Smart University Taxonomy: Features, Components, Systems

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Abstract Smart education creates unique and unprecedented opportunities for academic and training organizations in terms of higher standards and innovative approaches to (1) learning and teaching strategies—smart pedagogy, (2) unique highly technological services to local on-campus and remote/online students, (3) set-ups of innovative smart classrooms with easy local/remote student-to-faculty interaction and local/remote student-to-student collaboration, (4) design and development of Web-based rich multimedia learning content with interactive presentations, video lectures, Web-based interactive quizzes and tests, and instant knowledge assessment. This paper presents the outcomes of an ongoing research project aimed to create smart university taxonomy and identify main features, components, technologies and systems of smart universities that go well beyond those in a traditional university with predominantly face-to-face classes and learning activities.

Keywords Smart university · Smartness features · Smart university components · Systems · Smart pedagogy

1 Introduction

The "smart university" (SmU) concept and several related concepts, such as smart learning environment, smart campus, smart education, smart e-learning, smart training, and smart classrooms were introduced just several years ago; they are in permanent evolution and improvement since that time [1, 2].

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Smart education is rapidly gaining popularity among the world's best universities because modern, sophisticated smart technologies, smart systems and smart devices create unique and unprecedented opportunities for academic and training organizations in terms of higher standards and innovative approaches to (1) education, learning and teaching strategies, (2) unique services to local on-campus and remote/online students, (3) set-ups of highly technological smart classrooms with easy local/remote student-to-faculty interaction and local/remote student-to-student collaboration, (4) design and development of Web-based rich multimedia learning content with interactive presentations, video lectures, Web-based interactive quizzes and tests, instant knowledge assessment, etc. Additionally, "the analysts forecast the global smart education market to grow at a CAGR of 15.45 % during the period 2016–2020" [3]. "Markets and Markets forecasts the global smart education & learning market to grow from $105.23 Billion in 2015 to $446.85 Billion in 2020, at a Compound Annual Growth Rate (CAGR) of 24.4 %" [4].

Therefore, it is necessary to perform active research and obtain a clear understanding of what main features, components, technologies, software, hardware, pedagogy, faculty, etc. will be required by SmUs in the near future.

2 Smart University: Literature Review

Recently, various creative researchers and developers began presenting their vision of SmU concepts and principles; a brief summary of several remarkable publications on such concepts is given below.

Smart University. Tikhomirov's [5] vision is that "*Smart University* is a concept that involves a comprehensive modernization of all educational processes. … The *smart education* is able to provide a new university, where a set of ICT and faculty leads to an entirely new quality of the processes and outcomes of the educational, research, commercial and other university activities. … The concept of *Smart* in education area entails the emergence of technologies such as smart boards, smart screens and wireless Internet access from everywhere".

Smart Learning Environment. Hwang [6] presented a concept of *smart learning environments* "… that can be regarded as the technology-supported learning environments that make adaptations and provide appropriate support (e.g., guidance, feedback, hints or tools) in the right places and at the right time based on individual learners' needs, which might be determined via analyzing their learning behaviors, performance and the online and real-world contexts in which they are situated. … (1) A smart learning environment is context-aware; that is, the learner's situation or the contexts of the real-world environment in which the learner is located are sensed… (2) A smart learning environment is able to offer instant and adaptive support to learners by immediate analyses of the needs of individual learners from different perspectives… (3) A smart learning environment is able to adapt the user interface (i.e., the ways of presenting information) and the subject

contents to meet the personal factors (e.g., learning styles and preferences) and learning status (e.g., learning performance) of individual learners".

Smart Education. IBM [7] defines *smart education* as follows: "A smart, multi-disciplinary student-centric education system—linked across schools, tertiary institutions and workforce training, using: (1) adaptive learning programs and learning portfolios for students, (2) collaborative technologies and digital learning resources for teachers and students, (3) computerized administration, monitoring and reporting to keep teachers in the classroom, (4) better information on our learners, (5) online learning resources for students everywhere".

Cocoli et al. [8] described *smart education* as follows: "Education in a smart environment supported by smart technologies, making use of smart tools and smart devices, can be considered smart education… . In this respect, we observe that novel technologies have been widely adopted in schools and especially in universities, which, in many cases, exploit cloud and grid computing, Next Generation Network (NGN) services and portable devices, with advanced applications in highly interactive frameworks … smart education is just the upper layer, though the most visible one, and other aspects must be considered such as: (1) communication; (2) social interaction; (3) transport; (4) management (administration and courses); (5) wellness (safety and health); (6) governance; (7) energy management; (8) data storage and delivery; (9) knowledge sharing; (10) IT infrastructure".

Smart Campus. Kwok [9] defines *intelligent campus* (*i-campus*) "… a new paradigm of thinking pertaining to a holistic intelligent campus environment which encompasses at least, but not limited to, several themes of campus intelligence, such as holistic e-learning, social networking and communications for work collaboration, green and ICT sustainability with intelligent sensor management systems, protective and preventative health care, smart building management with automated security control and surveillance, and visible campus governance and reporting".

Xiao [10] envisions smart campus as follows: "*Smart campus* is the outcome of the application of integrating the cloud computing and the internet of things. …The application framework of smart campus is a combination of IoT and cloud computing based on the high performance computing and internet".

Smart Teachers. Abueyalaman [11] argues "A smart campus depends on an overarching strategy involving people, facilities, and ongoing faculty support as well as effective use of technology…. A smart campus deploys *smart teachers* and gives them smart tools and ongoing support to do their jobs while assessing their pedagogical effectiveness using smart evaluation forms".

Smart Learning Communities. Adamko et al. [12] describe features of smart learning community applications as follows: "… the requirements of the smart community applications are the following: (1) sensible—the environment is sensed by sensors; (2) connectable—networking devices bring the sensing information to the web; (3) accessible—the information is published on the web, and accessible to the users; (4) ubiquitous—the users can get access to the information through the web, but more importantly in mobile any time and any place; (5) sociable—a user can publish the information through his social network; (6) sharable—not just the data,

but the object itself must be accessible and addressable; (7) visible/augmented—make the hidden information seen by retrofitting the physical environment".

Smart Classrooms. An overview of smart classrooms of the first generations and requirements for second generation smart classrooms is available [13].

3 Research Project Goal and Objectives

The performed analysis of these and multiple additional existing publications and reports relevant to (1) smart systems, (2) smart technologies, (3) smart devices, (4) smart universities, (5) smart campuses, (6) smart classrooms, and (7) smart learning environments undoubtedly shows that "smart university" as a topic should be in the center of multiple research, design and development projects in upcoming years. It is expected that, in the near future, SmU concepts, features, hardware/software solutions and technologies will have a significant role and be actively deployed by leading academic intuitions—smart universities in the world.

Project Goal. The overall goal of the ongoing multi-aspect research project is to create a taxonomy of a smart university, i.e. to identify and classify a SmU's main (1) features, (2) components (smart classrooms, technological resources—systems and technologies, human resources, financial resources, services, etc.), (3) relations (links) between components, (4) interfaces, (5) inputs, (6) outputs, and (7) limits/constraints. The premise it that to-be-developed SmU taxonomy will (1) enable us to identify and predict most effective software, hardware, pedagogy, teaching/learning activities, services, etc. for the next generation of a university—smart university, and (2) help traditional universities to understand, identify and evaluate paths for a transformation into a smart university.

Project Objectives. The objectives of this project were to identify an SmU's main (1) features, (2) components, and (3) systems that go well beyond those in a traditional university with predominantly face-to-face classes and learning activities. Due to limited space, we present a summary of up-to-date research outcomes below.

4 Research Project Outcomes

4.1 Smart University: Distinctive Features

Our vision of SmUs is based on the idea that SmUs—as a smart system—should implement and demonstrate significant maturity at various "smartness" levels or smart features, including (1) adaptation, (2) sensing (awareness), (3) inferring (logical reasoning), (4) self-learning, (5) anticipation, and (6) self-organization and re-structuring (Table 1).

Table 1 SmU distinctive features (that go well beyond features of a traditional university)

SmU smartness levels	Details	Possible examples (limited to 3)
Adaptation	SmU ability to automatically modify its business functions, teaching/learning strategies, administrative, safety, physical, behavioral and other characteristics, etc. to better operate and perform its main business functions (teaching, learning, safety, management, maintenance, control, etc.)	• SmU easy adaptation to new style of learning and/or teaching (learning-by-doing, flipped classrooms, etc.) and/or courses (MOOCs, SPOCs, open education and/or life-long learning for retirees, etc.)
		• SmU easy adaptation to needs of students with disabilities (text-to-voice or voice-to-text systems, etc.)
		• SmU easy network adaptation to new technical platforms (mobile networking, tablets, mobile devices with iOS and Android operating systems, etc.)
Sensing (awareness)	SmU ability to automatically use various sensors and identify, recognize, understand and/or become aware of various events, processes, objects, phenomenon, etc. that may have impact (positive or negative) on SmU's operation, infrastructure, or well-being of its components—students, faculty, staff, resources, properties, etc.	• Various sensors of a Local Action Services (LAS) system to get data regarding power use, lights, temperature, humidity, safety, security, etc.
		• Smart card (or biometrics) readers to open doors to mediated lecture halls, computer labs, smart classrooms and activate features/software/hardware that are listed in user's profile
		• Face, voice, gesture recognition systems and corresponding devices to retrieve and process data about students' class attendance, class activities, etc.
Inferring (logical reasoning)	SmU ability to automatically make logical conclusion(s) on the basis of raw data, processed information, observations, evidence, assumptions, rules, and logic reasoning	• Student Analytics System (SAS) to create (update) a profile of each local or remote student based on his/her interaction, activities, technical skills, etc.
		• Local Action Services (LAS) campus-wide system to analyze data from multiple sensors and make conclusions (for ex: activate actuators and close/lock doors in all campus buildings and/or labs, turn off lights, etc.)
		• SAS can recommend administrators take certain pro-active measures regarding a student

(continued)

Table 1 (continued)

SmU smartness levels	Details	Possible examples (limited to 3)
Self-learning	SmU ability to automatically obtain, acquire or formulate new or modify existing knowledge, experience, or behavior to improve its operation, business functions, performance, effectiveness, etc. (A note: Self-description, self-discovery and self-optimization features are a part of self-learning)	• Learning from active use of innovative software/hardware systems—Web-lecturing systems, class recording systems, flipped class systems, etc.
		• Learning from anonymous Opinion Mining System (OMS)
		• Learning from different types of classes—MOOCs, blended, online, SPOCs, etc.
Anticipation	SmU ability to automatically think or reason to predict what is going to happen, how to address that event, or what to do next	• Campus-wide Safety System (CSS) to anticipate, recognize and act accordingly in case of various events on campus
		• Enrollment Management System to predict, anticipate, and control variations on student enrollment
		• University-wide Risk Management System (snow days, tornado, electricity outage, etc.)
Self-organization and configuration, re-structuring, and recovery	SmU ability automatically to change its internal structure (components), self-regenerate and self-sustain in purposeful (non-random) manner under appropriate conditions but without an external agent/entity. (A note: Self-protection, self-matchmaking, and self-healing are a part of self-organization)	• Automatic configuration of systems, performance parameters, sensors, actuators and features in a smart classroom in accordance with instructor's profile
		• Streaming server automatic closedown and recovery in case of temp electrical outage
		• Automatic re-configuration of wireless sensor network (WSN) because nodes may join or leave spontaneously (i.e. evolving network typology), university-wide cloud computing (with multiple clients and services), etc.

4.2 Smart University: Distinctive Main Components

SmUs may have numerous components of a traditional university; however, it must have multiple additional components to implement and maintain SmU distinctive features that are described in Table 1. Based on our vision of SmUs and outcomes of our research, the SmU main distinctive components should include at least those that are described in Table 2 below.

Table 2 SmU main components and main distinctive sub-components (that go well beyond components of a traditional university)

SmU components	SmU distinctive sub-components (that go well beyond those in a traditional university)
Software systems	• Web-lecturing systems (with video capturing and computer screen capturing functions) for learning content development pre-class activities • Smart classroom in-class activities recording systems • Smart cameraman software systems • Systems for seamless collaborative learning (of both local and remote students) in smart classroom and sharing learning content/documents • Collaborative Web-based audio/video one-to-one and many-to-many communication systems • Systems to host, join, form and evaluate group discussions (including both local and remote students) • Systems to replay automatically recorded class activities and lectures for post-class review and activities (by both local and remote students) • Repositories of digital learning content and online (Web) resources, learning portals • Smart learning analytics and smart teaching analytics systems • Speaker/instructor motion tracking systems • Speech/voice recognition systems • Speech-to-text systems • Text-to-voice synthesis systems • Face recognition systems • Emotion recognition systems • Gesture (activity) recognition systems • Context (situation) awareness systems • Automatic translation systems (from/to English language) • Intelligent cyber-physical systems (for safety and security) • Various smart software agents • Power/light/HVAC consumption monitoring system(s)
Technology	• Internet-of-Things technology • Cloud computing technology • Web-lecturing technology • Collaborative and communication technologies • Ambient intelligence technology • Smart agents technology • Smart data visualization technology • Augmented and virtual reality technology • Computer gaming (serious gaming) technology • Remote (virtual) labs • 3D visualization technology • Wireless sensor networking technology • RFID (radio frequency identification) technology • Location awareness technologies (indoor and outdoor) • Sensor technology (motion, temperature, light, humidity, etc.)
Hardware/equipment	• Panoramic video cameras • Ceiling-mounted projectors (in some cases, 3D projectors) • SMART boards and/or interactive white boards • Smart pointing devices • Controlled and self-activated microphones and speakers • Interconnected big screen monitors or TVs (“smart learning cave”) • Interconnected laptops or desktop computers • Smart card readers • Biometric-based access control devices • Robotic controllers and actuators

(continued)

Table 2 (continued)

SmU components	SmU distinctive sub-components (that go well beyond those in a traditional university)
Smart curricula	• Adaptive programs of study—major and minor programs, concentration and certificate programs with variable structures adaptable to types of students/learners, smart pedagogy, etc. • Adaptive courses, lessons and learning modules with variable components and structure suitable for various types of teaching—face-to-face, blended, online, types of students/learners, smart pedagogy, etc.
Students, learners, faculty	• Students and/or learners with blended or flexible learning • Fully remote (or fully online) students and/or learners • Life-long learners (retirees) in open education • Students with disabilities • Smart faculty (smart instructors)
Smart pedagogy	Active utilization and, if needed, adaptable combination of the following innovative types of pedagogy (teaching strategies): • Learning-by-doing (including active use of virtual labs) • Collaborative learning • e-Books • Learning analytics • Adaptive teaching • Student-generated learning content • Serious games- and gamification-based learning • Flipped classroom • Project-based learning • Bring-Your-Own-Device • Smart robots (robotics) based learning
Smart classrooms	Smart classrooms with corresponding technologies, software hardware systems, and smart pedagogy for smart education

4.3 Smart University: Distinctive Software Systems

As a part of this research project, for several classes of selected software systems, in Table 2 we

(1) analyzed about 10–15 existing systems usually—including both open source and commercial systems—by means of (a) review of system's functions and features, (b) review of system's demo version, (c) installation and testing of the systems, and (d) review of users and analysts' feedback,
(2) identified a list of main functions of those systems—functions to be required by SmUs, and (3) evaluated and ranked those systems. A brief summary of our research outcomes for selected classes of software systems for SmUs is presented in Table 3 below. A detailed list of references to all analyzed and mentioned below systems is available at Towards Smart University project web site at Bradley University at [14].

Table 3 Selected classes of software systems to be used by SmUs [14]

Class of systems	Open-source systems	Commercial systems	Our choice (1-best)
In-class activities recording systems	• Opencast	• Panopto	1—Opencast
	• ClassX	• Echo360 Lect. Cap.	1—Panopto
	• Kaltura	• Camtasia Studio	2—Kaltura
	• openEyA	• Mediasite Lecture C.	2—Mediasite
	• Lecture Record.x2	• Tegrity	3—ClassX
	• VSDC Video Ed.	• Valt	3—Echo360 L.C.
	• CamStudio	• Adobe Presenter 11	
	• SameView	• YuLa Lecture/Room C.	
Instructor-to-remote students audio/video conferencing systems (one-to-many, many-to-many)	• Skype	• WebEx Meeting Center	1—Hangouts
	• BigBlueButton	• TurboMeeting	1—BlackBoard C.
	• Open meetings	• Adobe Connect	2—BigBlueButton
	• DimDim	• Citrix	2—Adobe connect
	• Mconf	• Netop Vision ME	3—Skype
	• BlueJeans	• AB Tutor	3—GlobalMeet
	• Jitsi	• SoftLink	
	• Hangouts	• LAN School	
	• JoinMe	• GoToMeeting	
	• MeetingBurner	• GlobalMeet	
	• WebHuddle	• AnyMeeting	
	• Zoom	• BlackBoard Collabor.	
Web lecturing systems for pre-class learning content development activities	• InterLabs	• Camtasia Studio	1—CamStudio
	• ActivePresenter	• Adobe Presenter 11	1—Camtasia Stud.
	• Jing	• Movavi Studio V7	2—Ezvid Scr.Rec.
	• Webinaria	• CamVerse 1.95	2—Adobe Pres 11
	• Rylstim	• WM Recorder Bundle	3—Screen-O-Mat.
	• IceCream screen rec.	• Debut Video Capture	3—Movavi Stud.
	• CamStudio	• Fraps3.5.99	
	• Screen-O-Matic	• Snagit 12	
	• Flash Back Exp. Rec.	• 1AVCapture	
	• Ezvid Screen Rec.	• ScreenPresso	
Instructor motion tracking systems	• Motion	• Qualisys	1—Motion
	• Genious Vis. NVR	• Bosh Security	1—Bosh Security
	• iSpy	• Honeywell Mot.Sens.	2—Voodoo C.T.
	• OptiTrack	• Camera Viewer Pro	2—Qualisys
	• Zoneminder	• Netcam Studio	3—OptiTrack
	• Voodoo Camera Tr.		3—Netcam Studio

(continued)

Table 3 (continued)

Class of systems	Open-source systems	Commercial systems	Our choice (1-best)
Speech/voice recognition systems	• HDecode	• Dragon Natur.Sp.	1—Jasper
	• JULIUS	• IBM ViaVoice	1—Dragon N.S.
	• KALDI	• LH Voice Express	2—CSLU TK
	• CMU Sphinx	• Briana	2—Naunce Rec.
	• SHoUT Toolkit	• Kurzweil 3000	3—CMU Sphinx
	• SIMON	• IVR with SR	3—ViaTalk
	• eSpeak	• Tazti	
	• Jasper	• Speechlogger	
	• EmacSpeak	• iSpeech Translator	
	• MARF	• Rubidium	
	• IVONA	• ViaTalk	
	• CSLU Toolkit	• ClapCommander	
	• iListen	• Naunce Recognizer	
Gesture recognition systems	• OpenGesture	• GestureTek	1—GRT
	• GRT	• Cognitec	1—Myo
	• GR Engine	• Omek	2—HandVu
	• iGesture	• PointGrab	2—GestureTek
	• HandVu	• SoftKinetic	3—iGesture
	• LinHand	• Myo	3—Rithmio
	• GestureWorks	• Rithmio	
Face recognition systems	• OpenBR	• Cognitec FaceVACS	1- OpenBR
	• OpenCV	• EmoVu	1—FaceVACS
	• Skybiometry	• Kairos	2—FaceMark
	• FaceMark	• Eyeface	2—EmoVu
	• Libface	• Rekognition	3—Liccv
	• Libccv	• Face++	3—Kairos
Collaborative learning systems	• Cynapse	• Mikogo	1—Cynapse
	• Voki	• Socrative	1—Socrative
	• Storybirds	• Weebly	2—Sakai
	• Moodle	• Edmodo	2—ClassDojo
	• Sakai	• ClassDojo	3—Moodle
Context/situation awareness systems		• SARA	1—Qognify
		• Magitti	2—Magitti
		• Qognify	3—SARA

5 Conclusions

The performed research, and obtained research findings and outcomes enabled us to make the following conclusions:

(1) Leading academic intuitions all over the world are investigating ways to transform the traditional university into a smart university and benefit from the

advantages of a smart university. Smart University concepts, principles, technologies, systems, and pedagogy will be essential parts of multiple research, design and development projects in upcoming years.

(2) It is necessary to create a taxonomy of a smart university, i.e. to identify and classify SmU main (1) features, (2) components (smart classrooms, technological resources—systems and technologies, human resources, financial resources, services, etc.), (3) relations (links) between components, (4) interfaces, (5) inputs, (6) outputs, and (7) limits/constraints. The premise it that to-be-developed SmU taxonomy will (1) enable us to identify and predict most effective software, hardware, pedagogy, teaching/learning activities, services, etc. for the next generation of a university—smart university, and (2) help traditional universities to understand, identify and evaluate paths for a transformation into a smart university.

(3) Our vision of SmUs is based on the idea that SmUs—as a smart system—should implement and demonstrate significant maturity at various "smartness" levels or distinctive smart features, including (1) adaptation, (2) sensing (awareness), (3) inferring (logical reasoning), (4) self-learning, (5) anticipation, and (6) self-organization and re-structuring—the corresponding research outcomes are presented in Table 1.

(4) Based on our vision of SmUs, the identified SmU main components are presented in Table 2, and multiple analyzed and ranked software systems of selected classes to be used by SmU in Table 3.

Based on obtained research findings and outcomes, and developed SmU features, components and systems, the future steps in this research project are to (a) implement, test, validate, and analyze various identified software and hardware systems, technologies and smart pedagogy in smart classroom environment, (b) perform summative and formative evaluations of local and remote students and gather sufficient data on the quality of SmU main components—hardware, software, technologies, services, etc.).

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