# Predictive Analytical Framework based on Formal Method to Enhance Mobile and Pervasive Learning Experience

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Abstract: In this paper, we present a predictive analytical framework for mobile and ubiquitous learning environment based on three main dimensions: learner, contextualized activity and space. The main objective of this proposal is to assist pedagogical designer in developing engaging and effective courses by focusing on the learner's experience and his learning environment. To do that, a solid structure is essential to organize correlations between different activities and to assess their reliability with the learner's context. The strengths of our proposal lie in the fact that, in a formal manner through friendly graphical interfaces, it allows pedagogical designers:(1) to specify, model, simulate, analyse and verify different types of context-aware and adaptive learning activities and their related contexts, (2) to assess the reliability of the indoor and outdoor learning spaces within pervasive environment through factual cases and to experiment various learning scenarios, (3) To simulate and to verify interactions and co- adaptability rules between learner, contextualized activity and space.

## 1 INTRODUCTION

Mobile and ubiquitous technologies have emerged as facilitators in learning process, both in formal and informal educational contexts, offering new ways to access and use learning resources and drawing the mobile learning features. These technologies, combined with cloud services, foster learner interactions based on access to rich content across locations and any times using portable equipments (such as wireless laptops, personal digital assistants and smart-phone) which, in turn, might enable new self-regulated learning experiences (Moser, 2017). Then, students are oftenly asked to use their life experiences to make meaning of material introduced in classes (Kuh, 1996) and the question is not whether mobile devices are suitable as learning tools or not, but "*How can we improve learners' experience in mobile learning context?*"

With the emergence of adaptive mobile and ubiquitous learning environment and the improvement of teaching methodology, straightforward mediums are evolving into wealthy and interesting learning experiences. But in the other hand, learning scenario design gains importance and complexity and it becomes a complex process (Clark and Mayer, 2016).

While an authoring tool is useful and necessary, there is a real temptation to start using it straight away, before a clear idea of content and structure has been developed. However, once the scenario is broken up into its separate activities in the authoring tool, it is difficult to analyse the correlation between these brick and its convenience with the deployment's context. If the scenario has not been well-analysed at early stage, the learning environment could be inadequate and it does not tie to the pedagogical outcomes. Consequently, learners could find difficult to navigate through. Without an analytical framework, designing mobile and context-aware lesson become a complex process and focus on pedagogical objectives rather than the learning experience (Westera, 2011). In this sense, we introduce an analytical framework for mobile and context-aware learning scenario based on formal methods and consider three main dimensions: learner, contextualized activity and space. The strengths of our proposal lie in the fact that, in a formal manner through friendly graphical interfaces, it allows designers to analyse and assess the reliability of adaptive mobile learning activities at early stage.

This paper is organized as follows. In section 2, we are going to present some context-aware learning challenges that should be considered in order to enhance mobile learning experience. Section 3 describes key dimensions and features of our analysis fra-



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mework. We outline how this abstract definition of different learning scenario's components can improve our understanding and the current design practice. Section 4 focuses on our conceptual architecture definition while its supporting tools and modules tests are described in section 5. Section 6 concludes this article with perspective and future works.

# 2 MOBILE LEARNING CHALLENGES

The relevant literature identified different requirements and several technologies prerequisites for quality of mobile and ubiquitous learning.

From pedagogical point of view, the m-learning scenario should have clearly explicit pedagogical design principals with high interactivity appropriate to learner preference, needs and context which enables his mutual feedback with tutor and assists him in the identification of knowledge gaps.

The purely pedagogical aspects of quality in m-learning system are certainly important, but coupled with equally important technical aspect of quality. In fact, digital devices play an important role. Among these technologies, mobiles devices (laptops, smartphones, tablets, etc) are crucial for learning in mobile and context aware learning environment. They should fulfill several criteria, at least to a certain degree. These include mobility, accessibility, convenience, interactivity, study auxiliary, scalability and application costs (Moser, 2017).

M-learning technologies that are reliable, technically flexible and contain available resources are those are most likely to be successful. In this context, there are a number of aspects of M-learning quality that can be assessed from a technical perspective. Mobile learning scenario are tiny closed to several location-based services in order to enable learner to interact with real-life objects and surrounding computing node. Therefore, location-based applications and environments allow learners to transcend the boundaries of mobile devices.

A significant aspect of mobility is quality of service in terms of the reliability and speed of wireless connections. Although some learning content can be downloaded to a mobile device and used locally, the limitations on storage mean that network connectivity is an essential component of most mobile learning environments. The reliability and speed of such connections can influence which media types can be used in an M-learning system, for example video streaming is only feasible over a high speed connection.

Another technical aspect of M-learning quality is the limitation of energy and battery consumption on many mobile devices, with certain mobile device operating systems and software platforms supporting different types of display.For instance, communication, collaboration and interactivity issues can be affected by more than one of the learning contexts community, facilities, time and location activity and learner. Thus, we conclude that a quality technical assessment for M-learning environment should be encompass both functional and contextual aspects.

From learning experience (LX) designing point of view, the LX designer has complicated, challenging and versatile responsibilities with several duties that mostly concerns the improvement and adaptation of learning scenario to the development of digital technology. Based on user experiences theories, learner experience design is an iterative process that combines several activities such as: (a)Content and planning designing, (b) prototyping and Testing further improvements and development, and (c) Execution and Analytic (Davidson-Shivers et al., 2018).

Because the focus of learning is no longer on the simple acquisition of information but rather on actively interacting with the current context that encompass the information, the challenge of the learning experience design is to establish a connection between business aims and user's needs and expectations by testing and understanding the specifications of both sides in the process.

# 3 KEY DIMENSIONS FOR OUR PREDICTIVE ANALYTICAL FRAMEWORK

Our starting point has been a previous mobile learning assessment position that there are two dimensions to take into account in modelling and evaluating pervasive learning scenarios: Learner and learning scenario and their contexts (BenSassi et al., 2014). We propose in this work to widen the initial approach and to take into account Space as a key dimension in the mobile environment engineering, and not only as a contextual element related to learner. Our Framework leads us to consider mobile and pervasive learning systems in terms of three key dimensions: Learner, Learning scenario and Space.

The essence of our approach to the learning evaluation approach is the effective integration of space, by allowing teachers and pedagogical designers to assess the reliability of educational mobile application and its convenience to the physical space and to embed digital and smart components within it. Our approach

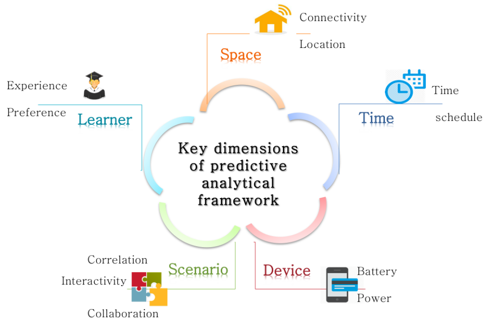


Figure 1: Key Dimensions of our predictive analytical Framework ReStart-Me.

has the potential of being a scenario driven analytical framework for the engineering and re-engineering of mobile and pervasive learning systems.
This framework models all possible interactions and constraints between Learner, Scenario and Space because they influence each others in learning processes. Three types of technology- driven interaction are evaluated (see fig. 1) (1) Learner-Space Interaction (2) Scenario-Space Interaction (3) Scenario-Learner Interaction. The question arises how to analyse, to evaluate and to assess the reliability of the conceived learning scenario at early stage in order to enhance learner's experience with mobile environment. Based on the quality aspects of Mobile Active learning research previously outlined, we have developed an analytical framework, named ReStart-Me, for M-learning based on a combination of design issues, dimensions of learning context and criteria. We consider that these features, described below, should be considered in the analysis process:

- **Time Constraint:** The time in the predictive analytical framework points out two aspects: the date elements (begin and duration) and the learning progress. Some of the learning resources are with date-duration constraint, which means accessing the learning contents and activities depends on when they are available. For example, the contents in a remote laboratory or museum would be accessible only when these venues are open . On the other hand, learner's progress is considered as a time sensitive factor because it can be used as a constraint for providing up to date learning contents to the learner.
- **Space:**The location in our analytical framework indicates the learner's current geographic position. The global position system of the smart device (GPS) can be employed to sense the current site of the learner. Therefore, space based learning scenarios can be implemented to enhance the contextual interaction for learners. In this sense, a significant aspect of Space-mobility is quality of service in terms of the reliability and speed of wireless connections. Although some learning content can be downloaded to a mobile device and used locally, the limitations on storage mean that network connectivity is an essential component of most mobile learning environments. The reliability and speed of such connections can influence which media types can be used in an M-learning system, for example video streaming is only feasible over a high speed connection.
- **Device Constraint:** It refers to the learner's smart device that is used to manage the learning process. The device's features are also considered as a contextual constraint for the mobile learning compared with other computer assisted learning scenarios. In fact, smart devices are heterogeneous with multiple operating platforms. They, also, have different and limited user- device interaction capabilities (energy and battery consumption) (Tan and Kinshuk, 2009) with certain mobile device operating systems and software platforms supporting different types of display. A client software application needs to run on the smart device to access its native hardware and features and provides contextual information to the learning management system. Therefore, it is essential to provide an adapted format (text, interactive presentation, or video) of learning contents to the smart device in order to properly render the contents and to enhance the capability for the learner to interact with the learning scenarios.
- **Scenario Constraint:** The learning scenario include learning objects, learning activities, and leaning instruction. The learning scenario can be basic learning resources or smooth adaptive learning activities stored in the learning contents repository of the learning management system. The learning scenario can be designed and retrieved based on pedagogical objectives and outcomes. For instance, communication, collaboration and interactivity issues can be affected by more than one of the learning contexts community, facilities, time and location activity and learner. Thus, different learning activities and its correlation should be properly described and tagged so that they could be easily designed and retrieved by the adaptation mechanism.
- **Learner:** The learner is the main actor who plays learning activities through smart device in the contextual learning environment. The learner's information contains static and dynamic data mainly including the learner's learning progress, learning behaviours, and learning assessment re-

sults. The data is either manually entered into or automatically collected from the learning management system before or while the learner plays his/her learning activities in the pervasive environment.

All these aspects are equally important, as the learning activity has to be simultaneously pedagogically and technically sound.

# 4 ReStart-Me FRAMEWORK

## 4.1 Conceptual Framework

We have built a conceptual framework of learning environment analyse that structures different steps and assists designers in this process. ReStart-Me (Reengineering of the Educational Scenario based on Timed Automata and Tracks Treatment for Malleable Learning Environments) is a modular architecture that is based on two fundamental components :

- **Trace** is a tool-kit of post-evaluation process that helps designers to build for each actor his effective learning scenario by organizing its events and actions. Trace tool-kit incorporate two components: the first one ScanUp is a mobile application that captures different states of device's sensor. The second one is program daemon that collects the data from several databases and commits it to a uniformed and structured file. In order to do so, it needs (1) the Document type definition of the destination file (in which to commit the raw trace) (2) the Document type definition of the raw data file that describes its structure and its different fields. This file is used by the data decoder in order to reconstruct the learning scenario for each actor as it was when the trace started. Trace allows designers through a friendly graphical interface: (1) to configure a trace session and alter the retrieved events (2) to specify weather some data or events (fields) are eventually omitted (3) to set a range of IP address for data collection and treatment.
- **Evals** is a graphical tool-kit through which the designer can:(1) Create the formal model for each activity (specify the title, learning objectives, prerequisites and outcomes of learning scenario); (2) Model graphically the correlation between different activities(scenario structure). Thus designer should specify temporal cartography and space constraints; (3) Generate a contextualized Scenario Model as shown in figure 2.

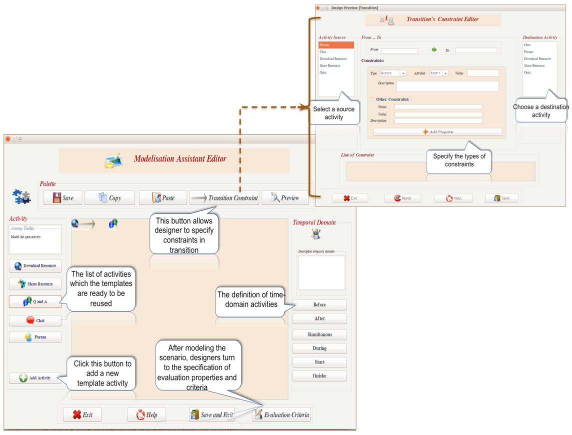


Figure 2: ReStart-Me interfaces.

## 4.2 Analysis Process

In this section, we present our proposed predictive analytical process ReStart-Me. It is a conceptual framework based on timed automata modelling and formal verification. The evaluation process contains essentially these three steps:

1. **Step 1:** Modelling M-learning scenario by selecting activities' template which are defined by Timed automata model expanded with global and local clocks, in the first step. By creating a formal specification, designers are guided to make and to define a detailed learning scenario analysis at early stage before its deployment into the mobile and pervasive learning environment. In the second step, designers had to specify temporal correlation between different activities and to describe contextual constraints that reflect the behaviours of different entities in and with the learning environment.
2. **Step 2:** Tracks simulation through which we can observe all possible interactions between corresponding to different entities involved in the learning scenario. This step generates simulated tracks that facilitate errors detection.
3. **Step 3:** Properties verification with formal verification through which we check the reliability of the designed learning scenario. This process aims to build a remedial scenario and to help designer in the re-engineering process by providing errors and warning reports. In the scope of our study, we tried to check the following properties:
   - *Deadlock* is a situation in which two or more active entities (for example students or groups) are each waiting for the other to finish, and thus neither ever does.

- *Live-lock* is similar to a deadlock, except that the states of the processes involved in the live-lock constantly change with regard to one another, none progressing
- *Starvation* describes a situation where a subgroup is unable to gain regular access to shared resources (for example helps of the coach) and is unable to make progress. This happens when shared resources are made unavailable for long periods by "greedy" actors. We want to be sure that each Subgroup will do his activity in time.

4. **Step 4**: Data collect and processing with Trace and Scan-Up tools in order to enrich the abstract model with different contextual value. This step is deployed when the learning scenario prototype is implemented.

This predictive analysis based on simulations helps designers to assess an evaluate the reliability of their designed learning scenario through the examination of possible dynamic executions. Thus, it provides an inexpensive mean of errors and fault detection that avoids costly and time- consuming scenarios deployment and ensures quality in scenario engineering to enhance learning experience.

### 4.3 From Framework to Reliability Analysis Tool: Evals

Having presented the component model and the tailoring platform, the question arises how to evaluate and assess the reliability of the conceived learning scenario at early stage in order to enhance learner's experience with mobile environment based on the key dimensions previously defined.
To go beyond the theoretical base and to operationalize the framework in a form that designers can readily use, we develop an analysis assistant tool ReStart-Me based on the model checker Uppaal (Bengtsson et al., 1996). To implement those extensions proposed we used:

- Domain specific modelling Eclipse Tools (EMF and GMF) for developing the graphical modeller;
- Template method pattern which is a behavioural design pattern that's let us define the skeleton of activity's model. At the same time, designers have the possibilities to redefine certain options without changing its global behaviours. In order to facilitate the modelling step, designers should:
  - *Select Activity*, in the first step. We have defined several model of activities: synchronous activity (for example chat), asynchronous activity (such as discussing in forum)...

```
method TemplateElementaryScenario() is
    selectActivity(){...};
    DefineIntraConstraint(){...};

method TemplateCompositeScenario() is
    ElementaryScenario(){...};
    DefineInterConstraint(){...};
```

Figure 3: Template Method for learning scenario modelling.

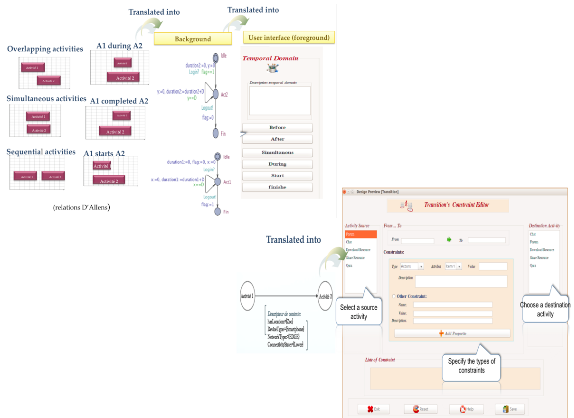


Figure 4: From theory to application tool.

  - *Define temporal correlation* intra-activity in the second step and the inter-activities in the last step of mlearning scenario modelling (see figure 4).

Our Design tool, in a formal manner through friendly graphical interfaces, allows pedagogical designers and teachers: (a) to specify, model formally, generate and simulate different types of context-aware and adaptive learning activities and their related contexts. (b) to evaluate indoor and outdoor spaces within pervasive environment (c) to simulate and to verify interactions rules between Learner, Contextualized Activity and Space.

## 5 CASE STUDY

### 5.1 Learning Scenario Description

The conceptual designers' meetings have produced a scenario design document that describes the sequencing of different activities and rules of the pervasive learning scenario. We used pervasive learning scenario models generated by the authoring tool *ContAct-Me* (Malek and Laroussi, 2011). To summarize, the learning scenario can be described as follows:
During a learning session of 4 hours, learners are instructed to carry out a proposed lesson that aims to consolidate collaborative and competitive works by enhancing interaction among them. To achieve this, the scenario is divided into two phases as a serious game. Each phase is composed of a set of activities to

Figure 5: Learners are working on Dinosaurs' scenario.

be performed sequentially.
In order to boost intra-group competition, students were divided in groups under the supervision of their coach and each group consisted of two pupils. The ultimate goal behind this clustering is to reinforce teamwork and collaboration within the individual subgroups and to make it a collaborative and challenging game that takes place in different locations. Each subgroup is equipped with a smart phone with a wireless internet connection. In the first phase, learners are divided into small groups. Additionally, each group is itself divided into two subgroups. The first subgroup collects information related to part of inquiry in zones 1 and 2. This trial enables pupils to learn through factual cases and to experiment various scenarios using social media and networks, pervasive and mobile technologies.
The physical setting of this trial is the scientific campus where a mobile and pervasive learning environment is developed for guiding pupils in their tours. This campus offers different learning activities in various disciplines: mathematical, ecological and historical activities. At the beginning of the first stage, the outdoor subgroup is localized by a localization sensor and a notification is sent to ask students to identify and take a photo of the QR-code stuck to the dinosaur. Instantly, a text adapted to the pupils' level and pictures that visualize and describe the activities to accomplish in the current stage is displayed on the screen of the smart phone (see fig. 5 ). After a pre-defined time, the subgroup will receive a stage-adapted quiz via automatic text message. Pupils need to write an answer using their smart phone and submit it. If the answer submitted by the group is not correct, the system sends an alert to the coach informing him/her that pupils need some support. The coach should send to them some hints.
In order to improve the coaching task, tutor decides that after three wrong attempts, the pupil is guided to start learning session by using his mobile device. The e-learning client allow the student to directly mash up widgets to create lesson structure and add powerful online test widgets, communication widget (chat, forum and personal messages), content scheduling widgets, communication tracking, announcements, content flows, cooperative content building widgets.
The pupil could drag from the widget repository and drops into the e-learning client UI all the widgets needed for providing video, audio and other multimedia content. The duration of the learning session depends on the intensity of the signal. Else, if the answer is correct the indoor subgroups will receive the list of activities of the second stage and will get joined by their corresponding outdoor subgroups that will hand over the picked plant samples.

## 5.2 Modelisation, Analysis and Evaluation

**Formal Modelisation.** Fig. 6 provide an overview of different automata modelled for the planned learning activities (outdoor activities, quiz, and lesson) and corresponding to student. We define a global variable ”clock named *Time* that gives idea about the duration of each activity. The timing constraints associated with locations are invariants. It gives a bound on how long these locations can be active. We also define other integer global variable *Power* to calculate the energy of battery of the smart-phone.
In order to facilitate the learning scenario analysis, we model each activity separately. The idea is to define templates for activities that are instantiated to have a simulation of the whole scenario. The motivation for the use of templates is that the understanding, the share and the reuse of different components of the learning scenario become easier. The whole scenario is modelled as a parallel composition of timed automata. An automaton may perform a transition separately or synchronise with another automaton (channel synchronisation) or it can be activated after a period of time through flags. Fig. 6 also shows a timed automaton modelling the behaviour of the Smart-phone. This device has several locations (or states):

1. *idle*: This initial state is activated when the smart-phone is switched on.
2. *InQuiz*: The learner is responding to the quiz's questions.
3. *Localisation*: This state is activated when the learner has to do his lesson. The smart-phone had to be connected to the given wireless network.
4. *LessonHigh*, *LessonMedium* and *LessonLow*: One of these three states is activated. The learner drags and drops into the elearning client UI all the widgets needed for providing video, audio and other multimedia content. We should note that *LessonLow* is undesirable state because technical studies demonstrate that in this zone, student couldn't download correctly the lesson.

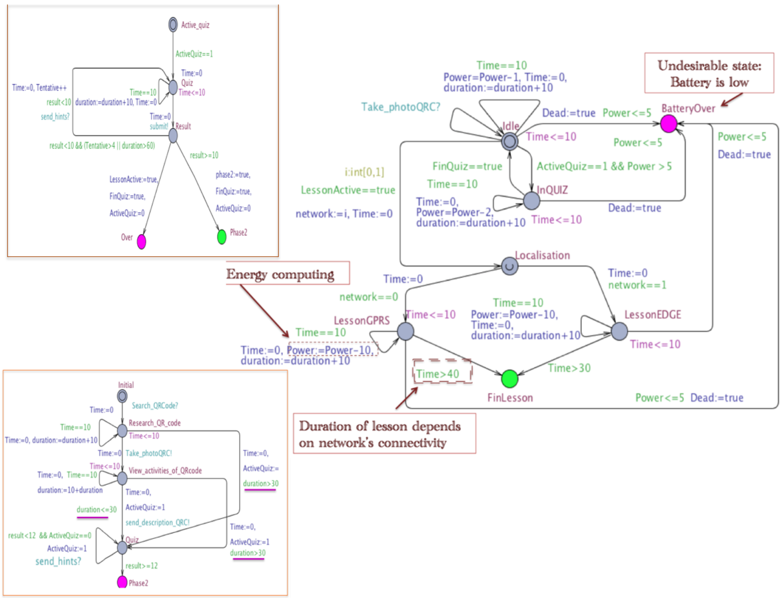


Figure 6: The automata model of different activities for one actor (Student).

5. *FinLesson*: The student has finished the lesson successfully.
6. *BatteryOver*: This undesirable State is activated when the smartphone is switched off because the battery state is over.

The dependability of the pervasive learning scenario heavily depends on several contextual constraints, especially the quality of the network connection and the energy provided by the mobile phone's battery. Based on studies introduced by (Perrucci et al., 2011), designers elaborate a technical report that shows values of power consumption of different activities that learners had to realize in the learning session. The power consumption is quite higher when student download lesson, and drop into the elearning client all widgets needed for providing video, son and representation.

**Simulation and Formal Verification:** Based on timed automata presented above, tracks simulations are generated visualizing all possible interactions between different actors. A screen dump of the simulation of the designed educational scenario is below (see Fig. 7). In order to help designers to improve their educational scenario and to obtain better outcomes, through the generated simulations, we try to localise design errors, to answer and to verify the following questions:

- *Does the description of the learning scenario clearly define time constraints for each activity and the whole scenario?*
- *Is there any situation of deadlocks, liveness or starvation?*

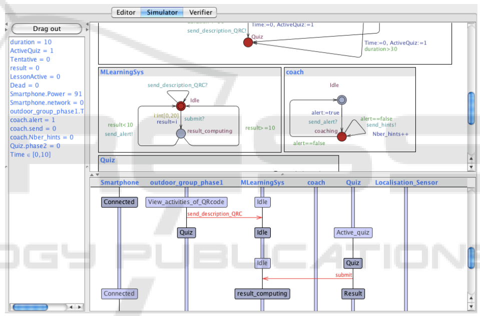

Figure 7: Simulation of the modelled Learning scenario.

Table 1: The simulation's parameters.

| Parameter | Value |
|---|---|
| Duration of the simulation | 240 units of time |
| Number of learners | 40 |
| Phone's energy | 100% |

We fix different parameters of the learning scenario's simulation as shown in tab. 1.

A first possible situation of deadlock is detected within tracks simulation of the whole scenario; In fact, students could have a period of inactivity especially when they begin their lesson in the lower quality zone where the network connectivity is lower and smart-phone's energy is limited. To check this property, we are based on reachability property that is considered as the simplest form of properties. We ask whether a given state formula, possibly can be satisfied by any reachable state. Another way of stating this is: **Does there exist a path starting at the initial state, such that "*the battery state*" is eventually over along that path?** We traduce this property in temporal logic formula: "**E** $<>$ **Smartphone.BatteryOver and duration** $< 240$" and this property is satisfied. A second possible situation of deadlock could happen when student starts lesson in the Lower zone. To check this property, we are again, based on reachability property: **Does there exist a path starting at the initial state, such that student couldn't finish the learning scenario successfully?"**. We traduce this property in temporal logic formula: "**E** $<>$**Smartphone.LessonLower and duration** $> 240$" and this property is verified. This experiment shows that 37% percent of students could be blocked at this stage. They couldn't progress in the lesson because the state of energy is low. Then, we conclude that dependability is not assured and we had to adapt mobile application to the learning environment's context (if the student is located in *Lower quality zone*, the mobile application had to reduce the energy's consumption by loading only the necessary widgets. Also, we propose to notify student whether the quality of signal doesn't allow to start learning session. Then, he should to move on.

# 6 CONCLUSION

ReStart-Me is a predictive analytical framework for mobile and pervasive learning scenarios. It aims at supporting pedagogical designers to assess reliability of their scenarios at an early stage through automata modelling, tracks simulations and properties verification. The proposed analysis process and supporting tools provide an inexpensive mean of errors and fault detection before starting implementation (thus returning on the learning scenario design phase to add missing elements and restraining development cost). Our contributions are three-folds as explained below. Firstly, we propose a framework to formally model and evaluate the system design and the environment inputs. Important key dimensions of mobile and pervasive computing systems such as contextual activities, actors and space interaction are discussed. Modelling patterns for these features are provided and illustrated with examples. Secondly, we identify critical properties of mobile and pervasive computing systems and provide their specification patterns in corresponding logics. According to the stakeholders (designers, engineers and users of these systems), reliability requirements are essential to pervasive computing systems. In our work, we classify the important requirements into reachability properties. Furthermore, formal specification patterns of these properties are proposed. We verify formal properties against the system model by using Uppaal model checker. Hence, design inconsistencies can be detected at the early design stage. Thirdly, to demonstrate our approach, we present a case study of applying the evaluation framework to mobile and pervasive learning environment. Finally, we will attempt in future works to deepen our proposal on learning scenario re-engineering process in such a way that a comparative report concerning different iterations of analysis can be generated automatically.

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