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The Intelligent Classroom : Beyond Four Walls

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Abstract. It has become standard practice to use the traditional information technologies such as web and email in education. But as the University campus becomes increasingly deployed with interconnected computing technology, we begin to ask how the resulting *"iCampus"* resource can be used in new and novel ways. This paper builds upon our previous work in the area of intelligent environments and goes beyond the typical use of computing technology within education. We report on our current research that aims to apply mixed reality and ubiquitous computing paradigms to enrich the teaching and learning experience and describe our deployments and innovations across the University of Essex campus.

Keywords. Intelligent environments, Smart classrooms

Introduction

Education manifests far beyond the four walls that constitute a traditional classroom; outside those walls, learning, teaching and administrative tasks continue and have been increasingly supported by various information technologies in recent years. Global and local computer networks enable the exchange of material such as email communications, lecture notes, instructional video, advice, timetabling, etc. This is leading to a world in which education is not only *supported* outside the classroom, but also *active* outside the classroom - available anywhere at anytime (and in some cases, accessible by anyone). In tandem, there has been increased technology deployment within classrooms themselves, this is matched by the availability of emerging pedagogical methods that take advantage of those deployments, such as [1] [2] [3].

Despite the increase of technology in education, the classroom remains in popular use for conducting the act of person-to-person knowledge exchange (in the various forms that exist) and remains *"dumb"* in the sense that its technologies, if any, are unintelligent (they are simply monolithic tools that require human control). Therein, many possibilities exist for the use of technology in transforming the classroom from a *"dumb space"* into a *"smart space"*. While there are many good reasons for this kind of *"intelligent classroom"* (such as energy conservation, security, automation, cost reduction, management, etc.), our primary motivation for the work presented herein lies

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in the pursuit of improving the way in which participants of the educational process can provide / acquire knowledge. Thus, the first high-level goal for this work is :

Goal-1. The construction and development of an intelligent classroom through the deployment of ubiquitous computing [4] and ambient intelligence (AmI) [5] that facilitates learning / knowledge transfer.

In carrying out this work, we draw on our previous experience in the area of ubiquitous computing, through which we have constructed the iDorm and iSpace intelligent environments [6] [7] [8]. With this in mind, and considering that the typical classroom experience is still one that requires the geographic and temporal collocation of all participants, regardless of the role they play within the teaching / learning activity; we are conducting our investigation with the second high-level goal:

Goal-2. The deployment and evaluation of technology to locations outside the classroom that permit interactive and immersive remote participation.

To address this goal, we are drawing on our previous experience in the area of mixed reality in teaching and learning environments (MiRTLE) [9] [10] [11] and developing a more engaging experience through the use of immersive display technology (as inspired by some previous conceptual exploration [12]).

In this paper, we present the current state of our work towards these goals through the description of our *"iClassroom"* and its interconnections that span the University of Essex campus (as shown in Figure 1.).

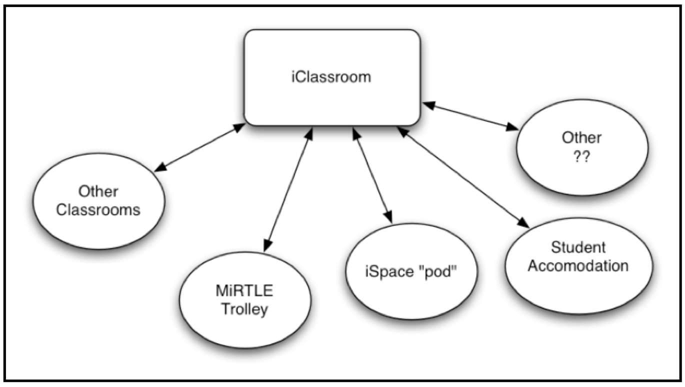

Figure 1. Deployment of the iClassroom and remote participants.

We begin by discussing the way in which technology is currently used in the classroom. This is followed by details of our iClassroom and a description of our other interconnected spaces. The discourse includes both the technologies used in achieving the desired functionality, but also the way in which education is delivered through its use. This is set within the context of our ongoing ubiquitous computing research. Finally, we provide conclusions and identify challenges that are to be addressed in our imminent future work.

1. The Current State of Technology in the Classroom

Much work has been done regarding the use of multimedia technologies to support education. *"Synchronous"* learning equips the classroom with technology that enables live video / audio to be sent over a computer network (a process also known as web-casting) to distance learners [13] [14] [44]. Some of this content may also be stored alongside additional multimedia content (such as lecture notes, presentation slides, etc.) for later *"asynchronous"* learning in which the content can be browsed and consumed at any time [15] [16] [17]. Studies have also been conducted that compare the two methods [18] and their effects on students [19] [20].

As a logical consequence of classroom digitisation, remote users are increasingly able to interact and participate (not just observe) [21] [22] in a class using technologies such as instant messaging, audio / video conferencing, etc. However, the lack of an *"immersive"* experience (among other reasons) has prompted further investigation from which the use of *"mixed reality"* is emerging as a new paradigm [23]. This permits local and remote users to experience a virtual world through which they may roam and interact with embedded video / audio streams, screencasts and avatars of other participants [11].

Beyond the resulting hybrid classroom-studios and mixed-reality environments; technology has also been used in the classroom to digitise (and then make available) material written on classroom whiteboards [24] [25] (with associated pedagogical work [26]), provide digital signage for room management [27] / navigation [28] and monitor student attendance [29] [30]. The use of *"information devices"* such as tablets, laptops and PCs are also in heavy use, but are more frequently deployed where the class participants are not intended to be focused on a human *"teacher"* (such as in labs or in novel teaching spaces such as [3]).

Although these technology deployments are focused on monolithic / integrated tools, there is considerable effort being conducted that seeks to turn the humble classroom into a ubiquitous computing deployment complete with devices, sensors and networks that sense and respond to human occupants [31], but can also integrate education material [32]. This opens the possibilities for new modalities of human interaction within the classroom using technologies such as RFID / NFC [33] or speech interaction [34]. With these newly available sensing and acting capabilities, comes the opportunity for applying agent-based and AmI techniques to achieve suitable context awareness through environmental sensor monitoring [7], camera based intention inference [35], affective sensing [36] and other means. The net effect is to provide a classroom that senses its environment and intelligently adapts to the occupants and their current activities (for example, by varying heat / light levels [7], modifying screen content [37] and providing the timely delivery of information and cues).

2. The iClassroom

2.1. A Purpose-Built Ubiquitous Computing Deployment

As with the construction of our other purpose-built smart spaces, the Essex iClassroom begins with the preparation of a physical space. For this we have selected a modestly sized, 'L' shaped room and divided it into two distinct sub-rooms by erecting a false wall (as shown in Figure 2). The larger (3m x 6m) of the two rooms will be the operational part of our classroom that participants will experience. This leaves a smaller space (3m x 3m), itself an *"intelligent office"*, that is intended to harbour developers / observers as they carry out their research (possibly while the operational part of the classroom is in use), but is also to be used for housing equipment (including servers, automation devices, network cabinet, etc.). To facilitate the deployment of necessary technologies, both as part of the original design and as later augmentation, false walls and ceilings provide hiding places for embedded devices / sensors. These are then over-populated with power and Ethernet sockets in support of the electronic artefacts they will eventually yield. All Ethernet sockets are wired to a central patch panel and are interconnected to form a network that is isolated from the rest of the university. A single access point provides secure wireless access to the iClassroom network, while a gateway / firewall provides internet access, basic network services (such as DHCP) and also allows certain service requests to be handled from outside the iClassroom. Overall, this forms a raw skeleton into which ubiquitous computing can be embedded – a procedure of deployment that has become our *modus operandi.*

Figure 2. A 3D model of our iClassroom during development.

We reuse the technologies developed in our previous works and deploy computer controllable lighting, HVAC, curtains, door-locks, RFID readers and ambient displays in addition to an array of sensors that are all exposed through middleware to the network where intelligent agents can discover, monitor and manipulate them based on embedded AI. As part of our ongoing research, both the middleware and the agent-based techniques can be swapped out and replaced by others - this permits the evaluation of many approaches, models and methods in various permutations. Thus, the space itself is as much a subject of research as the human activity that it supports.

To enable familiar human interaction, we add projectors, a large interactive whiteboard, wall-mounted touch-screens, handheld / tablet / pad devices and a traditional desktop PC (as part of a lectern setup that aids in the delivery of presentations). In combination with a multi-speaker audio setup (where each speaker is embedded in the ceiling and able to render an individual audio stream), the iClassroom is equipped for multimedia delivery, interaction and control.

To complete the design of our iClassroom; additional equipment is to be deployed that will provide various video streams (360° top down, 180° fly-on-the-wall, movable high definition and thermal spectrum) and affective monitoring of participants (galvanic skin response sensors, heart-rate monitors, embedded seat sensors, brain-computer interface headsets, etc.). It is intended that this overall deployment will provide a starting point for the development of new technologies across the whole spectrum of ubiquitous computing and AmI within the education context.

2.2. A Context Aware Space

In line with our primary goal of facilitating learning / knowledge transfer in its various forms, we seek to improve the learning experience through context awareness and environment adaptation in response to changes in the classroom and its occupants. That is; the iClassroom should be able to automatically recognise occupants presence, mood / emotion and activity at any time and adjust the classroom settings accordingly. To achieve this, intelligent software agents will use the multitude of devices and sensors that are deployed in the space to make observations, infer higher level knowledge, formulate plans and execute actions. Over time, the agents are intended to learn both generic and specific user preferences / behaviours and in turn become anticipatory – such is the overall vision of AmI.

In addition to the AmI techniques that we intend to explore; occupants of the iClassroom will have the opportunity to explicitly control and interact with the space through the use of RFID tags, graphical user interfaces, spoken dialogue systems and gesture recognition; indeed, we wish to make the space exhibit an "*adjustable autonomy*". This, as with all activity, will be subject to security / privacy privileges that are in turn influenced not only by occupant(s) but also by the information held in the electronic booking system (i.e. when the space is booked out, the activities and purpose of its booking will influence how the space behaves and what its occupants may do). Digital signage both inside and outside the classroom will provide feedback that reflects the bookings both present and future (within a certain temporal frame - such as a day), while more comprehensive information can be accessed and modified online.

It should be noted that we have avoided the deployment of traditional desktop PCs in order to avoid distraction of occupants away from the primary purpose of them being there. This work is intended to provide a technology supported teaching facility, not a computer lab! However, collaborative learning, group activities, electronic polling / questionnaires / quizzes, etc. may be carried out using tablet devices and the considerably larger smart whiteboard. This makes the space suitable not only as a classroom, but as a meeting / conference room and a space for groupware activity (that can support both live and remote users).

3. Education @ Home

In the Science Fiction Prototype *"Tales from a Pod"* we explored a vision for future learning systems that was based on the idea of using immersive, virtual-reality *"pods"* to connect geographically distributed teachers and students by providing virtual classrooms [12]. The story opened by describing how online-learning had developed in the 21st century to provide highly personalised learning via the introduction of a high-tech networked environment called the *ePod (educational pod)*. We explained that such a system could be regarded as a refinement of current online eLearning systems, which have evolved from Computer-Aided Instruction, through Intelligent Tutoring System, to web-based learning. e-Learning is heavily learner-centred and, as a result, emphasizes personalized learning technologies. Lessons can be delivered on a variety of screen-based platforms ranging from Smart phones, handheld computer *"Pads"* through conventional PCs and up to IP-TV. This is well exemplified by the Shanghai Jiao Tong University's Network Education College that supports almost 20,000 online learners [38] [39].

3.1. Distance Learning

The impetus and opportunities for such work is evident in the rapid proliferation of broadband, which is accelerating the adoption and use of computer based information technology in our everyday lives, especially our homes, making it possible for people to access a huge variety of services from home automation to new types of media-based services. Of particular relevance to this paper is that broadband has led to new ways of learning and education, enabling distance learners at home to receive and interact with educational materials and resources and to engage with teachers and peers in ways that previously may have been impossible [38] [39]. For example, a survey from the National Centre for Education Statistics [40] estimated the number of students being homeschooled in the United States was of the order of one million with more than 40% of them engaged in some sort of e-Learning. Numerous online colleges now exist such as the UK Open University, the Network Education College Shanghai Jiao Tong University, and the Hong Kong Open University, which have all developed and deployed their own eLearning platforms. The Shanghai test bed is a particularly interesting example for this paper as it makes massive use of ICT and consists of a large number (tens) of distributed smart classrooms, tens of thousands of enrolled students, and thousands of online users [38]. Learning environments range from interactive screen based interfaces to teaching resources such as WebCT and Blackboard, through live video based services such as the SJTU Network Education College [38], to experimental immersive virtual-reality systems such as Mirtle [23].

We intend to use such techniques in supporting distance learners, but to also use these techniques (and similar ones) to continue exposure of individuals to educational material in a pro-active way while they go about their daily lives at home (through the use of ubiquitous computing *"smart homes"*) and while on the move (through mobile devices that they carry with them). This is reflected in Figure 1, by the branching out from the iClassroom to the iSpace (our purpose-built smart home), university student accommodation (linked by a high-speed fibre optic network) and *"other"* spaces such as classrooms in other universities around the globe with which we are collaborating.

3.2. A More Immersive Home Experience

All the services discussed in the previous sub-section have one major commonality; there is a significant gap between the computer generated environment and the real classroom. In particular, the screen image in intrinsically flat, even when virtual reality is employed, thus limiting the extent of the immersive experience a student may enjoy (i.e. the benefits that a student accrues from being in a real class, such as the feeling of sharing a social and educational mutual support, is limited). For example, other work [41] has shown that remote learners frequently suffer a feeling of "*academic loneliness*" that impairs their learning ability by lowering motivation and substantially lowering mutual student support. In addition, studies have shown that cutting edge technology has a positive effect on engaging student interest and participation [38]. For these reasons, we are investigating the benefits of providing remote learners with a more immersive virtual-reality environment.

Classically, an immersive reality environment (also known as a CAVE[2]) takes the form of a cube-shaped room in which high-resolution images are projected onto the walls, ceiling and floor [42]. Frequently special glasses are used to provide enhanced 3D effects such as objects floating in the air. To synchronize the users position with the virtual objects elaborate sensing, similar to that in intelligent environments, is often used together with sophisticated computation. All these requirements result in such environments being both large and very expensive (e.g. room sized facilities, costing many tens of thousands of dollars). Clearly such a large and expensive construction would be out of the question for a home user, so the challenge addressed by this work is how to produce a smaller cheaper unit for use in the home. We are currently working with Immersive Displays (UK) Ltd to build a small table based unit (the Essex Educational Pod – ePod) as shown in Figure 3. This will be deployed in our iSpace "*living lab*" and facilitate our investigation through development and evaluation.

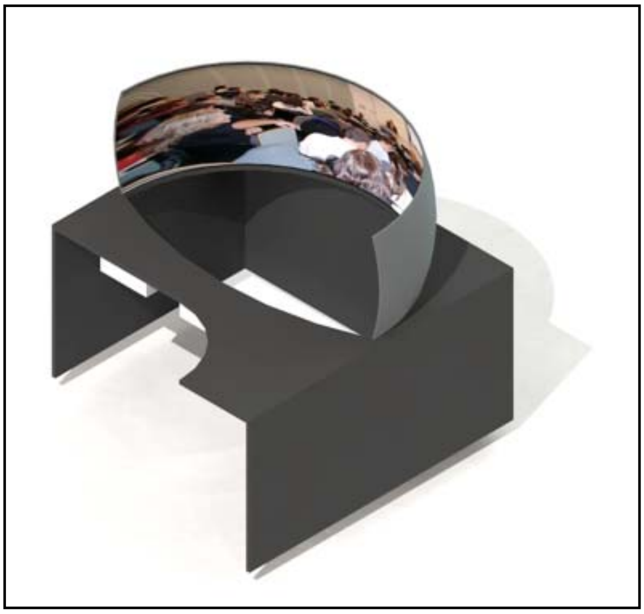

Figure 3. Concept Drawing of the Essex Immersive Learning ePod Desk

The unit design takes advantage of a student's normal working position being seated at a worktable, only able to move the upper body and head. This restricted user movement results in spatial restrictions that our design capitalises on, allowing us to provide what feels like a full immersive experience from a small semi spherical

[2] An allegory of the Cave in Plato's Republic in which reality is questioned.

sectioned screen that matches the possible head movement of the student. The projectors mounted in front of the screen and are integrated into the desk (reducing the overall physical footprint of the setup). As part of our investigation, we are integrating movement sensors, cameras and various HCI mechanisms into the desk. For example an interactive touch screen (embedded in the desk) acts as a means of interacting with the table and the virtual world, but can also display more traditional student based material. We are also planning a more mobile version of the ePod Table, which will allow is to conduct evaluations in the field (real peoples homes) and of multi connected ePod spaces as well as give public demonstration of the technology.

4. Mixed Reality - µMiRTLE

In [9] [10] [11] [23] [43], we reported on our collaborative research toward creating a *"Mixed Reality Teaching and Learning Environment"* (MiRTLE) that enables teachers and students participating in real-time virtual classes to interact with avatar representations of each other. The hypothesis underpinning this research is that avatar representations of participants will help create a sense of shared presence, engendering a sense of community and improving student engagement in online lessons.

The original objective of MiRTLE was to provide a mixed-reality environment for a combination of local and remote students in a traditional instructive higher education setting. The mixed-reality environment links the physical and the virtual worlds, augmenting existing teaching practices with the ability to foster a sense of community among remote students and between remote and co-located venues. This fits within our longer-term vision, which is to create an entire mixed-reality campus; so far we have developed the first component in this process: a mixed-reality classroom. MiRTLE has been built using the OpenWonderland toolkit to construct virtual classrooms (Figure 4).

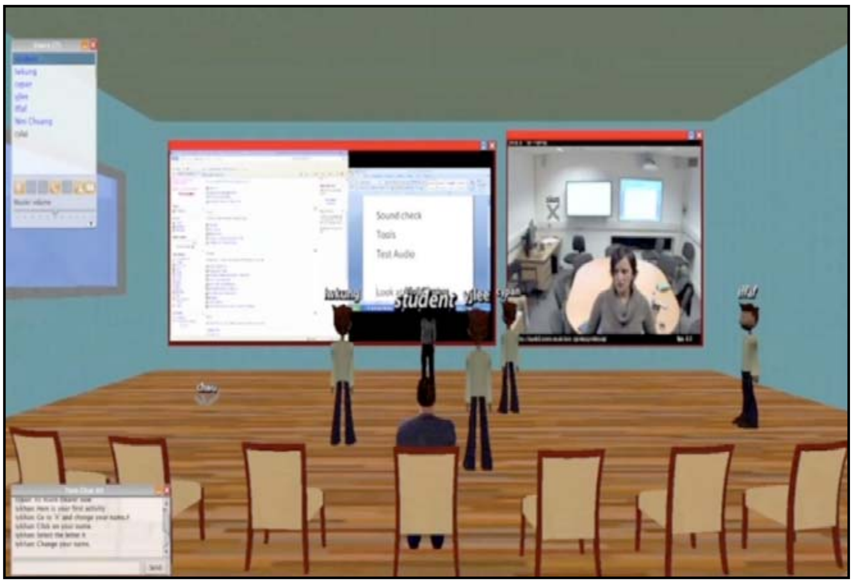

Figure 4. A MiRTLE class as seen by a participant.

The University of Essex already has a number of dedicated MiRTLE teaching rooms (within two departments), and we are currently planning further deployments on both the Colchester (UK) campus and Southend (UK) campus. From a practitioner point of view the intention is that teaching staff can use all of the facilities in the lecture room that they are already familiar with, such as presentation materials, whiteboards and display projectors. However, with MiRTLE they can make these live classroom sessions available to much larger groups of students who can now participate fully online. MiRTLE provides an interactive live wall-board in the class which allows the local teacher and students to see and interact with the remote virtual students. Remote students can raise their hands and ask questions in the normal way. They can text-chat with the class, and they can use a rich spatial audio interface that allows them to speak to the class and hear everything going on in the classroom. Virtual students also see the presentation slides as the lecturer is giving them. Also when MiRTLE is connected to a compatible smartboard, the teacher can share their work on the whiteboard with both the local and remote students.

We have so far built dedicated MiRTLE teaching rooms and are now investigating a more portable version of MiRTLE that we call *"mobile MiRTLE"* (μMiRTLE) which can be easily wheeled into a classroom and used by the teacher (as shown in Figure 5).

Figure 5. The μMiRTLE prototype.

Our current design (Figure 5) is based on a simple trolley, which holds the classroom display, the MiRTLE server and core peripherals (camera, speakers, microphone). We have also redesigned the software so that the teacher only has to power on the system – all of the software is automatically loaded and the MIRTLE server is started, so that the teacher need not worry about starting applications or configuring options; a single power and network connection brings it to life. Our plan is to deploy a number of these μMiRTLE solutions across the campus (including the iClassroom), and then carry out a number of studies into the issues arising for both practitioners, and for the institution.

5. Conclusions & Future Work

In this paper we have given an account of current technology deployment in classrooms and presented our current work regarding the use of ubiquitous computing, ambient intelligence (AmI), mixed reality and immersive display technology to further the state of the art and permit the investigation of new technology-supported education paradigms / methods. Some of this work builds on the concepts of distance learning and ubiquitous computing to promote socially acceptable education beyond the four walls that contain a classroom, thus increasing the outreach and exposure of educational material. The predicate here is to increase inclusion of people in education and thus boost the effectiveness of learning.

We are currently in the process of completing the iClassroom deployment and so there is much research that will proceed over the coming years. This will include all aspects of the space itself, the technology it contains, the online interconnection of spaces and the social / pedagogical evaluations that result.

Looking further forward, we hope that this work will progress beyond our intelligent classroom and scale to an entire campus of technology supported teaching facilities. This brings fresh new problems with regards to management and access control, but opens possibilities for virtual organisation in which geographically distributed classrooms (and remote learners) can be merged in mixed reality to form online learning environments. Thus the iCampus vision scales from a single physical deployment (albeit large scale) to virtual universities / classes / conferences that are composed of technology hotspots from around the globe.

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