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CHALLENGES AND OPPORTUNITIES FOR THE FUTURE OF iCAMPUSES

Abstract *Meeting the educational needs of students currently requires moving toward collaborative electronic and mobile learning systems that parallel the vision of Web 2.0. However, factors such as data freedom, brokerage, interconnectivity and the Internet of Things add to a vision for Web 3.0 that will require consideration in the development of future campus-based, distance and vocational study. So, education can, in future, be expected to require deeper technological connections between students and learning environments, based on significant use of sensors, mobile devices, cloud computing and rich-media visualization. Therefore, we discuss challenges associated with such a futuristic campus context, including how learning materials and environments may be enriched by it. As an additional novel element the potential for much of that enrichment to be realized through development by students, within the curriculum, is also considered. We will conclude that much of the technology required to embrace the vision of Web 3.0 in education already exists, but that further research in key areas is required for the concept to achieve its full potential.*

Keywords education, icampus, sensors, context, Web2.0.

1. Introduction

Modern students live in a world increasingly driven by new methods of gathering and visualizing data, and those data are increasingly accessed collaboratively, such as through Facebook and Moodle. Such perception sharing and joint study opportunities are obviously highly beneficial to academic life and parallel the vision of collaborative anthropocentric data inherent in Web 2.0. However, current trends dictate increasing needs for open and accessible gathering, brokerage, sharing and visualization of data in future education: all central concepts of the Internet of Things and critical tools in the user-translation of data into relevant and accurate information. Additionally, drivers for flexible, media-rich and remote learning within education require development of the iCampus concept, in parallel to iCities initiatives, the 'i' requiring interactivity and system-intelligence. That requires significant investment in sensor networks, mobile technologies and associated data processing, but with equally significant pay back in terms of connectivity between learning, research and the surrounding environments within which students live. For students this allows learning to take place around 'real-world' data personalized to their unique learning contexts and available for anywhere-anytime-study. For academics there is also the related enhancement of pedagogical processes.

The overwhelming amounts of data associated with use of wide ranging sensor types, and their comprehensive coverage within educational establishments, naturally lead to increased investment in network infrastructure and data storage. In turn, users then require novel and secure means of querying and visualizing those data in a manner that maximizes their educational value, and student-appeal, through adequate contextualization, personalization and 'on-the-fly' repurposing of data representations. As a future concept for education these needs closely parallel the vision for Web 3.0, in particular due to a need for a step-change in the intelligence of sensors, web agents and other systems required for end-user visualization and interpretation. Given the increasingly technology-dependent world around us, the increasingly competitive markets in which students will work, and the growing costs to them of obtaining a university education, such a future paradigm shift in education seems undeniable. Therefore, this paper aims to investigate and clarify that vision and, while not providing solutions to all aspects of its creation, attempts to consider the problems and opportunities inherent in research for development toward it.

2. Moving toward the iCampus

The purpose of the iCampus is not just to enhance interactivity in education, but to create a campus made up of appropriately intelligent computer-systems. Those systems must therefore understand the individual contexts of individual students, as well as having an intelligent understanding of the environments in which they study. As Ng et al. [32] state, this means a step change from 'smart' to 'intelligent', even going so far as to describe the intelligent campus as analogous to a central nervous system. An important question is, therefore, in what way must academic systems achieve intelligence? Obviously the most important factor is the need for effective learning, for which the seven key maxims of McMahon [26] listed below are useful. Of course, not all of these maxims require addressing in an online mode, as most students do not differentiate between offline and online modality, or even location, instead seamlessly mixing course content modes [12].

1. Visibly manageable workloads within time-constraints
2. Design out information overload.
3. Ensure students clearly understand what is required of them.
4. Ensure assessment regimes reward higher-order thinking and learning.
5. Require active participation.
6. Ensure students have as much choice as possible.
7. Give timely and effective feedback to students.

The list above is useful as it connects much of the work undertaken to create smart-learning environments. For instance, many campuses now rely on virtual learning environments (VLEs) such as Moodle (e.g. see [19]) for course and learning-document management, ensuring all participants can immediately see what is required of them. It also helps ensure that students are not overloaded with information from a variety of different sources and teaching staff members. However, VLEs such as Moodle are considered to have important limitations: for example Yasar and Adiguzel [43] identified key limitations including being course-centric rather than student-centric, having restricted interaction and activities, and less control to develop independent learning skills. That led to their enhanced VLE incorporating connection to 3D environments within Second Life. De Lucia et al. [11] went further in developing a whole virtual campus on Second Life, complete with lecture, collaborative and recreational areas. Their rationale crucially included the belief that "...learning is strongly related to the user perception of belonging to a learning community".

Similarly, the Alice Project [2] includes computer programming teaching within a 3D environment that they claim improves learning for students coping with object-oriented and event-driven coding additions to the curriculum (i.e. it addresses learning and information overload issues). It could be argued that virtual environments reduce interaction between participants, but Bourbonnais [5] suggests that when properly designed, web-based remote learning can still involve a high level of verbal interaction and socialisation can still occur. Also, Sze-yeng and Hussain [38] have considered use of Moodle in a multi-software system intended to facilitate self-directed learning. Facilitating participation, and even minimising information-overload through social media, has also been addressed through use of online wikis. In the case of inter-disciplinary design collaboration Biasutti and El-Deghaidy [4] found that wikis could develop teachers' knowledge management while also helping fulfill student satisfaction. Muscar and Beercock [31] noted that, after initial ICT-based learning acclimatisation, Moodle-based wiki use resulted in improved interaction and organising skills.

Another important area is teleconferencing: many IT solutions and training companies have, over the last few years, developed products to make dissemination, discussion and collaboration easier. Products are available for standard audio conferencing, via telephone, as well as web based audio and video conferencing. For example, Lync (Microsoft), GoToMeeting (Citrix) and Skype are available [35]. They allow desktop sharing and are particularly suitable for chairperson-controlled proceedings. However, they do not fully meet academic ideals for free form meetings, discussions, training where brainstorming is essential, and scenarios where students need to be broken into small groups or 'action-learning-sets'. Following such activities feedback must be given, by each sub-group, to the whole group, and systems such as WebEx (Cisco Systems) move teleconferencing towards a more intelligent learning environment. That is because it can assign students to groups and allocate chairpersons: each group having their own audio, video and work space that can be combined into the main session by tutors. This offers a many-to-many analogy of real-world teaching, thereby helping ensure students understand what is required of them. Through inclusion of features such as desktop sharing, white boards, group instant messaging, question posing, poll information, audio/video recording and integration with mobile devices, systems such as WebEx exhibit many features required of smart campuses.

It is also possible that future learning can be enhanced through natural-language 'chatbots' trained with domain-specific knowledge through conversation [36]. Those chatbots could be used in the form of physical robots or as software avatars, depending on context. However, their design would have to be carefully managed as aspects such as voice synthesis have been described by users as cold and insincere [33], Heerink [22] suggesting that robots with perceived extrovert social abilities are more likely to be enjoyed. Electronic whiteboards are also becoming pervasive in smart learning environments, although it is possible that their technology is not yet fully mature for iCampus use (see e.g.[1]) and may require enhancements to security [10], particularly from internal attacks [41]. However, in the study by Gursul and Tozmaz [18] teachers indicated that the two most important advantages of using whiteboards are increased visuality and increased opportunity for students to participate (which it is suggested that they actively volunteer for). The visuality is important as educational multimedia has been described as having huge potential, but with tremendous challenges and research opportunities [13]. Of course, in an iCampus, all of these enhancements have to be usable by 'cogitively-disabled' students, as in the smart tutoring for the autistic work of Vullamparthi et al. [40]. Also, in future, they are likely to be delivered as part of content within ubiquitous smartphone learning systems (e.g. see [37]).

Based on the above, it is apparent that much work has been done to move learning into the smart classroom. Also, much of that work, and work extending on it, provides the basis for moving out to the intelligent iCampus, which requires full awareness of surroundings on the part of computer systems: a need which largely requires addressing through sensor use. However, many challenges still exist as there is currently no adequately intelligent, fully aware of its environment, campus system incorporating all required functionality. Therefore, this paper considers the challenges, opportunities and research needs associated with adopting such a radical approach to higher education. It will achieve its goals through consideration of aspects such as available sensor and wireless technologies, web-based intelligent agents and data brokerage, security issues, mobile learn-anywhere-anytime systems, and the critical need for increased inclusion of semantics, contextualization and personalization in facilitating access to large-scale databases (and so maximize user engagement). A novel aspect of this is consideration of how the required systems can be incorporated into the curriculum: that is, with much of the design and development being undertaken as part of undergraduate and postgraduate projects.

3. Sensors and communications

Sensors are now becoming ubiquitous in daily student life, with technologies such as CCTV and RFID access systems installed at many universities and many data feeds present in modern building control systems, such as Smart Meters and climate control. Even low-end smartphones and mobile handheld devices incorporate sensors such as accelerometers, gyroscopes, temperature/light measurement, and even compass modules that can also be utilized for simple magnetometry. In some teaching areas those sensors can be utilised for development of virtual laboratories. Furthermore, games controllers now available are very sophisticated and can be used for interaction with iCampus interfaces as well as within ubiquitous sensing. For example, introduction of the Nintendo Wii represented a radical shift in freedom and interactivity for gamers, followed shortly by Microsoft Xbox and Sony PS3 consoles with their own unique controllers. They are ideal for rapid development using standard application interfaces and sample code, and so could significantly enhance iCampus student projects. Similarly, the Microsoft Kinect provides many opportunities for students to add motion capture and gesture recognition, and can provide 'shadow' data that may help overcome CCTV privacy issues. All of these devices allow the smart iCampus to transcend simple intelligence and become aware of the context in which it operates. A further bonus comes in the form of robotics education and research which harnesses a wide range of sensors for static and mobile platforms. This is demonstrated by the UK MicroMouse Championships (Figure 1) which have been hosted annually at Birmingham City University since 2004, and similar events held there in other years (e.g. TechFest in 2011 and 2012).

These static and mobile sensors are also often internet-linked through wired, WiFi or mobile-broadband links. Therefore, even without addition of wireless and wired sensor meshes most modern universities already have potential to leverage significant amounts of sensor data to provide context awareness. However, where such meshes are to be created there are a wide range of inexpensive sensors already available for use. Some of these are illustrated on the left side of Figure 2, which includes an RFID reader, proximity, infrared/ultrasonic distance, atmospheric pressure, light level, temperature, humidity, acceleration, rotation, sound level, methane gas, and dust sensors.

Figure 1. The 2012 MicroMouse Championships held in Birmingham (UK).

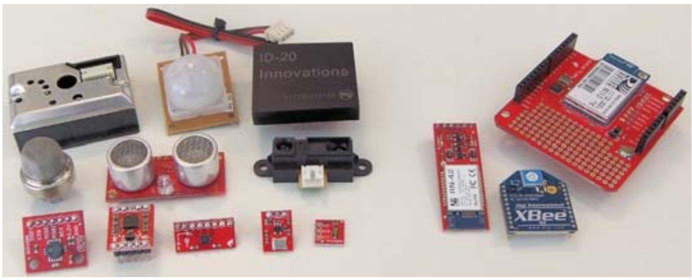

Figure 2. A selection of commonly available and inexpensive sensors and communications modules.

A significant advantage of these commonly available sensors, apart from low cost, is that they can be obtained as modules and so facilitate contribution to sensor-mesh data by students at all ability levels. In so doing students gain a greater ownership of the sensor systems, enhance their academic learning and gain skills relevant to future employment. As compared to developing such systems through engaging external specialists, this allows for a greater symbiosis between universities, students and technological systems. Similarly, use of sensors in student work can be facilitated at all academic levels through use of user-friendly microcontrollers, such as the widely used Arduino [3] compatible devices. For new students, and those not deeply engaged in electronics, this allows engagement with sensor systems and data, and for more advanced students does not preclude development of much more sophisticated, yet compatible, sensor circuits. This approach encourages engagement over a wide range of disciplines, including the built environment, art and automotive engineering, amongst others. There are also a wide range of communication options available for such scenarios, as illustrated on the right side of Figure 2 which shows relatively inexpensive XBee Pro (ZigBee), WiFly (WiFi) and Bluetooth modules. Use of modular systems in sensor meshes also allows them to be more dynamic by facilitating modification and relocation as required for academic use and student projects. They also allow for rapid prototyping, for students and researchers alike.

As there is a need for study and research if universities are to remain cutting edge, use of single communications systems is unlikely to be appropriate and so combinations of technologies and protocols are likely to be required. For instance, in addition to those shown in Figure 2, systems based around WirelessHART, Ultra-wideband technologies, 6LoWPAN, ISA100 and low-energy Bluetooth [17] are likely to be required as well as simple license-free RF transceivers and novel systems designed as part of academic research. Furthermore, such communications methods can face significant challenges when installed in modern buildings relying heavily on steel for their construction. For instance, the Birmingham City University offices at Millennium Point are a turn of the 21st Century steel-framed building significantly different to the brick and concrete structures traditionally common on campus at many universities. The prevalence of metal within the structure, floors and walls causes significant difficulty in terms of types, cost and coverage of sensor networks. Initial tests using Xbee Pro (ZigBee) transceivers, expected to provide open-air communications over more than a kilometer, provided only short range communications within the building. Therefore attempts to provide sensor-mesh coverage of all rooms on all four floors would most likely be prohibitively expensive. For that reason, incorporation of wireless sensor meshes into existing wired and wireless network infrastructure may often be the most appropriate approach in many modern buildings. Of course, that also provides additional challenges and diversity, and so real-life skills, for student projects based upon wireless sensor-node designs.

4. Cloud services and data brokerage

As discussed in [20], cloud computing may be considered to comprise four main elements: infrastructure, software, application and business clouds. However, this misses the potential to fully acknowledge the importance of education within all of those elements, so for the purposes of this paper an 'education cloud' is also considered to exist. As well as providing educational services an education cloud can include all of the other four clouds, including as a sandboxed environment for technology projects and teaching. Given the computer and networking facilities available for student use in modern universities, together with the creativity of the students, it is apparent that cloud and data systems creation for the iCampus could be a popular project area.

There are many advantages inherent in education cloud development, not least being the ability to offer tailored interactive content to students in an environment that fosters collaboration while providing student-specific advice to improve results and avoid plagiarism. For instance, rather than providing static graphics, text and equations to represent a design problem, students could be provided with 3D models that they can explore and adapt through changing key parameters (i.e. parametric modeling). This allows timely feedback to reinforce learning, is potentially more engaging than traditional course content, and allows students to easily consider 'what-if' approaches to learning that provide useful research skills for later employment. However, much more is possible with the education cloud. One example is development of interactive posters, which can be enhanced using many means, including incorporation of graphical encoding of information (e.g. QR codes), facial recognition, RFID tags and mobile-friendly communications systems such as near-field and Bluetooth [6]. Also, the trend toward significant use of multimedia within course content, especially important for remote delivery, is likely to rely heavily on cloud services in the future (see e.g. [35] for more details on the challenges and opportunities of distributed multimedia within the cloud).

Recent trends in sensor use for research and recreation have also led to an increasing need for data-brokerage, as illustrated by the success of the Cosm (previously Pachube) website [9]. For many student projects such websites provide an ideal platform, but as data creation grows in an iCampus it is obvious that continually retrieving data from a third-party server causes unnecessary overheads, especially when intelligent agents require continual access for data processing and scraping. Furthermore, growing data gathering and storage could lead to existing systems becoming overwhelmed both by data rates and data quantities. Also, access to such extensive databases requires increasingly sophisticated and context-relevant access methods, including natural language interfaces. Therefore, there is a need for development of suitable open-source data brokerage servers for educational use. As many universities do not allow ad-hoc use of corporate servers for running scripts and dynamic content, this is likely to require dedicated cloud systems.

Regardless of the above, it must be noted that security issues are a significant factor for adoption of cloud services and platforms, especially as their use effectively places reliance on a third party to maintain the requisite security levels [25]. For large educational institutions that concern may be partly alleviated due to the scale-of-operation allowing them to maintain their own cloud servers and software. Therefore, it is important to remember that the iCampus will require careful planning in terms of IT infrastructure design, as well as training of IT staff members, if it is to be successful in avoiding issues associated with data-bottlenecks caused by inadequate equipment and increased bandwidth needs. Development, and securing, of those university maintained cloud systems could also be bolstered by related academic research and projects. Given the increased power usage associated with processing large quantities of data, those projects are likely to require careful consideration of how the iCampus can be achieved as part of low-carbon, energy positive, neighborhoods.

5. Security, data validation and authentication

As with any risk, the potential problems of data security must be considered in terms of likelihood and magnitude [16]. In an academic context unauthorized access to such things as room temperature data, light levels and other similar sensor mesh variables may be of low importance. Also, where such data is offered openly, as is likely to be more common due to Web 3.0 and the Internet of Things, the importance may be inconsequential. For iCampus development therefore, security considerations may be primarily confined to data sources and control systems legally and/or ethically requiring significant containment. For students, development of security protocols, and methods for such data and systems, can be considered of significant benefit in terms of project-relevance and later employability.

Integrating varied data sources into the iCampus brings a significant challenge due to the varied communications methods involved. For instance, staff currently providing WiFi and wired network support, utilizing established security protocols, will have to adapt to the complexity of incorporating wireless meshes and associated protocols such as ZigBee and WirelessHART. Of course, in a student-centric design system that problem may be reduced through student engagement with system development. In terms of wireless sensor networks, a serious security threat comes from jamming, which often takes the form of overwhelming sensor signals with higher power transmissions that significantly reduce the signal-to-noise ratio (SNR) [30]. Jamming causes data loss, the significance of which will vary with the sensors context. For instance, occasional loss of environmental temperature data is unlikely to be significant, whereas loss of biometric sensor data in medical training could be life threatening.

The impact of SNR jamming can be largely overcome through good sensor network design, such as using directional antennas, monitoring received signal strength indicators and frequency-hopping, but a more pernicious threat may be that of 'deceptive jamming' [30]. This involves injecting fake data into the sensor network in order to corrupt datasets and/or overwhelm available communication bandwidths. Such deception is of course not limited to the sensor network per se, it being possible to introduce it at any point in the system. As it may be difficult, or impossible, to detect fake data, this form of spoofing can be considered a very serious threat to iCampus systems.

Interesting methods of reducing such spoofing intrusion are possible. For instance, signal strength information, together with known locations of static communication nodes, can be used to identify and localize attacks [7]. In parallel with other context data, and intelligent agents to process those data, such methods could allow early warning for university security personnel, especially when combined with CCTV. Other context data can also be used, such as the times at which sensor data are received. Figure 3 shows differences between scheduled transmission intervals (in this case hourly), and received intervals at a web server, for a ZigBee enabled sensor node at Birmingham City University. That latency is associated with timing accuracy, sensor measurements, wireless transmission and internet routing, and reduces outside of core business hours due to reduced internet access.

Even without a real-time clock, and operating over a three week period, it is obvious from Figure 3 that a probability of data not being fake can be significantly enhanced using reception timing, as a high degree of confidence can be placed on data arriving within a small window. That can be further improved through use of timing-variation algorithms that could enhance other encryption methods. Obviously there

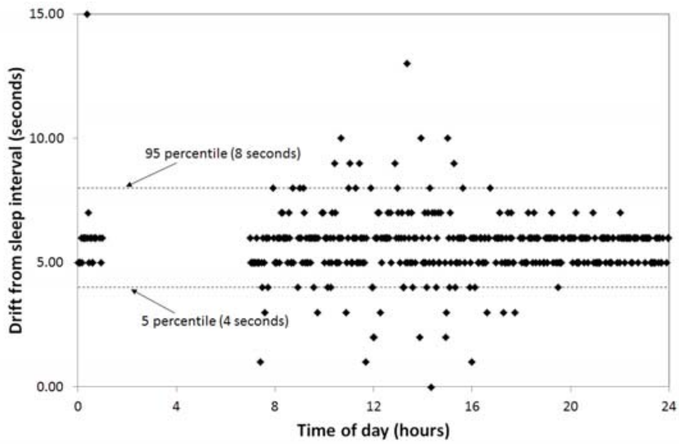

Figure 3. Example of wireless sensor communications timing accuracies, in terms of the difference between the programmed and web-server measured delay between transmissions (drift), at various times of the day.

would be some unwanted data loss due to variations in internet connection speeds. Where such data loss is unacceptable distributed measuring of internet-latency [21] could add greater intelligence to sensor data authentication in the cloud.

6. Learning-anywhere-anytime and Mobile Learning

Mobile handheld devices (MHDs), as well as laptops commonly used by students, offer significant potential for transforming education, allowing interaction with the Internet of Things and provision of anywhere-anytime study. This can include development of virtual laboratories to reinforce practical work outside of lectures, or even to move it to a virtual-platform for distance learning. As an example, Figure 4 shows a prototype virtual lab that allows access to simulated measurement data accurately representing those which can be obtained using real laboratory equipment. It also utilizes 3D graphics to allow student exploration of measurement probes where not physically available to them. Virtual labs can also be controlled by instructors through internet connections to sensors and measurement equipment, allowing online demonstrations before later use to reinforce that learning. It is possible to develop them for use on a wide range of mobile and PC platforms, the code for Figure 4 being based on the Processing (www.processing.org) Java libraries, allowing it to be used on Windows, Mac OSX, Linux, Android, iPads and most other devices if they have a modern HTML5 web-browser.

A significant advantage of MHDs for learn-anywhere-anytime systems is that they are owned by many students and so form a familiar basis for projects based on them. However, they also present many challenges largely due to variations in form factor,

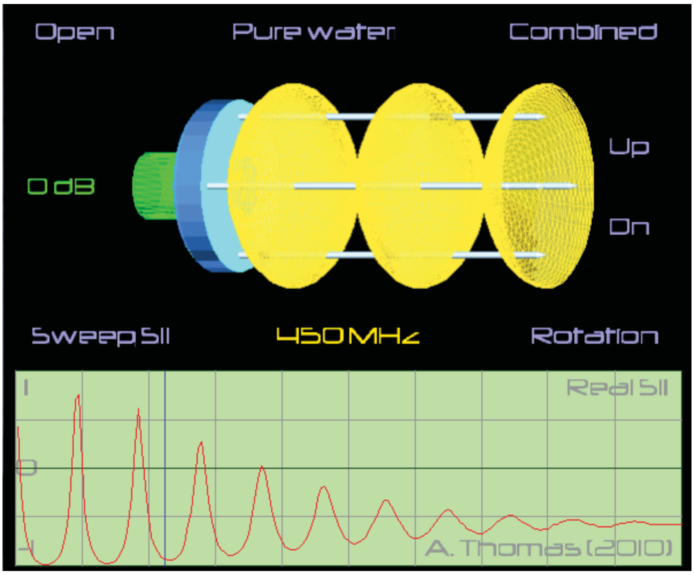

Figure 4. A prototype, Java-based, virtual science laboratory.

input devices, communications speeds and processing hardware [8]. Furthermore, they have limited battery power and what is available can be eroded by increasingly sophisticated features such as graphics with power requirements that can grow quicker than battery power density [27].

Further challenges ensue from the current wide range of available MHDs. As recently as 2010 Hu et al. [23] described the market transition from Microsoft's Windows Mobile, to Symbian OS, as the dominant operating system. At the time of writing, Apple and Android devices have become arguably the most targetable OS's for mobile learning systems, particularly in regard to their dominance of high-end mobile tablet markets. Those significant changes over a few years illustrate the risks and challenges faced in developing MHD educational software as it cannot be guaranteed that current OS's will remain dominant into the far future.

An important aspect of this is code portability between OS's, both between current devices and into future devices. Hu et al. [23] commented that "C/C++ dominates the handheld languages, with Java coming in a distant second." With the increasing prevalence of Android OS Java-based devices there is an obvious dynamism in the dominant programming languages required by MHD software developers. In an academic context where time and resources are limited, and risk is to be avoided, there is an obvious advantage in adopting cloud-based web apps, due to greater compatibility between devices utilizing Apple's WebKit in their browsers. However, depending solely on cloud computing raises the challenge of how to ensure adequate usability for students in low-bandwidth mobile-internet areas, as well as of how to provide minimum-bandwidth, maximum-learning, systems for devices with limited power-sources. Fortunately, such bandwidth problems may be reduced by near-future implementation of 4G networks, once devices able to access them become widespread.

MHDs also provide the opportunity for presenting rich media learning on the move, such as through use of audio and video streaming. However, a particularly exciting development in MHD use for data visualization is 3D content. Most common MHDs (e.g. iPhones, iPods and Android devices) already allow development of OpenGL ES 3D applications based on Khronos Group specifications. However, of significance to educational WebApp development is the increasing usability of WebGL on MHDs, such as through the Opera and Mobile Firefox browsers, which could significantly enhance student projects based on iCampus-data visualization. This raises challenges associated with controlling excessive power requirements for mobile 3D content [27] and minimizing associated delivery bandwidth requirements (e.g. see [24]). Current trends in autostereoscopic 3D displays on some MHDs also offer, in addition to increased realism of some 3D content, the potential to turn educational 3D content users with dual-camera devices into content-creators [15], thus enhancing collaborative MHD use.

It should also be noted that MHDs are themselves a context (and context-aware) requiring respect for bandwidth requirements in learn-anywhere systems, even if the introduction of 4G networks reduces that need mostly to GreenICT issues. An interesting method of minimizing bandwidth for complex, potentially interactive, 3D visualizations is parametric graphics.

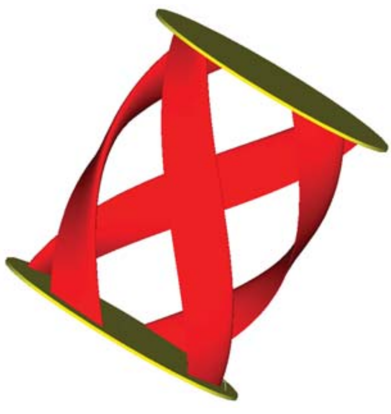

Figure 5. A bandwidth-efficient parametric geometry.

For instance, floating point representation of the color, location, scale and orientation of a cube in 3D-space can be achieved parametrically (or through use of vertex data and face indices) using less than 50 bytes. Representation of that cube as a full screen portable network graphics image on an iPad would require approximately 5000 times the bandwidth just to show a static image. Parametric data is therefore a highly bandwidth efficient means of delivering 2D and 3D interactive content for learning on MHDs, as demonstrated by Figure 5 which requires transmission of less than 100 floating-point values for its construction.

7. Context and personalisation

Contextual information is central to the effective realization of iCampus initiatives as it facilitates personalized service provision predicated on the accommodation of expressed preferences and system derived constraints [28]. Personalized service provision [29] provides a basis upon which intelligent context-aware systems can tailor course content and target resources to maximize educational success, based on historical measurements of engagement, assignment grades, and the provision of student support through difficult periods (including practical work through virtual laboratories). It can also help students identify where they risk plagiarism, reducing that risk by providing feedback at key stages during coursework preparation. As personalization is based on individual students, this would also provide a unique opportunity for them to engage with projects that tailor course content to their own personal preferences and contexts.

As detailed in this paper, useful contextual information (processed context data) can be obtained from sensors and MHDs. Context in terms of an iCampus is inherently complex and domain specific. It is formed around many complicated systems with many interconnections, as illustrated in Figure 6. Multiple users occupy a number of roles, including with multiple data sources, ranging from: (1) sensors, (2) communication systems, (3) microcontrollers, (4) computers, (5) cloud-based services including software-as-a-service, and (6) intelligent agents. Academic staff and students pervade that system at all points, in terms of development, maintenance and learning.

In a distributed, cloud-based, highly interactive and interconnected system the differentiation between concepts including sensors, context middleware, and user becomes blurred. For instance, sensors are generally in the form of electronic devices; however in the iCampus other sensors exist including systems which measure users' prevailing states, and even people as sensors into their own state (e.g. through user-interfaces and social media analysis). Advanced usage of contextual information has expanded the traditional uses of location and identity data and investigated a wider range of contextual information. These developments are characterized by investigations into the use of Kansei Engineering, using Kansei Words [34], which measures and digitizes users' feelings, sensibilities, and emotions. That is potentially very useful in measuring academic engagement which is an important element in delivering e-learning. Also, sensors in the web-agents address a number of functions; e.g., monitoring scheduled sensor data latency.

Additionally, in virtual personal networks, MHDs may act as middleware, without user intervention, to collect data from sensors and personal-area networks with limited energy-harvested power or short wireless transmission ranges. Furthermore,

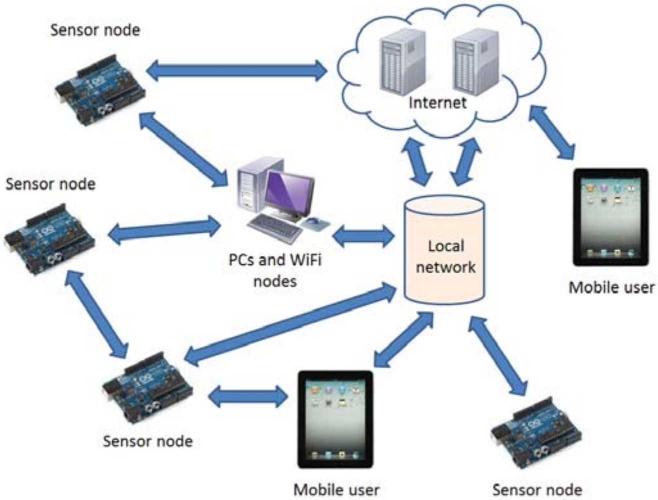

Figure 6. The complexity of data routing, storage and context in an intelligent context-aware iCampus implemented in a distributed mobile learning system.

sensors can act as end users of context data, adapting their sensing activities (and any associated control systems) to particular needs. The iCampus therefore needs to provide an extended network infrastructure and an intelligent physical infrastructure. Both need to be designed to provide significant, and highly distributed, intelligence within a large system incorporating hard (i.e. hardware and software) and soft (i.e. human and artificially intelligent software and hardware) components and interconnections. Development of ontologies, using ontology-based context modelling, can therefore be expected to play a critical role in iCampus development, due to the large number of interactions and connections described above, but also due to the increased context-categories inherent in its extension of the physical campus. A few of many examples of relevant context areas are:

- Student contexts: Greater utilization of social media is likely to add to the complexity of data personalization and sharing. However, even without that need content-provision, feedback, intervention, engagement-monitoring and suchlike will require an ontology reflecting individual needs, including special needs, abilities/disabilities and learning-styles.
- System contexts: Ontologies for intelligent student-support require knowledge of available resources and how they relate to different aspects of courses. For instance, intelligent systems providing feedback on learning must be linked to timetables to ensure the information is relevant: e.g. whether for in-depth learning or last-minute revision.

- Connection contexts: Content must obviously be tailored to device contexts (e.g. PC and mobile websites) and available bandwidth. However, in terms of the iCampus the means of connection has greater meaning within ontologies: it can represent, for instance, in-depth learning (e.g. PC access) or quick searches for learning-reinforcement and revision data (e.g. mobile-phone 3G/4G access).
- Location and time contexts: Compared to timetabled classroom teaching, learn-anywhere-anytime study requires ontologies that understand location and time constraints. For instance, students may require access to 'bite-size' information when quickly accessing their courses on the move, more in-depth information during student-specific core learning times, or lecture-specific notes in class.
- Physical contexts: iCampuses are likely to largely integrate into existing physical campuses for many students. Therefore, ontologies must reflect physical and electronic resources, including how the two relate, if they are to adequately support student needs, and ensure they are directed to the most relevant information sources.
- Virtual contexts: Use of virtual reality and chat-bot interfaces, for instance, allow creation of campus metaphors that do not represent a true physical layout or content, and participants in immersive worlds can exhibit altered ways of interacting with their environments compared to the real-world. Therefore, all of the above may require ontologies able to cope with both real and virtual interaction.
- External contexts: Future campuses will have to fit closely with initiatives such as iCities, open-data and GreenICT. Given increased financial costs associated with choosing university study, many students may even consider it their right to know how the iCampus can be judged in those terms. Therefore, there will be needs for interface ontologies that can provide personalized access to such data.

Contextual information, including data derived from sensor networks, also has the potential to facilitate improved collaborative environments. For instance, Tomek and Shakshuki [39] propose three main types of groupware appropriate to education environments: (1) space-based, (2) document-based, and (3) activity-based. For each of these environments students are obviously the most important element, but engaging in symbiosis with hardware and software based systems. They can be summarized in academic terms as follows:

- Space-based: collaborative environments utilizing geospatial clues for representation of data, such as in Second Life. Space-based and situated-computing (see [14]) environments can include use of virtual reality and 3D graphics, as well as maps. Such environments can be seen as an analogy for a real-life campus environment.
- Document-based: collaborative environments in which data is represented in terms of projects and documents including: text documents, books, spreadsheets, and presentations. This has an obvious analogy to libraries, research notes, lecture notes, coursework and examinations within academia.

- Activity-based: collaborative environments where virtual meetings take place and team decisions are discussed. There is an obvious analogy to formal (e.g. student discussion groups and seminars) and ad-hoc (e.g. corridor encounters and lunch meetings) information sharing and collaboration in academia.

Each of these forms of virtual collaboration is important to the iCampus concept and requires pertinent context data. For instance, spatio-temporal, proximity (of other users, I/O devices, wireless networks, printers and such like), coursework access records, and scheduling data, amongst others, are important. These data and contextual information can allow mobile learning systems to suggest the most relevant online content. Systems, such as the 'active badge' [42], have been developed that allow automatic updating of peoples locations within buildings, which when used on-campus could facilitate context capture for space-based iCampus systems. However, where extension of existing surveillance is required in the iCampus, user acceptance will need to be investigated, together with the legal issues around employer/lecturer surveillance of others, the need for adequate security, and the potential for misuse of those data.

For remote and distance learning, respect for the above forms of collaboration can allow students and researchers peer-contact for both study and recreational purposes. In distance learning the level of student engagement can be approximated, and for all students relevant feedback can be intelligently provided to enhance engagement and understanding. This not only adds to the potential benefits, in terms of the available contextual information, but also clearly adds to the overall complexity. However, it must be remembered that space, document and activity based environments already exist in physical university spaces, and so in the iCampus must be designed to work in parallel with them. For instance, moves toward greater use of electronic resources in libraries, as well as greater use of social media in education, allow a gradual move toward the iCampus concept, thus reducing risk and allowing time for it to be formed around the developing needs of students.

8. Conclusions

Many challenges, and significant complexity, are associated with development of the iCampus, but components such as sensors, wireless mesh architectures, cloud services, data brokerage/processing, intelligent software-agents, security, mobile learning, context and personalization are all currently available and widely researched. However, most are either not widely used, or do not exist, within educational establishments, so educational technology can currently be considered to parallel the vision of Web 2.0, making extensive use of collaborative technologies such as electronic whiteboards, Moodle, online forums, and student-accessible online course data. Therefore, moving toward a Web 3.0 analogy in education, as proposed in this paper, will also present challenges associated with appropriately integrating existing technologies into intelligent and context aware systems. That integration must obviously respect the pedagogical and study-method needs of students and academic staff (e.g. lecturers and researchers). However, it could bring significant benefit through personalized-learning if based around adequate ontologies fully recognizing the complexity inherent in attempting to develop intelligent and interactive learning systems, robustly based around student learning-needs.

Some of those benefits can already be achieved through interactive online course content, virtual labs and video-conferencing, which can provide opportunities for learn-anywhere-anytime study and reinforcement of knowledge acquisition through practical work outside of lectures. In terms of moving closer to the iCampus, use of virtual learning environments, with intelligent software-agents, is being actively researched. Such environments provide opportunities for campuses to transcend 'smart', becoming more 'intelligent' and bridging the gap between physical and virtual learning scenarios. This best-of-both-worlds approach can allow students greater flexibility in choosing their preferred learning methods, but requires significant use of sensors (and associated cloud systems) if it is to be able to interact intelligently with those students. For instance, sensors can provide the virtual senses, as a form of context data, for intelligent chat-bots and virtual reality avatars, leading to more appropriate interactive abilities. Coupled with greater use of mobile devices, and with adaptation of existing technologies, multi-modal interaction with the iCampus also becomes location-independent.

Therefore, it can be concluded that development of the iCampus concept is not primarily about developing individual components, but rather requires attention to detail in three key areas: tailoring those components for use in academic environments; developing their interconnectivity and interoperability to a high level of accuracy and robustness; and fully engaging with the concept that presentation of the data to end-users must maximize educational impact and enjoyment of knowledge acquisition. Each of those areas can be considered equally important if the iCampus is to be perceived as a useful extension to existing physical campuses, although it should be noted that robustness will depend upon first ensuring that networking infrastructures are carefully designed around the need for low-latency, low-downtime and high-bandwidth connections. However, it must be noted that the success of iCampus initiatives will be judged not on their technological sophistication, but on acceptance by the students around whom higher education is based and the iCampus must be designed. In this paper a novel element has been introduced that may facilitate increased acceptance: development of systems that can be achieved with significant student input.

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