

# Low Cost Ubiquitous Context-Aware Wireless Communications Laboratory for Undergraduate Students

Juan F. Valenzuela-Valdés,  
Pedro J. Pardo, Pablo Padilla, and  
Antonio José Lozano-Guerrero, *Member, IEEE*

**Abstract**—Wireless Communication technologies are in continuous evolution. Around the world, many Universities try to provide innovative laboratory courses to train their students in this field. In this paper, a ubiquitous laboratory course for wireless communications is described. The laboratory course has been designed so that the students have to complete six different experiments. Three of these experiments have been designed to use advanced professional network testing tools in order to provide practical experience in simulation tools. Two additional experiments have been implemented in order to provide hands-on measurements through the student's mobile device. This is a novelty and provides the students with an example of ubiquitous learning. Finally, in the last experiment, the students manufacture a WiFi antenna. The laboratory has been designed so that the students develop different practical skills in each experiment. This laboratory course facilitates applied learning and the consolidation of theoretical concepts.

**Index Terms**—Active learning methodologies, engineering education, ubiquitous learning, wireless communication

## 1 INTRODUCTION

THE new context of the European Area for Higher Education [1] and the current social environment marked by new technologies imply that new Telecommunication Engineers must be trained not only in technical knowledge but also in the professional skills that they must use in their professional life [2]. The effectiveness of hands-on experience to produce meaningful learning has been clearly demonstrated, for example [3], [4], indicating the need to train university students in specific professional skills. Over the last few years the ABET engineering criteria [5] have served as a guideline to develop professional skills in order to achieve this. In Problem-Based Learning (PBL) [6], [7], students are confronted with an open-ended, ill-structured, authentic (real-world) problem, whereas PBL begins with an assignment that must lead to the production of a final product—a design, a model, a device or a computer simulation. The former method is always active and collaborative and, typically, involves significant amounts of self-directed learning on the part of the students. For this reason, the learning methodology chosen in this laboratory-course is PBL.

Teaching wireless communications is usually oriented towards providing mainly a theoretical background for the students. A generic search through the academic plans of different universities in engineering reveals that lots of them provide laboratory courses in order to increase the effectiveness of the learning process.

We strongly believe that the efficacy of a course covering many theoretical topics can be increased through hands-on experiments as pointed out in [8], [9], [10], [11], [12]. Similar studies often

appear in the literature emphasizing the importance of a laboratory environment for teaching [8], [9], [10], [11], [12], moreover, in recent years there are several publications containing experiences that virtualize these laboratories courses [13], [14], [15]. These laboratories (e-learning) offer many advantages and some disadvantages compared to traditional engineering laboratories.

Analyzing some of the different communication laboratory courses around the world, it is possible to find different tools and methods focused on different aspects of wireless communications learning. In what follows, we provide an overview of them.

First, there are laboratory courses that use simulation software. These e-learning labs provide some advantages over conventional engineering laboratories. The simulation laboratory consists of a simplified version of a system. Although criticized for not incorporating enough real-life experiences, they have some advantages for the learning process. In this group, some university learning plans have been developed specifically for teaching with simulation tools. As a sub-group, it is possible to cite Wi-FiSiM from the University of Huelva (Spain) [16] and WeFiLab from the University of Hong Kong (Hong Kong) [17] and a very recent revision of this laboratory type can be found in [18]. Another type of simulation tools used by Universities is “OMNeT++”, an extendible, modular, component-based C++ simulation library for building network simulators that is used at the Universities of Budapest (Hungary) [19] and Monash University, (Australia) [20], among others. The last subgroup includes a great number of Universities that use communication tools developed on Matlab-Simulink in their laboratory courses, such as the John Hopkins University [21]. Whatever the sub-group, it is essential to take into account the software licenses available and whether these tools can be installed on the students' computer or if it is mandatory to use the software in the laboratory.

In a second group, there are laboratory courses that include some measuring tasks or the use of hands-on RF systems. For example, at Stanford University [22], students learn to use spectrum and network analyzers combined with some simulation tools. In addition, some laboratory courses offer the possibility of designing and building different parts of a wireless system or network. For example, at Texas University (USA) [23], the laboratory is based on LabVIEW and RF hardware. Spectrum and network analyzers, as well as other kinds of expensive equipment, have their advantages as reported in [22], [23] but are not always available.

The laboratory course described in this paper is a ubiquitous laboratory that includes measurements, real experiments and the building up of some parts of the system at almost no cost. This laboratory implements a new measurement method based on the mobile device of the student and combines the advantages of ubiquitous learning with some of the advantages of a physical laboratory. That is, this laboratory has the advantages reported in [22], [23] that provided the use of instrumentation combined with the advantages of learning anytime and anywhere. One of the strengths of this work is that we propose the use of mobile devices not only for the student to visualize the contents but also as a low cost, ubiquitous instrument of measurement as presented in the following section.

This paper is organized as follows: Section 2 reviews ubiquitous learning, Section 3 describes the general features and the student learning outcomes (LOs). The six laboratory experiments are outlined in Section 4. The impact of the new laboratory regarding teaching and learning is provided in Section 5. Finally in Section 6, the conclusions are discussed.

## 2 UBIQUITOUS LEARNING

M-learning is a teaching and learning methodology using small mobile devices, such as mobile phones, PDAs, tablets, PocketPC,

- J. F. Valenzuela-Valdés and P. J. Pardo are with the Universidad de Extremadura, Merida, Spain. E-mail: juanvalenzuela@unex.es.
- P. Padilla is with the Dpto. Teoría de la Señal, Telemática y Comunicación, Universidad de Granada, Granada, Spain. E-mail: pablopadilla@ugr.es.
- A. J. Lozano-Guerrero is with the Dpto. Tecnologías de la Información y las Comunicaciones, UPCT, Cartagena, Murcia, Spain. E-mail: antonio.lozano@upct.es.

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iPod. Modern learners have increasing demands on their time and are often forced to study during their lunch breaks, in the evenings and at weekends; and to study at work or on the bus, train or in the car. The use of portable technologies makes it easier for learners to study when and where they want by making it simple for them to transport their learning materials. They also facilitate “just-in-time” learning where learners can often take advantage of unexpected free time since they frequently have their devices with them.

There have been many recent studies on m-learning [24], [25], [26], [27], [28], [29], [30], [31], [32], [33]. A first group of studies analyze different ways to use mobile technology in learning [24], [25], [26], [27], [28], [29], in [27], the differences between e-learning and m-learning are compared, with some positive differences in favor of the latter, in [28], the use of mobile technology that enables the informal and semi-informal learning is analyzed. In [29], the impact of m-learning in students and educators is analyzed. Another group of studies focus on specific characteristics such as size and weight of mobile devices in [30] or in [31] the effectiveness of using different devices to access information with an eye tracking is analyzed and in [32] the effectiveness of a text summarization tool for mobile devices is studied. Finally, a review, analysis and synthesis of 164 studies of m-learning in the last years is performed in [33].

The concept of “context-aware ubiquitous learning” was introduced with the increase of different capabilities of the mobile device as: geospatial technologies, social networking and different camera uses (visual search or image capture) as explained in [27] and defined in [34] as “In a context-aware ubiquitous learning environment, single students are guided to learn in a really world situation with support or instructions from a computer system or using a mobile device to access the digital content via wireless communications”, That is, in u-learning wireless technologies are used to interact with the real world. More studies can be found in [35], [36].

In order to recap, m-learning uses the device to listen to or watch an audio or video broadcast or reproduce digital content for learning. U-Learning also uses wireless technology to interact with the real world. In this experience the use of mobile devices goes one step further and the students learn using their own device as measurement tool, adding a degree of interaction with the mobile device that help to achieve a meaningful learning. In addition, the different capabilities of the device allow to create one “context aware ubiquitous learning environment” to interact with the real word and moreover these capabilities are used to learn the concepts about wireless network, that is, these mobile applications allow studying wireless network parameters in real time and in the real word in order to learn how wireless networks work

### 3 OBJECTIVES AND LEARNING OUTCOMES OF THE LABORATORY COURSE

For each of the six experiments that comprise the laboratory-course, a theoretical section (with sessions of 2 hours) and a detailed instruction of the tasks to be done are provided, along with deliverables (slides of both parts are available online and a discussion forum is enabled in order to solve questions and doubts). The laboratory sessions are based on a ubiquitous learning methodology in which students can conduct the experiment at any time and any place, but lecturers have tutoring hours in which they are available to solve doubts face to face.

#### 3.1 Pedagogical Scenario

The laboratory course duration was 15 weeks with 4 hours per week. The laboratory is organized with 50 percent of the time for theoretical sessions and 50 percent of the time for practical sessions. In order to prepare each experience a week of theoretical

sessions where the theoretical basis and practical operation for experimentation were explained was scheduled. Experiments 3, 5 and 6 needed two weeks of practice and experiments 1, 2 and 4 just one week, that is, the experiences 3, 5 and 6 were performed in 8 hours and experiences 1, 2 and 4 should be completed within 4 hours. The experiences were scheduled in groups of two people preferably, but three people groups were allowed. To obtain the maximum qualification, the students had to defend the delivered report during an oral presentation.

As different types of experiences were created a higher interaction between different groups was promoted. For example, in the experiences of computer simulation (Practice 1, 2 and 3), students were quite autonomous and when doubts arose they addressed directly to the teacher in most of the cases. In addition, they were more experienced with this type of practice. However, in experiences 4 and 5 they had to perform them out of a classic learning context (This had to be done outside the classroom) and this led to an exchange of information between groups. For example, the students exchanged different types of information, from the apps that showed a better performance to the positions where they were finding the base stations or different Access Points in wireless networks. When the students start with this interchange of information a discussion is induced. This discussion usually results in a meaningful learning in any time and any place. The students are required to deliver a report of their work for each experiment within a fixed timetable. At the end of the term, a final mandatory exam evaluates their learning outcomes.

The laboratory, designed with wireless networks in mind, must be developed in a ubiquitous way. Therefore, the tool must be installable in the students’ computer or device. The license of the required software must be available for free to the maximum number of students possible. The laboratory-course covers three different aspects of wireless networks: the first covers the planning and dimensioning of wireless networks, related to experiments 1, 2 and 3. The second implements experiments 4 and 5 and is related to the measurement of the physical propagation layer in a novel way through mobile applications. The last aspect is related to the design, building and testing of components. The manufacturing of a homemade WiFi antenna is the objective of this last experiment. The LOs and the tools utilized in each experiment are shown in Table 1.

## 4 LABORATORY EXPERIMENTS

As mentioned, the laboratory is comprised of six different experiments. Experiments 1, 2 and 3 are related to the design of wireless networks, experiments 4 and 5 are related to network measurement and the last one is related to the implementation and building of WiFi antennas. All students have to submit a post-experiment report (10-15 pages) at the end of each experiment.

### 4.1 Experiment 1: Design of a WiFi Network (Part I)

The first experiment is designed to introduce the students to the use of professional simulation tools to design WiFi networks. The software tool chosen was RF3D WiFi Planner [37] because its demo-version is available for free and the interface is user-friendly. In order to design the WiFi networks, the students have to place all the different elements inside the building: the nodes (different nodes with different parameters are pre-charged) and the obstacles (e.g., beams, windows, bricks, concrete walls, etc.). The results of this simulation are also easily managed and are shown in relation to the signal-to-noise ratio (SNR) (dB), the received power (dBm), the data rate (Mbps) and the signal interference (dBm) are also provided.

Students are required to design a WiFi network which varies slightly each year to avoid plagiarism matters. For example one

TABLE 1  
Laboratory Experiments, Used Tools, and Learning Outcomes

Used tools		Learning outcomes (LOs)	
		Cognitive LOs	Psychomotor LOs
Ex.I	RF3D WiFi Planner	Knowledge of different WiFi standards Knowledge of different WiFi antennas	Work with “easy” wireless simulation tools. Know how to use different WiFi antenna Use simulation tool in order to design an “easy” WiFi network
Ex.II	Aerohive	Knowledge of different WiFi standards Knowledge of different WiFi antennas  Understand planning and optimization techniques in WiFi networks	Work with “hard” wireless simulation tools Use simulation tool in order to design a full WiFi network Know how to develop a capacity or coverage study of a WiFi network Know how to avoid interference in WiFi networks
Ex.III	Xirio Online	Understand different mobile standards  Knowledge of different base station types: macrocell, microcell, picocell etc. . . Understand planning and optimization techniques in mobile networks	Understand planning and optimizing in mobile networks Know how to design and operate GSM and UMTS networks Know how to develop a capacity or coverage study of GSM radio networks Know how to use different base stations types to increase coverage or decrease interference
Ex.IV	Mobile application: “WiFi Scanner”, “WiFi Analyzer” and “Speed test”	Understand mechanisms for propagation of radio waves  Know the differences between indoor/outdoor radio wave propagation Understand interference problems	Use mobile devices as a measurement tool for WiFi networks
Ex.V	Mobile application: “OpenSignal Maps”, “GSM signal monitor”, “G-Net Track” and “Speed test”	Understand concepts related to cellular telephony, such as roaming and handover  Understand mechanisms for propagation of radio waves Know the differences between indoor/outdoor radio wave propagation Understand interference problems	Use mobile devices as measurement tools for Mobile networks
Ex.VI	Cables, connectors and some materials	Become familiar with antennas and antenna parameters Knowledge of the most common types of antennas	Acquire some experience in the manufacture of antennas Know how to design basic antennas

year, they are required to develop a network with eight Access Point (AP) with 300 Mbps of data rate and one different antenna at each AP. In order to make this network it is necessary implement standard 802.11n with a MIMO option, therefore if the students are able to design a network using this standard the teachers can consider the cognitive LO “Knowledge of different WiFi Standards” to be satisfied. Likewise, if the students are able to use eight different antennas in order to complete their design adequately, the cognitive LOs “Knowledge of different WiFi Antenna” and the psychomotor LO “Know how to use e different types of WiFi Antenna” have been achieved. Similarly, if the experiment report contains a WiFi network that was designed with the software RF3D WiFi Planner the teacher can consider that psychomotor LOs have been achieved. The assessment of LOs through the evaluation report is complemented by the final exam results. Thus the main objective of this first experiment is to permit the students to become familiar with simulation tools for wireless networks.

## 4.2 Experiment 2: Design of a WiFi Network (Part II)

Once the basics of design of WiFi networks have been practiced in experiment 1, in the second experiment the students have to design a full WiFi network for one or more of the University Campus buildings or another group of buildings of their own choice. They are required to design the networks in order to take into account different issues related to wireless networks,

such as: security, cost, system definition (number of AP, data rates, standard, etc.), commercial equipment available and the applicable legislation (electromagnetic compatibility, public spectrum, etc.). In this case, the software tool chosen is Aerohive [38], which is available online. The evaluation of LOs achieved in this experiment is through the report and is very similar to the evaluation of the LOs in experiment 1. For example, if the networks designed by students are able to adequately provide indoor/outdoor coverage, the teachers consider the cognitive LO “Know how to implement planning and optimization techniques in WiFi networks” to have been achieved, if the networks designed contain a detailed study of coverage and capacity, the psychomotor LOs “Know how to develop a capacity or coverage study of WiFi networks” has also been achieved.

## 4.3 Experiment 3: Design of a Mobile Network

With the experience of designing a WiFi network acquired previously, the students must design a small mobile network. They are free to choose one standard among the different possibilities (GSM, UMTS, WiMAX, etc.) offered by the online platform “Xirio online” [39] in order to carry out the experiment. Moreover, this platform has cartography available for a great number of countries. Although this system only allows the free simulation to be performed with low resolution, it covers the educational objectives adequately.



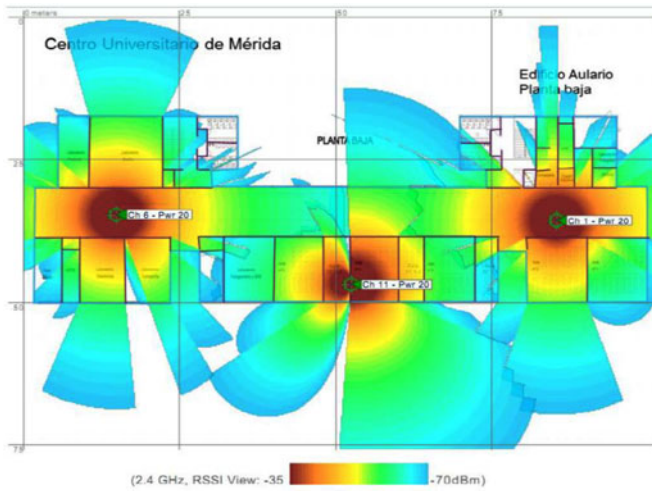


Fig. 1. Screenshots of Aerohive application.

Similarly to previous experiments the assessment of LOs achieved is through the evaluation report and the final exam mark. They must choose the best standard to implement the required mobile network, if they choose the right standard, they have achieved the cognitive LOs. A screenshot of this software tool is shown in Fig. 1 (This screenshot shows RSSI level simulated in our Campus”).

#### 4.4 Experiment 4: Measurement of a WiFi Network

The objective of this experiment is to measure and obtain the maximum information possible regarding a WiFi Network using the student’s own mobile or tablet device. The students are required to present a full study of the WiFi networks available in the University Campus (one or two buildings) or any other location they choose. This full study must contain several maps with signal strength and data rates that explain the values obtained. They must use free mobile applications, such as “WiFi Scanner & Net Discovery” [40] or “WiFi Analyzer” [41] to obtain information, or “Speed Test” [42] to measure data rates, using their devices as the measuring equipment in both cases. Moreover, other applications for PCs, such as “Heat mapper” from Ekahau [43], can be useful



Fig. 3. Screenshot of the routes.

for developing coverage maps. The students achieve the psychomotor LOs “Use with mobile devices as measurement tools for WiFi networks” if they provide coverage maps of the WiFi network with correct signal strength values in the report. Some screenshots of these applications are shown in Fig. 2.

#### 4.5 Experiment 5: Measurement of Mobile Networks

After having measured WiFi networks, the students are required to measure and identify different mobile networks. The students must search for applications that allow their mobile devices to provide them as much information as possible regarding the mobile network. The applications most frequently used are “OpenSignal Maps” [44], “GSM signal monitor” [45] and “G-Net Track” [46], which are freely available in Google Play Store. These applications provide information about signal strength, direction of arrival and RSSI among other mobile network parameters. Moreover, some of these applications are capable of testing the data-rate of the networks and locating the different mobile stations on a map. Fig. 3 shows one screenshot of one mobile application. Once this information is available, the students should follow a route through the city identifying the different mobile phone networks available on their route. They must also think about the various phenomena associated with signal propagation. For instance, they must find the approximate point where the handover occurs (most of the time this point is not in the middle point between the users and the mobile stations because of the different radio propagation conditions). They are also asked to make a small sketch including the mobile network cells and the different mobile systems available along the route. With this experiment, the cognitive LOs “Understand concepts related to cellular telephony, such as roaming and handover” is achieved if the report contains examples of handovers produced on the student’s device.

#### 4.6 Experiment 6: Build an WiFi Antenna

The sixth experiment consists of making a homemade WiFi antenna. This antenna has to be connected to their laptops to improve system performance. The antenna prototypes must increase the number of wireless networks reached, as well as the quality of the signal received from those wireless networks. The antennas are developed using their own technology, so the students must look for more information on making antennas, as well as the theory and practice of manufacturing WiFi antennas. Moreover, in this experiment knowledge is gained through the process of problem solving. The different designs made by students are shown in Fig. 4.

### 5 LABORATORY ASSESSMENT

This laboratory ran in the academic years 2011/2012 and 2012/2013 and is also running this academic year. This laboratory is part of the last year of studies in “Telematic engineering”. The number



Fig. 2. Screenshots of Wi-Fi explorer scanner & net discovery and WiFi analyzer applications.



Fig. 4. Prototypes of WiFi antennas developed by students.

TABLE 2  
Mean and Standard Deviation Scores in the Final Exam and Post-Experiment Report from Different Academic Years

ITEM	Mean 11/12	Mean 12/13	Standard Deviation 11/12	Standard Deviation 12/13
1.-Test.	7.19	7.09	0.77	1.03
2.-Reports	7.50	7.45	0.66	1.05

Response (0 to 10).

of students ranges between 15-24 students per year. This section presents the project assessment in two different ways: the first approach discusses the LOs achieved by students, the second one shows the students' opinions.

### 5.1 Learning Outcomes Achieved

All students have to write a post-experiment report. The results of the evaluation of the post-experiment reports and the final exam are shown in Tables 2 and 3. The final exam is divided into six different parts that correspond to the six different laboratory experiments. The report scores are higher than those achieved in the exam. In experiment 6, not all students built an antenna that improves the performance of the laptop's internal antenna in at least one of the evaluated aspects. However, there were two designs that improved performance in the first year and three in the second year.

The results of the final exam lead to the following conclusions:

- The results in both years are reasonably good.
- Post-Report 1, 4 and 5 have maximum scores. For the post-experiment 1, these scores are probably due to the fact that the first experiment is easier compared with the other 5. For post-experiments 4 and 5, the explanation is probably that the students are highly motivated by the use of their own devices as a measurement tool.
- Post-Report 6 has the worst mean scores and the highest standard deviation, this is due to the fact that some students were very interested in antenna design and tried to improve the design and therefore obtained high scores, however other student did not finish and received a low mark.
- The questions related to experiment 1 (T1) have the best scores, this is due to the question related to experiment 1 is the basic part of question included in experiment 2 (T2).

### 5.2 Students' Opinion of the Project

This section provides the opinion of the students regarding the project expressed through an anonymous survey. The survey shows the degree of satisfaction with the projects, in each item

TABLE 3  
Mean and Standard Deviation Scores in the Final Exam and Post-Experiment Report

ITEM	1	2	3	4	5	6
1.-Test Mean.	7.56	6.85	7.35	7.29	7.41	6.43
2.-Test Standard D.	0.81	0.89	0.81	1.01	1.04	0.99
3.-Reports Mean.	7.90	6.99	7.38	8.03	7.70	6.85
4.-Reports Standard D.	0.57	1.11	0.69	0.78	0.89	1.24

Response (0 to 10).

TABLE 4  
Students Survey Response (1 to 5)

ITEM	Mean 11/12	Mean 12/13
1.-The work on this project has been an experience. ... Very bad(1) / Very good (5)	4.16	4.36
2.-Because of this work, I have improved my skills Nothing (1) / Lot (5)	4.08	3.88
3.-The methodology used for the project is: Very bad (1) / Very good (5)	4.22	4.63
4.-Teacher evaluations: Very bad (1) / Very good (5)	4.37	4.5

there are several questions and Table 4 shows the mean values for all students and questions by item.

From the results of the survey, the following can be concluded: first, a good score in all items was achieved and second, the students valued the experience and the methodology used more than the acquired skills. Finally, the support of teachers during the project was evaluated very positively by the students in spite of the reduced number of face to face lessons.

## 6 CONCLUSIONS

The laboratory course described offers three main advantages in relation to the laboratories used by other universities: first, it provides ubiquitous context-aware learning environments, including physicals measures that address a weak point in ubiquitous learning; second, the material needed to implement the laboratory work is almost free; third, the students learn how to exploit the capabilities of their mobile devices. Moreover, a new technological use/functionality of a mobile device is introduced, that is, to use the mobile device as a low cost measurement tool that allows students to learn about wireless networks, exploring the ubiquitous context-aware learning environments in an innovative way.

Moreover, the results of the final exam have improved, if compared to those in previous years. The good results on reports and the final exam demonstrates a high degree of achievement of curriculum goals. In addition, the students have developed skills such as "Research" and "Troubleshooting", both educational goals in higher education. Finally, the teachers believe that these learning experiences are quite encouraging, given the positive feedback obtained and the degree of satisfaction reflected in the student's survey. In relation to future upgrades, the online platform of experiment 3 has been upgraded with an Long Term Evolution (LTE) simulation tool and will be included in the experiment in the future.

## REFERENCES

- [1] M. J. Garcia-Garcia, C. Gonzalez, and R. Argüelles, "Methodological changes in technical teaching in order to the European higher education area comparison between countries: Italy and Spain," in *Proc. Soc. Behavioral Sci.*, 2009, pp. 2701-2706.
- [2] Á. Cajander and M. Daniels. "Development of professional competencies in engineering education," in *Proc. Frontiers Educ. Conf.*, 2011, pp. 51C 1-5.



- [3] J. Gil, A. L. Pérez, M. I. Suero, P. Solano, and P. J. Pardo, "Evaluation of the effectiveness of a method of active learning based on Reigeluth and Stein's elaboration theory," *Int. J. Eng. Educ.*, vol. 26, pp. 628–641, 2010.
- [4] G. Martínez, A. L. Pérez, M. I. Suero, and P. J. Pardo, "The effectiveness of concept maps in teaching physics concepts applied to engineering education: experimental comparison of the amount of learning achieved with and without concept maps," *J. Sci. Educ. Technol.*, vol. 5, pp. 1–11, May 2012.
- [5] *Engineering Accreditation Commission, ABET, Criteria for Accrediting Eng. Programs*, [Online]. Available: [http://www.abet.org/uploadedFiles/Accreditation/Accreditation\\_process/Accreditation\\_Documents/Current/eac-criteria-2012-2013](http://www.abet.org/uploadedFiles/Accreditation/Accreditation_process/Accreditation_Documents/Current/eac-criteria-2012-2013)
- [6] I. De los Ríos, A. Cazorla, J. M. Díaz-Puente, and J. L. Yagüe, "Project-based learning in engineering higher education: Two decades of teaching competences in real environments," in *Proc. Soc. Behavioral Sci.*, 2010, vol. 2, pp. 1368–1378.
- [7] A. Kartal and M. Bakaç, "The effects of problem based learning and traditional teaching methods on students' academic achievements, conceptual developments and scientific process skills according to their graduated high school types," in *Proc. Soc. Behavioral Sci.*, 2010, vol. 2, pp. 2409–2413.
- [8] J. Sarik, A. I. Akinwande, and I. Kyymissis, "A laboratory-based course in display technology," *IEEE Trans. Educ.*, vol. 54, no. 2, pp. 314–319, May 2011.
- [9] A. Drosopoulos and M. Hatziprokopiou, "Planning and development of lab training activities for powerline communications," *IEEE Trans. Educ.*, vol. 53, no. 3, pp. 384–389, Aug. 2010.
- [10] M. E. Radu, C. Cole, M. A. Dabacan, J. Harris, and S. Sexton, "The impact of providing unlimited access to programmable boards in digital design education," *IEEE Trans. Educ.*, vol. 54, no. 2, pp. 174–183, May 2011.
- [11] A. Hofstein and V. H. Lunetta, "The laboratory in science education: Foundations for the twenty-first century," *Sci. Educ.*, vol. 88, no. 1, pp. 28–54, 2004.
- [12] S. Jung, "Experiences in developing an experimental robotics course program for undergraduate education," *IEEE Trans. Educ.*, vol. 56, no. 1, pp. 129–136, Feb. 2013.
- [13] T. Wolf, "Assessing student learning in a virtual laboratory environment," *IEEE Trans. Educ.*, vol. 53, no. 2, pp. 216–222, May 2010.
- [14] M. A. Marques, M. C. Viegas, M. C. Costa-Lobo, A. V. Fidalgo, G. R. Alves, J. S. Rocha, and I. Gustavsson, "How remote labs impact on course outcomes: Various practices using VISIR," *IEEE Trans. Educ.*, vol. 57, no. 3, pp. 151–159, Aug. 2014.
- [15] I. Santana, M. Ferre, E. Izaguirre, R. Aracil, and L. Hernandez, "Remote laboratories for education and research purposes in automatic control systems," *IEEE Trans. Ind. Informatics*, vol. 9, no. 1, pp. 547–556, Feb. 2013.
- [16] T. J. Mateo Sanguino, C. Serrano Lopez, and F. A. Marquez Hernandez, "WiFISiM: An educational tool for the study and design of wireless networks," *IEEE Trans. Educ.*, vol. 56, no. 2, pp. 149–155, May 2013.
- [17] L. Cui, F. P. Tso, D. Yao, and W. Jia, "The WeFiLab: A web-based WiFi laboratory platform for wireless networking education," *IEEE Trans. Learn. Technol.*, vol. 5, no. 4, pp. 291–303, Oct.-Dec. 2012.
- [18] A. Gampe, A. Melkonyan, M. Pontual, and D. Akopian, "An assessment of remote laboratory experiments in radio communication," *IEEE Trans. Educ.*, vol. 57, no. 1, pp. 12–19, Feb. 2014.
- [19] A. Varga and R. Hornig, "An overview of the OMNeT++ simulation environment," in *Proc. 1st Simutools*, 2008, vol. 60, pp. 1–10.
- [20] Performance of Telecommunication Networks. Dept. Elect. Comput. Syst. Eng., Monash Univ. [Online]. Available: <http://titania.ctie.monash.edu.au/netperf/>
- [21] Johns Hopkins University establishes virtual laboratory for wireless communications with Simulink. The MathWorks. [Online]. Available: [http://www.mathworks.es/company/user\\_stories/Johns-Hopkins-University-Establishes-Virtual-Laboratory-for-Wireless-Communications-with-Simulink.html](http://www.mathworks.es/company/user_stories/Johns-Hopkins-University-Establishes-Virtual-Laboratory-for-Wireless-Communications-with-Simulink.html)
- [22] EE144/EE245—Wireless electromagnetic design laboratory. Stanford Univ. [Online]. Available: <https://ccnet.stanford.edu/ee144/>
- [23] EE 471C / EE 381V: Wireless Communications Lab. The Univ. of Texas. [Online]. Available: <http://www.profheath.org/teaching/ee-371c-ee-381v-wireless-communications-lab/>
- [24] S. S. Liaw, M. Hatala, and H. M. Huang, "Investigating acceptance toward mobile learning to assist individual knowledge management: Based on activity theory approach," *Comput. Educ.*, vol. 54, no. 2, pp. 446–454, 2010.
- [25] C. Evans, "The effectiveness of m-learning in the form of podcast revision lectures in higher education," *Comput. Educ.*, vol. 50, no. 2, pp. 491–498, 2008.
- [26] M. E. Marwan, A. R. Madar, and N. Fuad, "An overview of mobile application in learning for student of Kolej Poly-Tech Mara (KPTM) by using mobile phone," *J. Asian Sci. Res.*, vol. 3, no. 6, pp. 527–537, 2013.
- [27] F. Martin and J. Ertzberger, "Here and now mobile learning: An experimental study on the use of mobile technology," *Comput. Educ.*, vol. 68, pp. 76–85, 2013.
- [28] A. C. Jones, E. Scanlon, and G. Clough, "Mobile learning: Two case studies of supporting inquiry learning in informal and semiformal settings," *Comput. Educ.*, vol. 61, pp. 21–32, 2013.
- [29] H. R. Abachi and G. Muhammad, "The impact of m-learning technology on students and educators," *Comput. Human Behav.*, vol. 30, pp. 491–496, Jan. 2014.
- [30] D. Furió, S. González-Gancedo, M.-C. Juan, I. Seguí, and M. Costa, "The effects of the size and weight of a mobile device on an educational game," *Comput. Educ.*, vol. 64, pp. 24–41, May 2013.
- [31] A. I. Molina, M. A. Redondo, C. Lacave, and M. Ortega, "Assessing the effectiveness of new devices for accessing learning materials: An empirical analysis based on eye tracking and learner subjective perception," *Comput. Human Behav.*, vol. 31, pp. 475–490, Feb. 2014.
- [32] G. Yang, N.-S. Chen, Kinshuk, E. Sutinen, T. Anderson, and D. Wen, "The effectiveness of automatic text summarization in mobile learning contexts," *Comput. Educ.*, vol. 68, pp. 233–243, Oct. 2013.
- [33] W. H. Wu, Y. C. Jim Wu, C. Y. Chen, H. Y. Kao, C.-H. Lin, and S. H. Huang, "Review of trends from mobile learning studies: A meta-analysis," *Comput. Educ.*, vol. 59, pp. 817–827, Sep. 2012.
- [34] C. C. Chen and T. C. Huang, "Learning in a u-Museum: Developing a context-aware ubiquitous learning environment," *Comput. Educ.*, vol. 59, pp. 873–883, Nov. 2012.
- [35] G. Y. Hwang, T. C. Yang, C. Tsai, and S. J. H. Yang, "A context-aware ubiquitous learning environment for conducting complex experimental procedures," *Comput. Educ.*, vol. 53, no. 2, pp. 402–413, 2009.
- [36] C. K. Chiou, J. C. R., Tseng, G. J. Hwang, and S. Heller, "An adaptive navigation support system for conducting context-aware ubiquitous learning in museums," *Comput. Educ.*, vol. 55, pp. 834–845, 2010.
- [37] RF3D WiFi Planner. [Online]. Available: <http://www.psiber.com/en/home/products/wifi-simulation/rf3d-wifiplanner2.html>
- [38] Aerohive. [Online]. Available: <http://www.aerohive.com/solutions/solutions-industry/education>
- [39] Xirio online. [Online]. Available: <http://www.xirio-online.com/>
- [40] Wifi Scanner & Net Discovery. [Online]. Available: <https://play.google.com/store/apps/details?id=com.nutsaboutnets.wifiexplorer>
- [41] WiFi Analyzer. [Online]. Available: <https://play.google.com/store/apps/details?id=com.farproc.wifi.analyzer>
- [42] Speed test. [Online]. Available: <https://play.google.com/store/apps/details?id=org.zwanoo.android.speedtest1>
- [43] Ekahau Heat mapper. [Online]. Available: <http://www.ekahau.com/wifidesign/ekahau-heatmapper>
- [44] OpenSignal- mapas 3G/4G/WiFi. [Online]. Available: <https://play.google.com/store/apps/details?id=com.staircase3.opensignal>
- [45] GSM Signal Monitoring. [Online]. Available: <https://play.google.com/store/apps/details?id=com.signalmonitoring.gsmmonitoring1>
- [46] G-NetTrack. [Online]. Available: <https://play.google.com/store/apps/details?id=com.gyokovsolutions.gnettrack&hl=es>