mation rules described previously. A part of the XMI generated model is showed in Figure 9 where technological objects are taken from the CPSML model and pedagogical ones from EML4.0 model.

5 CONCLUSIONS

The objective of this paper is to introduce a model-based engineering methodology for Educational Cyber Physical Systems, focusing on the design phase, which aims to help educators to develop IoE applications to fully achieve the benefits of this new paradigm in teaching and learning. The approach comprises a method and three modeling tools, which are aligned with proven concepts from system engineering and software architecture literature. Our proposal ensures reusability of the proposed modeling languages (CPSML, EML4.0, ECPSML). They are languages tailored for a specific application domain. They offer substantial gains in expressiveness, ease of use and benefit from model generation features. Our first perspective is to test the genericity of our method by changing the educational model and dealing with the same CPS model and vice-versa. Therefore, we could validate the fact of acting on either PIM or PDM in order to generate the required educational environment. Still, our second perspective is to adapt this method to model other environments (smart grid, smart building, medical environment, etc.). Our aim is also to study another case in an other domain, in order to generate the required model by acting on the domain model and transformation rules.

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