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Towards the Next Generation of Learning Environments:

An InterReality Learning Portal and Model

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***Abstract*— Advances in technology are enabling different and interesting ways of experiencing education outside the traditional classroom. For example using network technology it is possible for people to follow courses remotely via technologies such as eLearning, podcasts and 3D virtual learning environments. This paper describes research towards the integration of some cutting edge concepts, such as mixed reality, learning design, cloud learning and 3D environments that we have utilised to form a novel InterReality portal and associated pedagogical model. Our InterReality model applies Problem-based Learning (PBL) pedagogy, including co-creative learning, to the realization of a mixed reality laboratory environment for teaching embedded-computing and emerging computing applications such as the Internet-of-Things. Moreover our model proposes the use of learning design to structure the tasks and activities, their assignment to roles, and their workflow within a unit of learning (UoL) approach to allow a standardised learning activity construction, and re-use. The main contributions of this paper are the InterReality model and architecture and the supporting pedagogical analysis and rationale.**

Keywords- Mixed reality; intelligent learning; learning design; cloud learning; co-creative learning; constructionism; interreality portal.

I. Introduction

Learning is an innate characteristic of human beings that involves the processing and synthetizing of information into knowledge, behaviours and skills. In recent years and with the advance and integration of technology into our daily activities and lifestyles, new models of teaching and learning based on technology are becoming more popular. Learning has been transformed from traditional classroom-centred education to education based on, firstly, web-based resources (e-Learning) and later to mobile learning through portable devices (m-Learning). A different approach of the use of technology in education is Ubiquitous Learning (u-Learning).

One example is the University of Essex iClassroom[1] which is a purpose-built classroom provided with networked embedded devices/sensors and ambience intelligence (AmI) agents which is used as a test bed for pervasive computing research applied to education. The iClassroom also contains projectors, an interactive whiteboard, wall-mounted touch-screens, handheld/tablet/pad devices and multi-speaker audio all networked together thereby providing a complete multimedia interaction experience to support teaching and learning. By recognising occupants' presence, mood/emotion and activity at any time the iClassroom has the ability to adjust the classroom environment (both physical and pedagogical) according to the occupants' needs [1].

A different example is the use of mixed-reality by connecting elements of real world with elements in virtual worlds, a concept that is illustrated well by Milgram & Kishino's Reality-Virtuality Continuum [2]. Work on co-creative mixed reality models has been developed in projects such as University of Essex's MiRTLE project [3] [4], the Shanghai Jiao Tong University (SJTU) open eLearning platform [5] [6] and San Diego State University' work on Second Life education applications [7]. These approaches create virtual co-creative environments based on teacher/student interaction in classrooms regardless their physical location. In these, teachers and instructors use familiar tools such as presentation materials, whiteboards and display projectors simultaneously in real and virtual classroom. Real and virtual students are able to see all these tools and participate in the class or lecture via chat/audio/video tools.

Another approach is the use of Augmented Reality (AR) as a tool for education [8]. Augmented learning refers to on-demand learning that overlays virtual educational information on the real world based on context-aware systems that sense the learner's location and needs [9]. In these environments supplemental information is presented to the learner based on the current context using identification and location technology such as Global Positioning System (GPS), Quick Response (QR) codes for teaching diverse topics such as anatomy or languages [10] or animated intelligent tutors [6].

A diversity of resources may be available to support learning; however this process cannot be complete without establishing learning goals based on correct designs to ensure that the activities are properly structured with clear learning objectives. The design of these learning activities should be able to be performed by any teacher or trainer without the need to be technology experts and, independently of the subject of study or the environment where it will be performed. The subject of this paper is the development of such a model.

II. IMS Learning Design (LD)

The Instructional Management Systems (IMS) Global Learning Consortium proposed a specification used for the creation and planning of the activities to be performed by student(s) during a teaching session in order to achieve some goals regardless of the pedagogical methods utilised [11].

One benefit of this specification is the portability and reusability of the learning sessions. Figure 1 simplifies the model wherein the teaching staff create a sequence of activities

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using the services in the environment in order to accomplish the learning goals.

The structured sequences of activities are known as Units of Learning (UoL) and can be preceded by zero or more conditions before starting or completing the tasks. The learner is the person who performs this sequence of actions in order to fulfil one or more particular inter-related learning objectives.

Traditional implementations of this specification have been applied to eLearning through the use of Learning Management Systems (LMS) such as LAMS or CooperCore [12] [13]. Some research in the integration of UoL and 3D Virtual Learning Environments (3DVE) has been done recently [14]; however it is necessary to continue with the integration between these two technologies to generate re-usable UoL based on best practices and, especially from the viewpoint of this work, to encompass support for mixed-reality co-creative learning activities which form the focus of our inter-reality learning portal research.

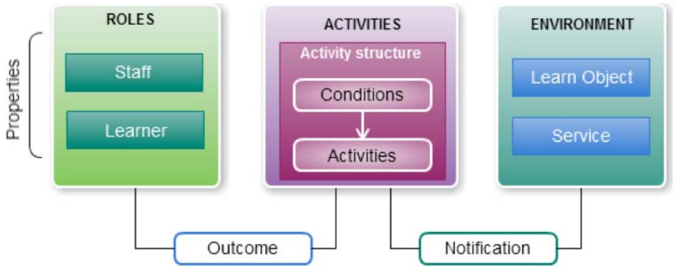

Figure 1. IMS Learning Design specification

III. INTELLIGENT LEARNING

Intelligent learning (iLearning) is an innovative paradigm of learning which promotes education on a context-aware environment able to offer ubiquitous personalized content. Kim et al. propose the addition of a cloud learning infrastructure to this model in order to allocate computing resources for iLearning systems [15].

Cloud computing is a model which allows on-demand access to massive computing resources by virtualization [16]. Some benefits of the services offered by cloud computing are:

- Capability to allow dynamic allocation of physical resources according to the necessities of the user (elasticity).
- High availability of services and data allowing customers to use the resources at any time.
- Lower-cost infrastructure and cost reduction in technology and maintenance.
- Multi-tenancy use of resources.
- Services can be accessed regardless of the physical location of the user.

Based on these benefits some models have been proposed to apply this to the entire learning ecosystem [17] [18] including the management of users and school resources, security policies, etc. Our work focuses in the application of these concepts to the educational process of providing and acquiring knowledge. Thus some benefits of cloud computing applied to learning are: 1) the possibility to store, share and adapt resources within the cloud, 2) increased mobility and accessibility 3) and the capacity to keep a unified track of learning progresses, 4) the use of resources such as synchronous sharing and asynchronous storage allows the model to be available at any moment that the student requires [15] [19] .

A. *A Mixed Reality iLearning model*

Papert et al. defined two approaches on the transmission of knowledge: instructionism and constructionism. Instructionism refers to traditional classroom-based education where the knowledge is transmitted from teacher to student based on isomorphic concepts [20] [21]. The second theory explores the acquisition of knowledge generated by the interaction between personal experiences and ideas and relating them to active behaviour by constructing meaningful tangible objects in the real world [20].

Based on the characteristics of the iLearning paradigm and Papert's theories we suggest a conceptual architectural framework (Fig. 2) able to deliver personalised content enhanced with co-creative mixed reality activities that support the learning-by-doing vision of the constructionism approach. By this means the learner can benefit of the construction of their own knowledge by the correlation between concepts and authentic tasks performed in meaningful realistic settings, developing problem-solving skills. Problem-based Learning (PBL) is a constructionist student-centred pedagogy in which students work in co-creative problem solving and learning occurs as a side-effect of problem solving [22]. Our model applies PBL pedagogy, including co-creative learning [23], to the realization of virtual lab activities in a mixed reality immersive environment. Moreover we propose the creation of these co-creative mixed reality activities using learning design to structure the tasks and activities, their assignment to roles, and their workflow within a UoL to allow a standardised learning activity construction, and the sharing and re-using of these designs. Perhaps, somewhat surprisingly, our work can be seen as being part of the experientialism and enactivism pedagogy schools as our work emphasises the importance of interacting with tangible objects, rather than mathematical abstractions [24]. Centred on these theories our model is composed of the following parts:

1) *Authentication:* Allows the identification of the user in order to assign a specific role via the Profile Manager.

2) *3D Virtual Environment:* Is the user interface where the different learning processes will be performed. Allows for communication and collaboration between different roles.

3) *Context-Awareness Agent:* This agent gets information of changes and interactions between the user and other actors and sends to presents user options according to the session characteristics (e.g. role of the user and/or logging device) and to reflect changes on the learning environment. By doing this we aim to improve the user experience. Also the integrity of the learning sessions or UoL creation session is guaranteed

due to the fact that the agent will show only the options in the virtual environment available to him or her.

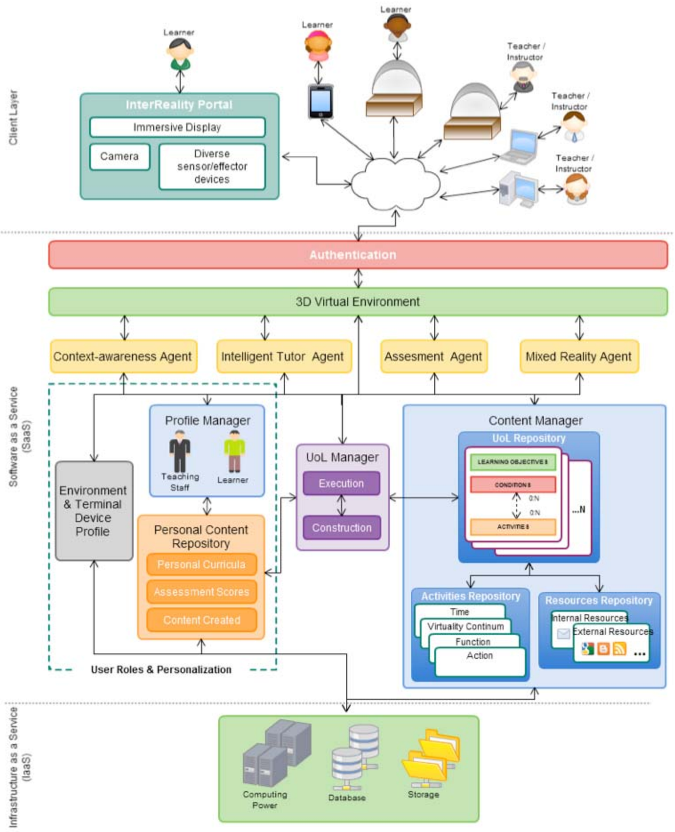

Figure 2. Mixed Reality iLearning Model

4) *Intelligent Tutor Agent:* The Intelligent Tutor Agent evaluates and suggest new content to the user according differenet variables such as the frequency and time dedicated to study, the result of its assesments and the personal preferences and characteristics of the user. The main objective of this agent is perform the instructor role as a facilitator, supporting and guiding the learners as they acquire knowledge.

5) *Assessment Agent:* Creates the learning outcomes and notifications according to the learning objectives, conditions and activities defined on each unit of learning.

6) *Mixed Reality Agent:* This agent works with the Virtuality Continuum activities, as part of the InterReality portal, allowing processing changes on the environment and reflecting them in their respective scope.

7) Profile Manager: Contains the roles availables (learner, Teaching staff/activity designer) with the privileges and settings for the learning environment.

8) Personal Content Repository: This repository contains user information derived from their interaction with the educational environment. It is formed by the following modules:

a) Personal Curricula: Contains all the units of learning assigned to the user either assigned or self-selected for the learner role. In the case of teaching staff it will contain all the units of learning that were created or are under current modification.

b) Assessments Scores: For the learner it contains all the results of previous units of learning taken. The teaching staff will have access to all the learners' scores that have been taken.

c) Content Created: Contains available resources uploaded or created via external resources.

9) *Environment & Terminal Device Profile:* This module contains information on the environment and configuration needed for the Context-awareness Agent.

10) *UoL Manager:* The UoL Manager is the one that allows creation and execution of the units of learning and encloses the next modules:

a) *Execution Module:* The execution module interprets the UoL specification and performs the selected activities within the environment according to the structure and sequence defined.

b) *Construction Module:* The construction module creates the units of learning following the conditions and sequence defined by the teaching staff.

11) *Content Manager:* Mantains and manages the repository of activities, resources and UoL. Also supports the process of exportation/importation of UoL files. It is composed by:

a) Activities Repository: This repository contains all the activities available in the environment. Figure 4 shows a classification proposed for these activities.

b) *Resources Repository:* The resources repository encloses all the resources available to use in the environment. This includes internal (e.g. internal messaging system, internal e-mail, etc.) and external (e.g. web search engines, blogs, rss, etc.) resources.

c) *UoL Repository:* Contains all the UoL created which are the sequence of activities contained in the *Activities Repository* that use the resources stored in the *Resources Repository*.

According to Collins et al. [25], education is experiencing a new era; passing from apprenticeship to schooling to lifelong learning in which three main factors are crucial in this transformation: customisation, interaction and control.

- Customisation refers to the possibility of providing the learners the knowledge they need in the moment they want it (intelligent learning paradigm).
- Interaction refers to the communication between learners and learning environments through accomplishing realistic tasks and by obtaining immediate feedback (constructionist approach).
- Control refers to allow learners to be in charge of their learning process (constructionist approach).

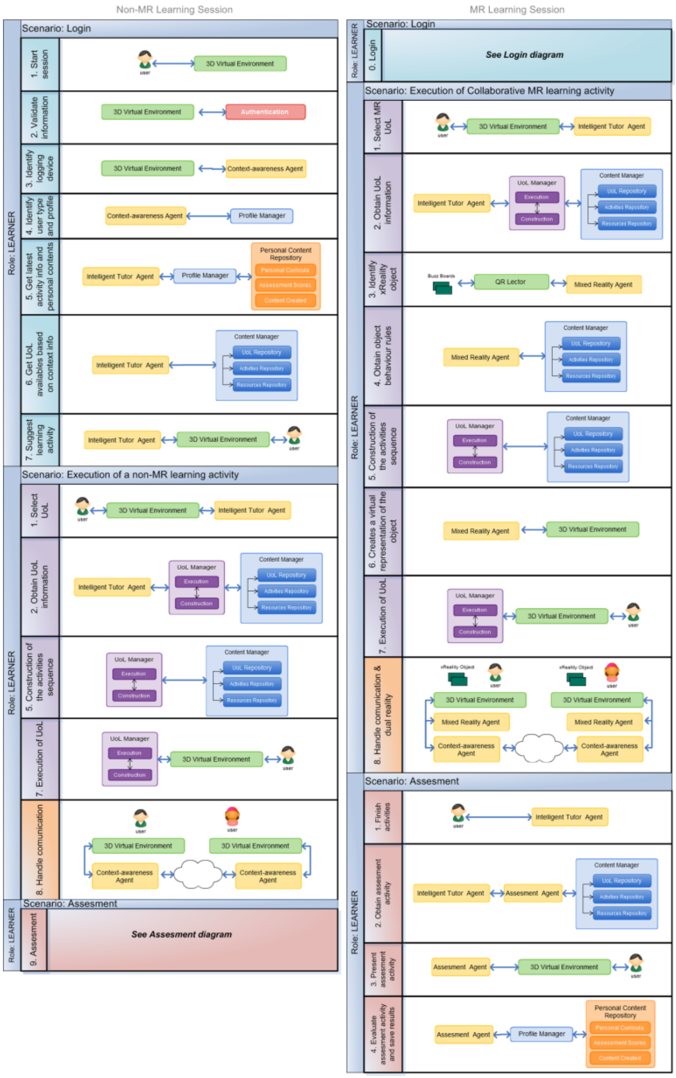

Figure 3. Execution of scenarios

In our model "Customisation" involves the interaction between the *Context-Awareness Agent*, which gets contextual real-time information to be used by the *Intelligent Tutor Agent*, together with static roles and privileges deposited on the *Profile Manager* and previous user data stored on the *Personal Content Repository*. Once this information is available the *Intelligent Tutor Agent* evaluates the user profile (role, previous activity performed on the learning environment, results on assessments and personal curricula) and the login device to create tailored contents

"Interaction" is achieved by communication between the *UoL Manager* which constructs and executes the sequence of activities stored on the *Content Manager*, the *Mixed Reality Agent* which identifies the cross-reality object and establishes the behaviour rules to be used on the MR learning activity, and the *Context-awareness Agent* which synchronise the status of the cross-reality object. Once the activity is reported by the learners as completed the *Assessment Agent* evaluates the completion of the learning goals by an assessment activity (generally a questionnaire), and the learning experience by a standard poll on the activity completed. The result of these activities is stored on the *Personal Content Repository* for further use.

Finally "Control" is established by the possibility for the user to customise their learning programme and environment such as selecting UoLs proposed by the *Intelligent Tutor Agent* and the opportunity to complete the activities of a UoL on different learning sessions. Figure 3 exemplifies the module interaction for a learning session.

B. *Classification of Learning Activities*

In order to create a set of test beds we established a classification of learning activities (Fig. 4) according to four aspects. This is not a strict classification, as the activities may evolve or even fuse with one another in order to create new learning experiences. Likewise it is important to point out that some activities may be included in one or more of the categories described below.

1) Virtuality Continuum: These are activities which involve interaction in real time and manipulation between real and virtual objects. Traditional lectures and team work within the enviroment are examples of Virtual Learning Activities. Mixed Reality Activities can be performed within labs using real and virtual resources.

2) Timing: This clasification refers to the timing when the activity is being executed. Synchronous activities involve the execution of activities between two or more roles (e.g. classes, *co-creative* work, etc.). Asynchronous activities may be completed for single individuals, these include research, sub-component delevlopment and personal assessment.

3) Function: Function clasification denotes the nature of the activity. For example, if it is a main Learning Activity such as a lab session or a Support Activity such as coursework.

4) Action: This clasification involves the main work being undertaken in the activity. Task-based activities are events that result in a deliverable. Simulation activities involve a completing work (e.g. software module, hardware design) that complies with an agreed specification (e.g. conditions and rules to be fullfiled) in order to complete the assignment. Finally role-play activities refers to role definitions performed within game structures and supported by co-creative rules.

Figure 4. Classification of Activities

C. An InterReality Portal

In the science-fiction prototype "*Tales from a Pod*" [26] we described a computer based education scenario with immersive mixed-reality teaching environments (*pods*), in which students experience personalised learning. These modular *pods* could be connected to create geographically distributed large-scale education environments. We adopted this vision, or design specification, in the design aims for the work described here, albeit taking a more practical stance based on the current state-of-the art.

Based on the iLearning concept, the access to activities and units of learning should be open to any device with Internet access but the real immersive experience is proposed to be achieved by the concept of the *InterReality Portal*. An *InterReality Portal* can be defined as a collection of interrelated devices comprising a 3D virtual environment, physical counterparts and software agents that allow users to complete activities at any point of Milgram's Virtuality Continuum [2]. The characteristic of being context aware can be obtained by the use of diverse technologies such as sensor monitoring, network eventing, camera based interaction, RFID/NFC identification, speech recognition, etc. By these means the InterReality Portal can obtain information from the user (identification, physical state, emotional mode, etc.), the current user role (one user may hold a different role at diverse moments) and the activity he is working on at that moment; in order to provide the best configuration of resources available to complete the activity.

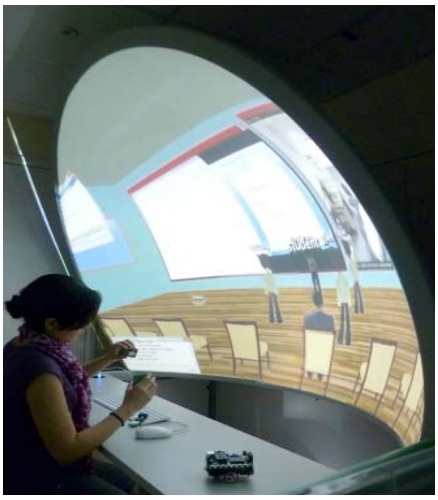

Figure 5. ImmersaStation

In this work-in-progress project we are utilising the Immersive Display Group's ImmersaStation [27] (Fig. 5) to create an immersive InterReality Portal. The ImmersaStation is a semi-spherical sectioned screen with a workspace which allows the student to perform tasks in a natural way and creates an immersive sensation due to the free-range of head movement without the need of any other body instrumentation (e.g. special glasses) [1]. In order to communicate between real and virtual worlds, our prototype includes a camera that, in addition to videoconferencing, is used, together with some sensor/effector devices, to capture elements of augmented reality and augmented virtuality in MR Learning activities (Fig. 4) via QR codes and other mechanisms.

D. Implementation

To exemplify and study the application of co-creative iLearning in an immersive environment we define a series of test beds using *Virtuality Continuum* activities described in section 3B. Our test bed UoL is a co-creative virtual lab in which students use a kit of embedded devices (both physical and virtual) to construct various Internet-of-Things appliances, such as a small desktop mobile robot. It is important to note that, as we previously stated, the iLearning model could be managed using other interactive systems (e.g. a desktop computer screen) but the *Virtuality Continuum* activities can be only fully completed via the InterReality Portal. In this case the test bed activity could also be classified as a class of *Learning activity* (Function), *Task based* (Action) and *Synchronous (*Timing).

For the construction of learning projects we utilise Fortito's *Buzz-Boards* [28] [29]. Buzz boards (Fig. 6) are a modularised educational toolkit of embedded computing hardware and software components that allow students to create a variety of Internet-of-Things projects such as mobile robots, mp3 players, heart monitors etc., as part of educational science and engineering assignments. The usage of the devices is communicated via network events, thereby augmenting information gathered from other sources.

To perform the learning activity the *Context-Awareness Agent* identifies the object being used in a learning task with the aid of QR codes, camera and network eventing data. This information is sent to the *Mixed Reality Agent*, which obtains from the *Resources Repository (*via the *Content Manager)* a set of rules and actions (behaviours) available for the object. This information is sent to the *UoL Manager*, which constructs the sequence of activities in the UoL. In support of these activities, the *Mixed Reality Agent* instantiates a virtual representation of the *Buzz-Boards* and other objects in the *3D Virtual Environment*. Finally the *UoL Manager* starts with the execution of the activities. Figure 3 shows this interaction between system components.

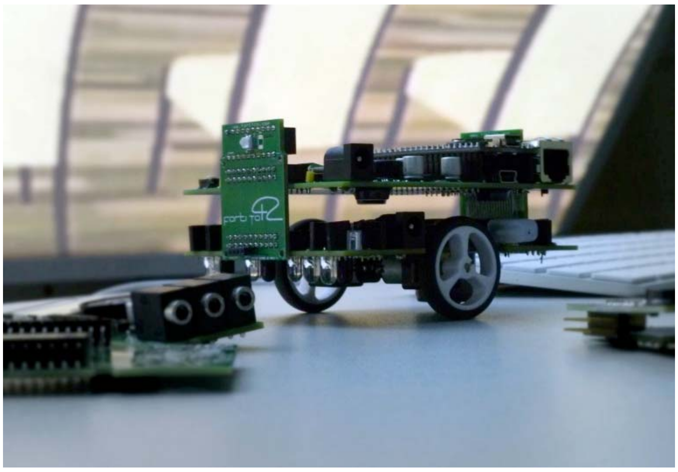

Figure 6. Fortito Buzz Boards

For the co-creative virtual lab, additional learners perform the same steps, and then through the *3D Virtual Environment* establish communication with other online learners. At this point we have a "*Dual Reality*" state in which the objects in the virtual world are a copy of the real world. If there is a change in either the virtual or the real world, the *Context-Awareness Agent (CAA)* perceive it and send the updates to the *Mixed Reality Agent (MR*) which symphonises the states of the all virtual world views. As long as the session continues changes to any of the Inter-Reality Portal objects, the *Mixed Reality Agent* can handle the following situations:

a) A change in any virtual component of a given InterReality Portal results in identical changes to all subscribing InterReality portals

b) A change in a real component of a given InterReality Portal results in changes in the representation of the real device on all subscribing InterReality portals.

```
IF UoL_percentage = 100% THEN
        IF UoL_assessment >= 60% THEN
                SUGGEST next_UoL_value
        IF UoL_assesment < 60% THEN
                IF User_Opinion <> DIFFICULT THEN
                        SUGGEST same_UoL_value
                IF User_Opinion = DIFFICULT THEN
                        SUGGEST previous_UoL_value
IF UoL_percentage_completed <> 100% THEN
        SUGGEST same_UoL_value
```

Figure 7. Tutor Agent Decision Rules

Through the process of combining real and virtual components the students are able to build a working system to satisfy the UoL exercise goal (i.e. a mobile robot or some sub-part of that task that may form a UoL). To assess the comprehension of the concepts and skill acquired in the virtual lab, the *Assessment Agent* sends a final activity to the learners. Once this is done a set of decision rules are executed by the *Intelligent Tutor Agent* to suggest to the student the subsequent UoL exercise based on: a) the percentage and nature of the activity completed; b) the finding of the *Assessment Agent* with regard to the relative difficulty the student experienced (e.g. the number of attempts and prompts provided, etc.) and c) the student's personal opinion on the difficulty of the task (Fig. 7).

Figure 8 describes the implementation phases of the model. The first stages of iLearning model implementation involve the construction of a fully immersive InterReality Portal able to work with *Virtuality Continuum* UoLs.

The following stage of the implementation consists of the construction of a second InterReality Portal and performs the virtual lab described previously in a co-creative way between two people in separate locations. By doing this we will expand usage into a wider geographical and pedagogical context thereby allowing InterReality portal educational resource and immersive environment sharing based on cloud computing technology plus a deeper exploration of co-creative PBL pedagogies.

E. *Learning Maturity Model*

Kapp et al. [30] specified a classification to determining the maturity of the learning models in order to define how learning is being performed in the environment, and how close to genuine (natural) learning tasks are those that have been integrated into the model. They define four levels of maturity:

Level 1 discusses synchronous learning provided by avatars/instructors in virtual environments reconstructed from real physical spaces, such as classrooms. In this level, learning focuses on information that must be memorized and the knowledge that is transferred (which generally uses 2D synchronous learning software as a comparison benchmark). This level provides a learning experience derived from the synchronous co-creative work among individuals within the environment (e.g. Virtual Learning Environments (3DVLE)). In our model, the interface between the users and the model is an immersive 3D virtual environment. Learning in 3D virtual worlds provides a co-creative ubiquitous venue for students to communicate and create interactive content.

Level 2 describes the evolution from functional locations to a personalized learner context with specific learning goals. At this level declarative knowledge is still being taught but also conceptual ideas are learned through examples and interactions within the environment that would be difficult to transfer via a lecture. This level offers a learning experience derived from interactive participation between the learner and the environment and provides a context to apply the skills learned from reading and discussing situations within the classroom. The designed learning activities defined in our test bed reflect the application of these concepts, encouraging the learning of theoretical concepts and the use of this to improve practical skills following specific learning goals.

In level 3 the learner is wholly immersed and completes tasks in the same manner as if they were in a real environment. Through this level the learners can understand and experience the challenges they will encounter during the process of learning. The learning experience at this level involves declarative knowledge, application of conceptual ideas, rules, procedures and usage of soft skills allowing the effective interaction with colleagues and teaching staff via the paradigm of learning-by-doing. Through the proposed *InterReality Portal* the immersive experience provides learning in the same manner as if were performed in a traditional laboratory session.

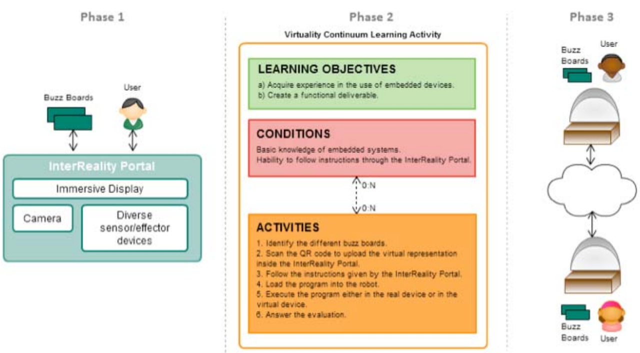

Figure 8. Implementation phases

The last level of maturity involves two or more geographically separated people working together, and joined seamlessly via the *InterReality Portal* environments, learning through the process of co-creation of deliverables. The learning experience at this level encourages learning through problem solving, work, collaboration and innovation. The success at this level depends on the ability to create something of value. The third phase of our work-in-progress promotes collaboration and creativity between learners to create a fully functional deliverable, either in virtual or/and the real world.

According to the Learning Maturity Model, the main goal can be achieved only when the last level is implemented in a learning environment. To evaluate the effectiveness of our model we propose to build a series of test beds to allow a group of students to work on mixed-reality lab activities (described earlier in the 3D section) via the InterReality Portal. Once the students have completed the activities involved in the UoL and have completed the assessment task, they will be given a questionnaire to assess the technical and pedagogical effectiveness of our Prototype InterReality learning portal. Some earlier user studies on the University of Essex's SIMiLLE project, a MiRTLE-based learning environment (described in section 1), showed that students' accepted the use of simple virtual environment for tasks and discussions related. [31]. Other research in problem-based learning has shown that student progress is positively affected by the use of technology, improving the grades on the subject evaluated [32] [33]. We propose the evaluation of our model based on Kapp's model combining user's acceptance and interaction with the environment with the completion of learning goals in the UoL.

Summary and Future Directions

Within this paper we have explored a novel learning paradigm; a co-creative (Co-creation) mixed reality InterReality portal for problem based learning aimed at educating students in the science and engineering of the Internet-of-Things. We proposed and explained a novel conceptual framework based on the fusion of learning design, cloud learning and mixed reality activities. We contend that these concepts will provide deeper and richer learning experiences and offer personalised learning activities. In addition, we discussed the Learning Maturity Model, comparing our conceptual framework to it. Finally, we have begun construction of the InterReality portal, and the BuzzBoard system, shown in fig. 5 & 6 respectively, which will be the physical and pedagogical test bed for our practical work.

The main contribution of this paper is the pedagogical and technological model of a co-creative InterReality learning portal. This work presents a number of novel research challenges. First the overall architecture (combining a number of technically challenging e-learning technologies) second, the formally structuring of educational activities using learning design and third, developing a mixed reality portal to support co-creative learning. This model is wide ranging and our main contribution will be to explore how decomposed software and hardware can be combined with the use of end-user programming to create a type of educational virtual object that can be constructed and shared by teams of geographically dispersed students working inside a mixed reality immersive learning environment. To those ends we have already built and tested the networked assignment student assignment system; Buzz-Boards and we have the immersive video environment working. In our next stage we will implement the UoL modules so we can create and evaluate the first level of our pedagogical model; the independent but immersed learner. This will be our future contribution in a follow on paper. We look forward to presenting significant progress on this on-going work at subsequent conferences.

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