Zhu et al. Smart Learning Environments (2016) 3:4
DOI 10.1186/s40561-016-0026-2

Smart Learning Environments

RESEARCH Open Access

A research framework of smart education

Zhi-Ting Zhu[1*], Ming-Hua Yu[2] and Peter Riezebos[2]

* Correspondence:
ztzhu@dec.ecnu.edu.cn
[1]Shanghai Engineering Research Center of Digital Education Equipment, East China Normal University, Shanghai, China
Full list of author information is available at the end of the article

Abstract

The development of new technologies enables learners to learn more effectively, efficiently, flexibly and comfortably. Learners utilize smart devices to access digital resources through wireless network and to immerse in both personalized and seamless learning. Smart education, a concept that describes learning in digital age, has gained increased attention. This paper discusses the definition of smart education and presents a conceptual framework. A four-tier framework of smart pedagogies and ten key features of smart learning environments are proposed for foster smart learners who need master knowledge and skills of the 21st century learning. The smart pedagogy framework includes class-based differentiated instruction, group-based collaborative learning, individual-based personalized learning and mass-based generative learning. Furthermore, a technological architecture of smart education, which emphasizes the role of smart computing, is proposed. The tri-tier architecture and key functions are all presented. Finally, challenges of smart education are discussed.

Keywords: Smart education, Personalized learning, Seamless learning, Smart learners, Smart learning environments, Smart pedagogy, Smart computing

Introduction

With the exponential technological advances, anything could be instrumented, interconnected, and infused with intelligent design, so is education. Smart education has gained significance attention in recent years. Educational projects focused on smart education have been performed globally in recent years (e.g. Chan 2002; Choi and Lee 2012; Hua 2012; IBM 2012; Kankaanranta and Mäkelä 2014). In 1997, Malaysia first carried out a smart education project, Malaysian Smart School Implementation Plan (Chan 2002). Smart schools, which are supported by government, aim to improve the educational system in order to achieve the National Philosophy of Education and to prepare work force that meets the challenges of the 21st century. Singapore has implemented the Intelligent Nation (iN2015) Master plan since 2006, in which technology-supported education is an important part (Hua 2012). In the plan, eight Future Schools that focus on creating diverse learning environments are established. Australia collaborated with IBM and designed a smart, multi-disciplinary student-centric education system (IBM 2012). Their system links schools, tertiary institutions and workforce training. South Korea had the SMART education project, the major tasks of which are reforming the educational system and improving educational infrastructures (Choi and Lee 2012). New York' Smart School program emphasizes the role of technology integrated into the classroom (New York Smart Schools Commission Report, 2014). They

Springer Open

© 2016 Zhu et al. **Open Access** This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

focus on enhancing student achievement and prepare students to participate in 21st century economy. Finland also realized a smart education project that is on-going systemic learning solutions (SysTech) in 2011. The project aims at promoting 21st century learning with user-driven and motivational learning solutions (Kankaanranta and Mäkelä 2014). United Arab Emirates (UAE) began to invest a smart learning program named Mohammed Bin Rashid Smart Learning Program (MBRSLP) in 2012, which aims to shape new learning environment and culture in their national schools through the launch of smart classes. Overall, the smart education focus and developments has become a new trend in the global educational field.

In the following sections, the related research topics of smart education development are reviewed; The concept of smart education and a conceptual framework for research are proposed; Also a research framework on smart education is depicted. Furthermore, the technological architecture of smart education is mentioned and the role of smart computing is depicted. Finally, the challenges of facilitating smart education are presented to inspire researchers and educators who are interested in smart education design and development.

Literature review

The evolution of smart learning

As a new educational paradigm, smart learning bases its foundations on smart devices and intelligent technologies (Lee et al. 2014; Kim et al. 2011). As identified and heavily studied over the last decennia, technology can be implemented and utilized in helping learners learn. This is described as technology-enhanced learning (TEL). TEL is used to provide flexibility in the mode of learning. Technologies can be as media or tools for accessing learning content (Daniel 2012), inquiry, communication and collaboration, construction (Bruce and Levin 1997), expression (Goodman 2003), and evaluation (Meyer and Latham 2008) in TEL.

With the development of mobile, connected and personal technologies, mobile learning has become a major TEL paradigm. Mobile learning emphasizes the utilizing of mobile devices and focuses on the mobility of the learner, in contrast to the static traditional educational types. In addition to that, the supporting of ubiquitous technology has caused further changes that moving learning style away from the mobile learning toward to the ubiquitous learning which emphasizes learning can take place anytime and anywhere without the limitations of time, locations, or environments (Hwang et al. 2008).

Recently, many research begin to pay attention to the importance and necessity of authentic activities in which learners work with problems in the real world (Hwang et al. 2008). In order to situate students in authentic learning environments, it is important to design learning that combine both real and virtual learning environments. Seamless learning, which overlaps with some aspects of mobile learning and ubiquitous learning, is expounded as an one-to-one TEL model which learners can learn across time and locations, and they can convert the learning from one scenario to another conveniently encompassing formal and informal learning, individual and social learning through the smart personal device (Chan et al. 2006).

Also other intelligent technologies, such as cloud computing, learning analytics, big data, Internet of things (IoT), wearable technology and etc., promote the emergence of

smart education. Cloud computing, learning analytics and big data, which focus on how learning data can be captured, analyzed and directed towards improving learning and teaching, support the development of the personalized and adaptive learning (Lias and Elias 2011; Mayer-Schönberger and Cukier 2013; Picciano 2012). With these adaptive learning technologies, learning platform reacts to individual learner data and adapts instructional resource accordingly based on cloud computing and learning analytics, and it can leverage aggregated data across mass learners for insights into the design and adaptation of curricula based on big data (NMC 2015).

In addition, the IoT and wearable technology support the development of contextual learning and seamless learning. The IoT can connect people, objects and devices. Learners carrying smart devices can benefit from various related information that is pushed to them from their surroundings (NMC 2015). Wearable technology can integrate the location information, exercise log, social media interaction and visual reality tools into the learning.

The concept of smart learning

There is no clear and unified definition of smart learning so far. Multidisciplinary researchers and educational professionals are continuously discussing the concept of smart learning. Still, some crucial components have been discussed in literature. Hwang (2014) and Scott & Benlamri (2010) consider that smart learning is context-aware ubiquitous learning. Gwak (2010) proposed a concept of smart learning as follows: first, it is focused on learners and content more than on devices; second, it is effective, intelligent, tailored learning based on advanced IT infrastructure. The technology plays an important role supporting smart learning, but the focus should not just on the utilization of smart devices. Kim et al. (2013) considered that smart learning, which combines the advantages of social learning and ubiquitous leaning, is learner-centric and service-oriented educational paradigm, rather than one just focused on utilizing devices. Middleton (2015) also stipulates on the learner-centric aspects of smart learning and how it benefits from the use of smart technologies. The personal and smart technologies make learners engaging in their learning and increase their independence in more open, connected and augmented ways by personally richer contexts.

Also, others attempt to indicate the features of smart leaning. MEST (2011) presented the features of smart learning that is defined as self-directed, motivated, adaptive, resource-enriched, and technology-embedded. Lee et al. (2014) proposed that the features of smart learning include formal and informal learning, social and collaborative learning, personalized and situated learning, and application and content focus.

Smart learning environments

Generally, smart learning environment is effective, efficient and engaging (Merrill 2013). The learner is always considered as the heart of smart learning environment. And the goal of smart learning environment is to provide self-learning, self-motivated and personalized services which learners can attend courses at their own pace and are able to access the personalized learning content according to their personal difference (Kim et al. 2013). Koper (2014) proposed that smart learning environments are defined as physical environments that are enriched with digital, context-aware and adaptive

devices, to promote better and faster learning. Hwang (2014) specified that the potential criteria of a smart learning environment include context-aware, able to offer instant and adaptive support to learners, and able to adapt the learner interface and subject contents. Smart learning environment not only enables learners to access ubiquitous resources and interact with learning systems anytime and anywhere, but also provides the necessary learning guidance, suggestions or supportive tools to them in the right form, at the right time and in the right place.

Learning can take place anytime and anywhere via the utilization of smart devices. The context-aware aspect plays an important role in smart learning environments that can support to provide proper learning service to learners. Kim et al. (2011) designed a smart learning environment based on cloud computing. The smart learning service provides context-awareness supporting push smart learning content to learners through collecting and analyzing their behaviors. It aims to provide personalized and customized learning services to learners. Scott and Benlamri (2010) built a smart learning environment, which is learner-centric and service-based, based on semantic web and ubiquitous computing. The learning environment is composed by ubiquitous collaborative learning spaces, which transform traditional learning spaces into intelligent ambient learning environments through context awareness and real-time learning services. Huang et al. (2012) considered a smart learning environment is high-level digital environment that realizes learning context awareness, recognizes learner's characteristic, provides adaptive learning resources and convenient interactive tools, records learning process automatically and evaluates learning outcomes. Its goal is to support easy, engaged and effective learning for learners.

Based on interactive resources and services, smart learning environment is learner-initiated and collaborative (Noh et al. 2011). Spector (2014) considered that smart learning environment supports planning and innovative alternatives for learners and instructors, and should be effectiveness, efficiency, engagement, flexibility, adaptivity, and reflectiveness. And these features might include support for collaboration, struggling learners and motivation.

Through reviewing these literatures, we can find that smart learning environment emphasizes learner-centric, personalized and adaptive learning service, interactive and collaborative tools, context-aware and ubiquitous access. And smart learning environment aims to support to realize the effective, efficient and meaningful learning for learners.

The meaning of smart in smart education

Globally many countries have participated in projects focused on smart education. Malaysian smart schools aim to help their country to foster the workforce of 21st century by utilizing and enabling the leading-edge technologies into schools. And the smart schools not only focus on stimulating thinking, creativity, and caring for the students, but also considering the individual differences and learning styles among their learners. The smart education in Singapore also emphasizes the role of technology. Their goal is to foster engaging learning experience to meet the diverse needs of learners, through the innovative use of information and communications technology (Education and Learning Sub-Committee, 2007). In order to realize this, Singapore created an enriching and personalized learner-centric environment, and additionally

created a nation-wide education and learning architecture for educational institutions and life-long learning. Korea carried out the smart education project to provide the customized and adaptive learning for students to foster self-directed learning ability and have fun to use various resources and technology. Individualized instruction and creativity-centered education is considered as the main keyword of smart education. Australia aims to build a smart, multi-disciplinary student-centric education system using the following strategies: adaptive learning programs and learning portfolios for students, collaborative technologies and digital learning resources for teachers and students, computerized administration, monitoring and reporting, and online learning resources. New York proposed the keys for achieving Smart School as following: embracing and expanding online learning, utilizing transformative technologies, connecting every school using high-speed network, extending connectivity between inside and outside of the classroom, providing high-quality, continuous professional development, and focusing on foster 21st century skills (New York Smart Schools Commission Report 2014). Finnish smart education aims at using user-driven and motivational learning solutions to promote 21st century learning (Kankaanranta and Mäkelä 2014). They proposed a pedagogical network of educational institutions called "value network" that is the central of program. It has five categories as following: to understand user experience and usability, to receive expert feedback, to indicate learning outcomes, effects and quality of learning, to develop skills and expertise (Mäkelä et al. 2014). United Arab Emirates (UAE) aims to advance their education system to student-centric through the application of world-class teaching science and latest technology. They encourage learner to develop creativity, analytic thinking and innovation. Their approach encompasses learning both inside and outside the classroom. The students can control and active participant into their own learning process in interactive, engaging and enabling learning environments.

Through analyzing these smart education projects, we can find some generalities as follows. The goal of smart education is to foster workforce that masters 21st century knowledge and skills to meet the need and challenge of society. Intelligence technology plays an important role in the construction of smart educational environments. In smart educational environments, learning can happen anytime and anywhere. It encompasses various learning styles, such as formal and informal learning, personal and social learning, and aims to realize the continuity of learning experience for learner. In this learners are provided with personalized learning services as well as adaptive content, and according to their (learning) context and their personal abilities and needs. So generally, 'smart' in smart education refers to intelligent, personalized and adaptive. But for different entities and/or educational situations, the meaning of 'smart' has different definitions.

For learner, 'smart' refers to wisdom and intelligence. Wisdom is defined as the ability to use your knowledge and experience to make good decisions and judgments. According to Confucius who is the most famous educator of China, wisdom can be achieved by three methods: reflection (the noblest), imitation (the easiest) and experience (the bitterest). In addition, the intelligence is the ability to solve problems that are valuable in one or more cultural settings (Gardner 2011). According to the concepts of wisdom and intelligence, we comprehend that smart for learner means an ability enabling people to think quickly and cleverly in different situations.

For educational technology, 'smart' refers to accomplish its purpose effectively and efficiently (Spector 2014). The technology includes the hardware and software. For

hardware, 'smart' refers to the smart device much smaller, more portable and affordable. It is effective to support learner take place the learning anytime and anywhere with smart devices. And some hardware (e.g., smartphones, laptop, Google glass, etc.) has functions to recognize and collect the learning data to engage the learner into contextual and seamless learning. For software, 'smart' refers to adaptive and flexible. It is efficient to carry out personalized learning for learner according to their personal difference, with adaptive learning technologies (e.g. cloud computing, big data, learning analytics, adaptive engine, and etc.).

For educational environment, 'smart' refers to engaging, intelligent and scalable. Smart educational environment can provide tailored and personalized learning service (e.g. context awareness, adaptive content, collaborative and interactive tool, rapid evaluation and real-time feedback, etc.) to engage the learner into effective, efficient and meaningful learning. And the open system architecture is required to better support the integration of increasing interfaces, smart devices and different learning data.

Research framework of smart education

Based on the generalities of different countries' smart education and the meaning of smart, the concept of smart education is proposed. Zhu and He (2012) stated that "the essence of smart education is to create intelligent environments by using smart technologies, so that smart pedagogies can be facilitated as to provide personalized learning services and empower learners, and thus talents of wisdom who have better value orientation, higher thinking quality, and stronger conduct ability could be fostered "(p. 6).

And based on this definition of smart education, a research framework is proposed in Fig. 1. This framework describes three essential elements in smart education: smart environments, smart pedagogy, and smart learner. Smart education emphasizes the ideology for pursuing better education and thus had better to be renamed as smarter education, which address the needs for smart pedagogies as a methodological issue and smart learning environments as technological issue, and advances the educational goals to cultivate smart learners as results. Smart environments could be significant influenced by smart pedagogy. Smart pedagogies and smart environments support the development of smart learners.

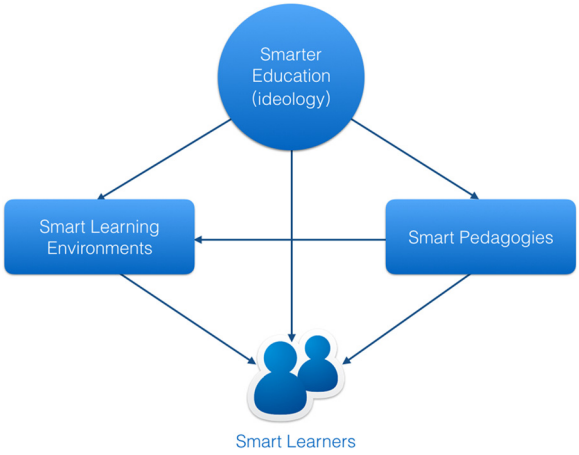

Fig. 1 Research framework of smart education

Smart learners

Learning is conventionally defined as the process of acquiring competence and understanding. It results in a new ability to do something, and an understanding of something that was previously not understood. Competence is sometimes described in terms of possessing specific skills, understanding in terms of possessing specific knowledge.

The 21st century demand skills and competence from people in order to function and live effectively at work and leisure time. Education needs to prepare workforce for the demand. So the goal of smart education is to foster smart learners to meet the needs of the work and life in the 21st century.

There are many organizations developing the 21st century skills independently. The Organization for Economic Co-operation and Development (OECD) have organized ten 21st century skills into four categories which include ways of thinking, tools for working, ways of working and ways of living in the world (Ananiadou and Claro 2009). Partnership for 21st century (P21 2015) skills proposed a framework for the 21st century learning and indicated that the 21st century student should master these knowledge and skills as follows: key subjects and 21st century themes; learning and innovation skills; information, media and technology skills; life and career skills. North Central Regional Educational Laboratory (NCREL) proposed that digital-age literacy, inventive thinking, effective communication and high productivity compose the 21st century skills (Burkhardt et al. 2003).

Based on these researches, we propose four level of abilities in smart education that students should master to meet the needs of the modern society. These abilities are basic knowledge and core skills, comprehensive abilities, personalized expertise and collective intelligence. These are grouped under knowledge, skills, attitudes, and values. The four levels of abilities are presenting in detail as following.

(1) Basic knowledge and core skills. Basic knowledge and core skills referring to knowledge and skills in core subjects such as STEM, reading, writing, art and etc. Mastery of these core subjects is essential to students' success (P21 2015). Jenkins (2009) also considered that the reading, writing and mathematics are core capabilities for 21st century.

(2) Comprehensive abilities. Comprehensive abilities refer to abilities to critical think and solve real-world problem. Most of the 21st century skills frameworks raise the demands of thinking ways for people (Ananiadou and Claro 2009; Burkhardt et al. 2003; P21 2015). These abilities let student use appropriate reasoning and comprehensive thinking in different complex situations. Based on analyzing and making judgments and decisions, students should solve different problems and produce better solutions.

(3) Personalized expertise. This level ability demands the students to master information and technology literacy, creativity and innovation skills. Information and technology literacy demands students master ICT skills that include using different ITC applications and combining cognitive abilities or higher-order thinking skills for learning (Ananiadou and Claro 2009). Creativity and innovation skills demand students to think and work creatively with others, and can act creative ideas to make contributions to the field in which the innovation will occur.

(4) Collective intelligence. The ways of working are important which need communication and collaboration. Collective intelligence refers to knowledge that built up by a group

of people via communication and collaboration. After the previous work with information and knowledge, students need to reflect about the ways to share and transmit the results or outputs to other people (Ananiadou and Claro 2009). So students need to communicate clearly and effectively in various ways. Also collaboration demand students work effectively and respectfully in diverse teams (p21 2015).

Smart pedagogies

With the rapid development of technologies, increasingly flexible and efficient learning methods for students are developed. Research in cognitive science has indicated that knowledge and skills are closely intertwined (Scardamalia and Bereiter 2006). It needs mixing content knowledge and process skills to produce understanding which learners need. Then learners execute their understanding in practice to produce their performances. The critical thinking and learning skills are very important, but these skills cannot be taught independently and some appropriate factual knowledge need to be taught in particular domain and context (Ananiadou and Claro 2009). Using the deliberate instructional or learning strategies can be related to cultivate the knowledge and skills for learners. So in order to fostering different abilities of smart learners, we searched the literatures about related pedagogies or learning strategies using conventional subject searching method in some databases. Through analyzing the literatures, we summarized and adopted relevant practical methods.

Students usually accept basic knowledge and core skills in the classroom. Learning goal and process always are the same for each student in traditional classroom. But students with different backgrounds have different needs. Every student deserves a strict education matched with content and performance standards that promote the understanding (Tomlinson and McTighe 2006). The classroom should be differentiated and responsive to vary learners' readiness levels, interests and learning profiles (Tomlinson and Kalbfleisch 1998). Differentiated instruction emphasizes the different needs of each individual student and cultivates the basic knowledge and core skills for students.

Whether learning happens in the classroom or online, students who have different performances often need to learn together in-group or team to fulfill common task or achieve common goal. In collaborative process, learners can be fostered comprehensive abilities including critical thinking and solve problem ability (Gokhale 1995; Stahl 2006). Students in cooperative teams can keep knowledge longer through sharing information and engage in discussion at higher levels of thought to take responsibility for their own learning (Totten et al. 1991).

Learning processes should be tailored according to the students' learning needs that include requirements, background, interests, preferences, etc (Sampson et al. 2002). In particular, personal interest is more important than external motivation because it is driven by students' own passion (Malone 1981). Interest-driven personalized learning emphasizes the interests of students and can fosters intrinsic motivations, and then promote the personalized expertise for students (Atkins et al. 2010).

Intelligence is an ability to get things done that matter. Sternberg (1999) describes the three basic aspects of successful intelligence that include analytical thinking, creative thinking and practical application. As mentioned before, we facilitate abilities

including problem solving, decision making, creative thinking and interest-driven learning for learners. We need to integrate these abilities to generate intelligence. It is similar to the transfer of learning, or something in which we have been learned in specific situations that are intentionally applied in other different related conditions (Barnett and Ceci 2002). Learning is a generative process. In such a process, the learner is an active recipient of information who works to construct meaningful understanding of information found in the environment (Wittrock 1974). Generative learning can enable learners to flexible apply the intelligence what they have learned and generated to various relevant future situations (Engle 2006; Fiorella and Mayer 2015).

So, in order to foster the learners' performances, we propose four instructional strategies as demonstrated in Fig. 2. These strategies include class-based differentiated instruction, group-based collaborative learning, individual-based personalized learning (interest-driven predominantly) and mass-based generative learning (through online interactions predominantly). All these strategies encompass formal and informal learning, in both the real and the digital world. The four levels of smart strategies are presented in detail as following.

(1) Class-based differentiated instruction. Differentiated instruction is a process to approach teaching and learning for students with different abilities in the same class (Hall 2002). And it can coexist with standard-based education (McTighe and Brown 2005). The classroom is considered as a community that the students are treated as individual learners (Lawrence-Brown 2004). Teachers set different levels of expectations for learning task completion within a lesson or unit through differentiated instruction (Waldron and McLeskey 2001). Under differentiated instruction, all the students have tailored learning preferences and learn effectively.

(2) Group-based collaborative learning. Collaborative learning is a situation that two or more people learn or attempt to learn something together (Dillenbourg 1999). Teachers design the collaborative learning process to make meaningful learning experiences and promote students' thinking through solving real world problem. With the development of technology, computer-supported collaborative learning (CSCL) has emerged using computer and information technology to improve learning (Stahl et al. 2006). Koschmann (2002) presents that CSCL is "a field of study centrally concerned with meaning and the practices of meaning making in the context of joint activity, and the ways in which these practices are mediated through designed artifacts". (p. 18) CSCL can engage students in joint problem solving by designing

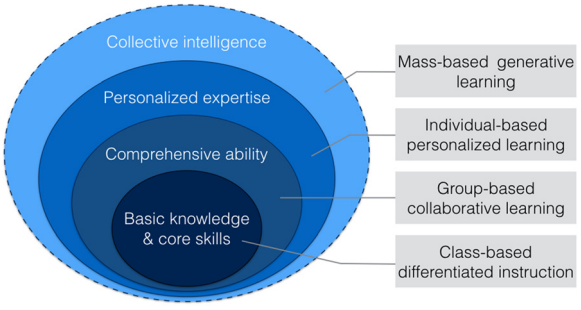

Fig. 2 Four-tier architecture of smart pedagogies

software to support meaning making, focus on the students' methods of problematization, and promote intersubjective meaning making when students learn in small groups (Stahl 2006).

(3) Individual-based personalized learning. Personalized learning is defined as adjusting pace (individualization), adjusting approach (differentiation) and connecting to the learners' interests and experiences (Atkins et al. 2010) to meet the student's needs and provide supporting to foster learning ability among individual students (Bentley and Miller 2004). In the personalized learning process, students achieve goals or explore interests based on their motivation. But it is not enough, the essential of personalized is that content is flexible to meet the interests of particular students. When students interact with the personal learning environments, their information and technology literacy will be enhanced. They can be engaged in learning activities and their creativity can be inspired in the learning process (Järvelä 2006). There are four key issues to enabling personalized learning through information technologies as follows: make informed learning decisions by students, develop and diversify different knowledge and skills, create various learning environments, and focus the evaluation and feedback from students (Green et al. 2005).

(4) Mass-based generative learning. The fundamental concept of generative learning involves the creation and refinement of personal mental constructions about the environments (Ritchie and Volkl 2000). Engle (2006) proposed a theoretical framework for generative learning that combines content and context analysis. The goal is to let students participate in the construction of the transferred content and to frame the learning and transfer contexts to create intercontextuality. When students are learning online, they are able to link new information to old, acquire meaningful knowledge and use their metacognitive abilities (Bonk and Reynolds 1997). These activities can promote the students to active participate in constructing relevant content. Also online learning allows students to collapse time and space limitation (Cole 2000). It has high interactivity, collaboration and authenticity. These features can support to frame time and participation to create intercontextuality. Then in the leaning process, the abilities especially the communication and collaboration should be facilitated generate for students.

Smart learning environments

The traditional learning paradigm has been criticized for being too artificial, rigid and unresponsive to the needs of today's society (Kinshuk and Graf 2012). With the development of new technologies and the emergent of new pedagogies in digital age, the use of technologies to facilitate learning and engage learners has become a universal phenomenon. Piccoli et al. (2001) define and expand the dimensions of learning environments, which include space, place, time, technology, control and interaction. So it is possible to design new learning environments, both technically and pedagogically.

From the technical perspective, ambient intelligence (AmI) is growing rapidly as a new research paradigm recently (Shadbolt 2003). In AmI environments, devices support people in executing their daily life activities and tasks in an easy and natural way by using intelligence and information from the network. Devices can interact and communicate independently without coordination with people and make decisions based on a series of

factors, including people's preferences and other people's presence in the neighborhood (Preuveneers et al. 2004). Most students today are digital natives, who have been immersed in the use of smart mobile devices and digital resources for communications, learning, and entertainment in everyday life (Bennett et al. 2008).

From the pedagogical perspective, learning analytics as underlying methods enables institutions to support learners making progress and to enable rich and personalized learning (Siemens and Long 2011). The general goal of learning analytics is to monitor the learning process and then use the data analysis to predict the future performance of students as well as to find their potential problems (Siemens 2013; Zhu and Shen 2013). It is possible for teachers to offer informative feedbacks to learners through virtualized learning dashboards via learning analytics. It is beneficial to have a general view of the learners' activities and how these are related to their peers or other actors in the learning experience through visualizations for learners and teachers (Duval 2011).

Smart learning environments supported by technologies should not only enable learners to digital resources and interact with the learning systems in any place and at any time, but also actively provides them with the necessary learning guidance, supportive tools or learning suggestions in the right place, at the right time, and in the right form (Hwang 2014). There are many different types of technologies used to support and enhance learning, which include both hardware and software. Hardware include those tangible objects such as interactive whiteboard, smart table, e-bag, mobile phone, wearable device, smart device, sensors which using ubiquitous computing, cloud computing, ambient intelligence, IoT technology, etc. Software include all kinds of learning systems, learning tools, online resources, educational games which using social networking, learning analytics, visualization, virtual reality, etc.

Based on the support of various technologies, we consider that the goal of smart learning environments is to provide rich, personalized and seamless learning experience for learners. To provide seamless learning experience, smart environments can encompass formal and informal learning. To realize personalized learning experience, smart learning environments can provide accurate and rich learning services by using learning analytics. So based on smart education demand, we propose ten key features of smart learning environments as following.

1. Location-Aware: Sense learner's location in real time;
2. Context-Aware: Explore different scenarios and information of activity;
3. Socially Aware: Sense social relationship;
4. Interoperability: Set standard between different resource, service and platform;
5. Seamless Connection: Provide continuous service when any device connects;
6. Adaptability: Push learning resource according to learning access, preference and demand;
7. Ubiquitous: Predict learner's demand until express clearly, provide visual and transparent way to access learning resource and service to learner;
8. Whole Record: Record learning path data to mine and analyze deeply, then give reasonable assessment, suggestion and push on-demand service;
9. Natural Interaction: Transfer the senses of multimodal interaction including position and facial expression recognition;

10. High Engagement: Immersing in multidirectional interaction learning experience in technology-riched environment.

Technological architecture of smart education environments

Smart computing is the latest cycle of tech innovation and growth that began in 2008 (Bartels 2009) and an important technology in smart learning environments. It blends elements of hardware, software and networks together with digital sensors, smart devices, Internet technologies, big data analytics, computational intelligence and intelligent systems to realize various innovative applications. All these technologies can effectively support learning to happen in different situations. Above all, the advancement of computing technologies leads smart computing to a new dimension and improves the ways of learning.

In section 3, we proposed ten key features of smart learning environments in smart education. All these features make learning environments smarter. To better understand the technological architecture to support the key features, we present a technological architecture of smart education environments based on smart computing.

Tri-tier architecture of smart computing

Today's world is moving fast towards an era of seamless networks as mobile devices are becoming smaller, smarter and more affordable. Ubiquity of such devices is an essential element for location based services and learning data transmission. Also computing is rapidly moving away from traditional devices. The tri-tier architecture of smart learning environments is essential which includes cloud computing, fog computing and swarm computing. In this tri-tier architecture, the cloud, fog and swarm are companions. Learning applications may have components running in the cloud, fog and swarm. The cloud and fog may help control and manage the resources of the swarm. Learning contents can move and be analyzed across this tri-tier architecture.

(1) Cloud computing. The innermost layer is the cloud computing, which provides software as a service. It deploys groups of remote servers and software networks that allow centralized data storage and online access to computer services and resources. In smart learning environments, we need method to rationalize the way managing the resources. It is the infrastructure of smart learning environments and provides the platform, virtualization, centralized data storage, and educational services in education. Using cloud computing, the smart learning environments can realize smart pull, smart prospect, smart content, and smart push (Kim et al. 2011).
(2) Fog computing. The middle of the tri-tier architecture is the fog computing. Nowadays in IoTs, literally anything can part of it, so very diverse types of services can be produced. This requires much better infrastructure and sophisticated mechanism. This technology is a highly virtualized platform that provides compute, storage, and networking services between end devices and traditional cloud computing data centers, typically, but not exclusively located at the edge of network (Bonomi et al. 2012). Through the features of fog computing, smart learning environments can realize real-time interaction, location-awareness, large-scale sensor networks, supporting for mobility and so on.

(3) Swarm computing. The outermost layer is the swarm computing. As the computing technology continues to become increasingly pervasive and ubiquitous, we envision development of environments that can sense what we are doing and support our daily activities (Essa 2000). Swarm computing, is also called environment-aware computing, can execute on swarms of smart devices and the networks of sensors due to ubiquitous sensing. And these sensors' data will transfer to data management systems to analysis.

Key functions of smart computing

In addition, smart computing allows computing technologies smarter because of five key functions of intelligence that are awareness, analysis, alternatives, actions and auditability (Bartels 2009). In the tri-tier architecture, the swarm computing support awareness, the fog computing support analysis, alternatives, and the cloud computing support actions and auditability. When smart computing is used in building smart learning environments or systems, it is able to support every stage of intelligent activities.

(1) Awareness. Learning happens anywhere and anytime. We can use technologies such as swarm computing, pattern recognition, data mining, learning analytics, and other tools, capture data on students' identity, status, condition, and location. Networks can transport this data from learner devices back to smart learning systems central servers for analysis.
(2) Analysis. When system servers receive real-time data from learner devices, intelligence and analytical tools such as learning analytics, data mining, and big data, are used to analyze and store the learning data, and then recommend learning patterns and resources to learners.
(3) Alternatives. Using learning flow or workflow engines, it is able to identify either automatically or through human review alternative courses of action in response to the learning patterns. Once a decision is made, it will trigger the learning action.
(4) Actions. Using integrated links, systems can execute actions to the appropriate process applications. These process apps can be adapted to various scenarios, with specific app components pushed down to our smart devices where we can execute action, that learner receive related learning resource in the museum or acquire location information outside.
(5) Auditability. Whether right learning action was actually taken can only be determined under the auditability. In smart education, it is important to monitor learning process and to make it more efficient. Smart learning systems need to capture, track, and analyze data of learning activities at each stage for purposes of learning evaluation and improvement.

The implementation strategies for research

The first author and his East China Normal University (ECNU) team have engaged in substantial research and development relating to smart education, only a part of efforts is mentioned here:

(1) Developing standards for e-Textbook and e-Schoolbag. Under the leadership of the ECNU team, delegations from sixty ICT companies participate in the development of a set of standards (17 projects) since November of 2010.
(2) Conducting pilot of using e-schoolbag. The ECNU team is invited by Minhang district to design application models of using e-schoolbags in 67 schools since 2012, about seven thousands of students are involved.
(3) Undertaking national research project. The first author undertakes a national project on THE BUILDING OF SMART LEARNING ENVIRONMENTS AND APPLICATIONS since 2014, which is from the 12th Five Year Research Program in Educational Sciences. 300 schools from a decade of provinces over the country are planned to join the project. The ECNU team gives theoretical guidance, teacher trainings, and application assessments. It is expected that this project will help to test different architectural model of smart learning environments and to tryout the smart learning pedagogy as above-mentioned.

Case studies based on the research framework

Based on the research framework of smart education, we began to carry out some pilot studies. Here introduces two case studies of them. One is flipped classroom project that integrated smart pedagogies and constructed smart learning environments for students. Another pilot project is called "Online J classroom" that also integrated smart pedagogies into learning process to realize precision teaching.

The flipped classroom pilot project is carried out in a middle school of north China. The core idea of flipped classroom is to flip the common instructional approach (Tucker 2012). Instruction, which used to happen in class, is now occurred at home with teacher-created videos and interactive lessons. The project aims at fostering self-regulated and collaborative learning abilities for students. At first, there are four classes participating into the project, and then it is extended to all the classes of the school. A process model of flipped classroom based on the idea of smart pedagogies is proposed that includes two phases that include self-regulated questioning and practice showing. Self-regulated questioning phase is consisted of learning objective guiding, textbook self-regulated learning, micro-lecture assisted learning, cooperative learning, and online assessment. Practice showing phase is consisted of difficult breakthrough, practice showing, cooperative improving, evaluated guiding, and summarize reflection. Every student uses the tablet PC to support learning. Through analyzing the questionnaires and interviews data, we found that students' learning statement, learning capacity and problem consciousness have significantly enhanced. To teachers, they began to more focus on students' personal learning, and their professional competence has been significantly improved. To school, the overall teaching level has obviously raised.

Online J-Classroom is a district-based project that aims at providing micro-videos in pre-learning process for students. A data-driven instructional decision model is proposed for designing precision teaching interventions. Precision teaching is the educational decisions based on changes in continuous self-recording performance frequencies using the standard celeration charts (Lindsley 1992). The online J-Classroom platform has three major functions including resources co-building and sharing, data recording and analyzing, cooperating and innovating between teachers

and students. The latest platform version is delivered in October 2015. Through monitoring and analyzing the data of learning process, platform can provide personalized instructional design including direct teaching based on problem, problem solving oriented cooperative inquiry, and task-driven self-regulated learning for students. Students can be ensured to master all the knowledge after pre-learning as well as their self-regulated learning ability should be enhanced.

Conclusion: challenges of facilitating smart education

As stated, smart education is a new paradigm in global education. The objective of smart education is to improve learner's quality of life long learning. It focuses on contextual, personalized and seamless learning to promote learners' intelligence emerging and facilitate their problem-solving ability in smart environments. With the development of technologies and within a modern society, smart education will confront many challenges, such as pedagogical theory, educational technology leadership, teachers' learning leadership, educational structures and educational ideology.

In our expectation on smart education, the smart learning environments could decrease learners' cognitive load, and thus enable learners to focus on sense making and facilitate ontology construction. Also students' learning experience could be deepened and extended, and thus help students' development in an all-round way (affectively, intellectually, and physically). Students can learn flexibly and working collaboratively in smart learning environments, and thus could foster the development of personal and collective intelligence of learners. Furthermore, better customize learning support could be provided for students to improve learners' expectation.

As the concept of smart city has been paid more attention (Hollands 2008), the requirements of smart education based on smart city are promoted. The overall goal of smart education under smart city architecture is to provide every citizen personalized services and seamless learning experience. Learning happens in anywhere and anytime and produce lots of behavioral data of learners. How to integrate the data of different scenarios in smart cities and build data-centric smart education is a big challenge to educators in order to provide seamless learning experience and customized personalized service for learners. The interconnected and interoperable learning service and experience between smart education system and other systems of smart city are the future research focus.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
ZTZ has made substantial contributions to conceive and design the research. And he proposed and provided the core frameworks and content of the research. MHY has made substantial contributions to draft this manuscript. PR has improved the manuscript's language and given comments on the manuscripts. ZTZ reviewed and revised the manuscript into its final shape. All authors read and approved the final manuscript.

Acknowledgements
This research work is supported by the "The research on Smart learning environment construction and application" (BCA140051) from the 12th Five-year National Research Programme on Educational Sciences in China (2014). Finally, this paper is our original unpublished work and it has not been submitted to any other journal for reviews.

Author details
[1]Shanghai Engineering Research Center of Digital Education Equipment, East China Normal University, Shanghai, China. [2]Department of Educational Information and Technology, East China Normal University, Shanghai, China.

Received: 12 October 2015 Accepted: 17 March 2016
Published online: 31 March 2016

References

K. Ananiadou, M. Claro, *21st century skills and competences for new millennium learners in OECD countries*. OECD Education Working Papers, vol. 41, 2009

D. E. Atkins, J. Bennett, J. S. Brown, A. Chopra, C. Dede, B. Fishman, B. Williams, Transforming American education: Learning powered by technology. Learning. **114** (2010)

S.M. Barnett, S.J. Ceci, When and where do we apply what we learn?: A taxonomy for far transfer. Psychol. Bull. **128**(4), 612 (2002)

A. H. Bartels, Smart computing drives the new era of IT growth. Forrester Inc. (2009)

S. Bennett, K. Maton, L. Kervin, The 'digital natives' debate: a critical review of the evidence. Br. J. Educ. Technol. **39**(5), 775–786 (2008)

T. Bentley, R. Miller, *Personalised Learning: Creating the Ingredients for Systemic and Society-wide Change* (IARTV, Jolimont, 2004)

F. Bonomi, R. Milito, J. Zhu, S. Addepalli, Fog computing and its role in the internet of things, in *Proceedings of the first edition of the MCC workshop on Mobile cloud computing, Helsinki, Finland*, 2012

B.C. Bruce, J.A. Levin, Educational technology: media for inquiry, communication, construction, and expression. J. Educ. Comput. Res. **17**(1), 79–102 (1997)

G. Burkhardt, M. Monsour, G. Valdez, C. Gunn, M. Dawson, C. Lemke, *enGauge 21st century skills: Literacy in the digital age* (North Central Regional Educational Laboratory, Naperville, 2003)

F.M. Chan, *ICT in Malaysian schools: Policy and strategies. ICT in Education*, 2002, pp. 15–22

T.W. Chan, J. Roschelle, S. Hsi, M. Sharples, T. Brown, C. Patton et al., One-to-one technology-enhanced learning: an opportunity for global research collaboration. Res. Pract. Technol. Enhanc. Learn. **1**(01), 3–29 (2006)

J. W. Choi, Y. J. Lee, The Status of SMART Education in KOREA. World Conference on Educational Multimedia, Hypermedia and Telecommunications. 2012(1): 175-178(2012)

R.A. Cole, *Issues in Web-based pedagogy: A critical primer* (Greenwood Press, Westport, 2000)

J. Daniel, Making sense of MOOCs: musings in a maze of myth, paradox and possibility. J. Interact. Media Educ. **3**, Art-18 (2012)

P. Dillenbourg, *What do you mean by collaborative learning? Collaborative-learning: Cognitive and Computational Approaches*, 1999, pp. 1–19

E. Duval, Attention please!: learning analytics for visualization and recommendation. In Proceedings of the 1st International Conference on Learning Analytics and Knowledge, Banff, AB, Canada, 27 Februry-01 March 2011

Education and Learning Sub-Committee, *Empowering learners and engaging minds, through infocomm* (Ministry of Education, Singapore, 2007)

T. Elias, *Learning Analytics: The Definitions, the Processes, and the Potential*, 2011

R.A. Engle, Framing interactions to foster generative learning: a situative explanation of transfer in a community of learners classroom. J. Learn. Sci. **15**(4), 451–498 (2006)

IA Essa, Ubiquitous sensing for smart and aware environments. Personal Communications, IEEE **7**(5), 47–49 (2000)

L. Fiorella, R.E. Mayer, *Eight Ways to Promote Generative Learning. Educational Psychology Review*, 2015, pp. 1–25

H. Gardner, *Frames of mind: The theory of multiple intelligences* (Basic books, New York, 2011)

A. A. Gokhale, Collaborative learning enhances critical thinking. J Technol Educ. 7(01) (1995)

S. Goodman, *Teaching youth media: A critical guide to literacy, video production and social change* (Teachers College, New York, 2003)

H. Green, K. Facer, T. Rudd, P. Dillon, P. Humphreys, *Futurelab: Personalisation and digital technologies*, 2005

D. Gwak, *The meaning and predict of Smart Learning, Smart Learning Korea Proceeding, Korean e-Learning Industry Association*, 2010

T. Hall, *Differentiated instruction* (National Center on, Wakefield, 2002)

R.G. Hollands, Will the real smart city please stand up? Intelligent, progressive or entrepreneurial? City **12**(3), 303–320 (2008)

M.T.A. Hua, Promises and threats: iN2015 Masterplan to pervasive computing in Singapore. Sci. Technol. Soc **17**(1), 37–56 (2012)

R. Huang, J. Yang, Y. Hu, From digital to smart: the evolution and trends of learning environment. Open Educ. Res. **1**, 75–84 (2012)

G.J. Hwang, Definition, framework and research issues of smart learning environments-a context-aware ubiquitous learning perspective. Smart Learning Environments **1**(1), 1–14 (2014)

G.J. Hwang, C.C. Tsai, S.J.H. Yang, Criteria, strategies and research issues of context-aware ubiquitous learning. J. Educ. Technol. Soc **11**(2), 81–91 (2008)

IBM, Smart Education (2012), https://www.ibm.com/smarterplanet/global/files/au__en_uk__cities__ibm_smarter_education_now.pdf. Accessed 20 Mar 2015

S. Järvelä, *Personalised learning? New insights into fostering learning capacity. Personalising education*, 2006, pp. 31–46

H. Jenkins, *Confronting the challenges of participatory culture: Media education for the 21st century* (MIT Press, USA, 2009)

M. Kankaanranta, T. Mäkelä, Valuation of emerging learning solutions, in *World Conference on Educational Multimedia, Hypermedia and Telecommunications, Tampere, Finland*, 2014

T. Kim, J.Y. Cho, B.G. Lee, Evolution to smart learning in public education: a case study of Korean public education, in *Open and Social Technologies for Networked Learning*, ed. by L. Tobias, R. Mikko, L. Mart, T. Arthur (Berlin Heidelberg, Springer, 2013), pp. 170–178

S. Kim, S.M. Song, Y.I. Yoon, Smart learning services based on smart cloud computing. Sensors **11**(8), 7835–7850 (2011)

S. Kinshuk, *Graf, Ubiquitous Learning* (Springer Press, Berlin Heidelberg New York, 2012)

R. Koper, Conditions for effective smart learning environments. Smart Learning Environments **1**(1), 1–17 (2014)

T. Koschmann, Dewey's contribution to the foundations of CSCL research. In Proceedings of the Conference on Computer Support for Collaborative Learning: Foundations for a CSCL Community, New Orleans, 2002, edited by G Stahl

D. Lawrence-Brown, *Differentiated instruction: Inclusive strategies for standards-based learning that benefit the whole class. American secondary education*, 2004, pp. 34–62

J. Lee, H. Zo, H. Lee, Smart learning adoption in employees and HRD managers. Br. J. Educ. Technol. **45**(6), 1082–1096 (2014)
O.R. Lindsley, Precision teaching: discoveries and effects. J. Appl. Behav. Anal. **25**(1), 51–57 (1992)
T. Mäkelä, M. Kankaanranta, B. Young, Q. Alshannag, In Search of Localization Criteria for Learning Solutions: Examining the localization needs of Finnish learning solutions in the United Arab Emirates. In World Conference on Educational Multimedia, Hypermedia and Telecommunications, Tampere, Finland, 23-27 June 2014
T.W. Malone, Toward a theory of intrinsically motivating instruction. Cogn. Sci. **5**(4), 333–369 (1981)
V. Mayer-Schönberger, K. Cukier, *Big data: A revolution that will transform how we live, work, and think* (Houghton Mifflin Harcourt, Boston, New york, 2013)
J. McTighe, J.L. Brown, Differentiated instruction and educational standards: is Detente possible? Theory Pract. **44**(3), 234–244 (2005). doi:10.1207/s15430421tip4403_8
M.D. Merrill, *First principles of instruction: Identifying and designing effective, efficient and engaging instruction* (Wiley, San Francisco, 2013)
MEST: Ministry of Education, Science and Technology of the Republic of Korea, Smart education promotion strategy, President's Council on National ICT Strategies (2011)
B.B. Meyer, N. Latham, Implementing electronic portfolios: benefits, challenges, and suggestions. EDUCAUSE Q. **31**(1), 34–41 (2008)
A Middleton, Smart learning: Teaching and learning with smartphones and tablets in post compulsory education (Media-Enhanced Learning Special Interest Group and Sheffield Hallam University, 2015)
New Media Consortium, *The NMC Horizon Report: 2015 Higher Education Edition*, 2015, pp. 1–50
New York Smart Schools Commission Report (2014), http://www.governor.ny.gov/sites/governor.ny.gov/files/archive/governor_files/SmartSchoolsReport.pdf. Accessed 20 Feb 2016
K.S. Noh, S.H. Ju, J.T. Jung, An exploratory study on concept and realization conditions of smart learning. J. Digit. Convergence **9**(2), 79–88 (2011)
Partnership for 21st century learning, P21 Framework Definitions (2015), http://www.p21.org/storage/documents/docs/P21_Framework_Definitions_New_Logo_2015.pdf. Accessed 20 Mar 2015
A.G. Picciano, The evolution of big data and learning analytics in American Higher Education. J. Asynchronous Learn Netw. **16**(3), 9–20 (2012)
G. Piccoli, R. Ahmad, B. Ives, *Web-based virtual learning environments: A research framework and a preliminary assessment of effectiveness in basic IT skills training. MIS quarterly*, 2001, pp. 401–426
D. Preuveneers, J.V. den Bergh, D. Wagelaar, A. Georges, P. Rigole, T. Clerckx, Y. Berbers, K. Coninx, V. Jonckers, K.D. Bosschere, *Towards an extensible context ontology for ambient intelligence. Ambient intelligence* (Springer, Berlin Heidelberg New York, 2004), pp. 148–159
D. Ritchie, C. Volkl, Effectiveness of two generative learning strategies in the science classroom. Sch. Sci. Math. **100**(2), 83–89 (2000)
D. Sampson, C. Karagiannidis, Kinshuk, Personalised learning: educational, technological and standardisation perspective. Interact. Educ. Multimedia **4**, 24–39 (2002)
M. Scardamalia, *C Bereiter* (Knowledge building, The Cambridge, 2006)
K. Scott, R. Benlamri, Context-aware services for smart learning spaces. Learning Technologies, IEEE Transactions on **3**(3), 214–227 (2010)
N. Shadbolt, From the editor in chief: ambient intelligence. IEEE Intell. Syst. **18**(4), 2–3 (2003)
G. Siemens, Learning analytics: the emergence of a discipline. Am. Behav. Sci. **57**(10), 1380–1400 (2013)
G. Siemens, P. Long, Penetrating the fog: analytics in learning and education. EDUCAUSE Review **46**(5), 30 (2011)
J.M. Spector, Conceptualizing the emerging field of smart learning environments. Smart Learning Environments **1**(1), 1–10 (2014)
G. Stahl, *Group cognition: Computer support for building collaborative knowledge* (MIT Press, Cambridge, 2006)
G. Stahl, T. Koschmann, D. Suthers, Computer-supported collaborative learning: an historical perspective. Cambridge handbook of the learning sciences **2006**, 409–426 (2006)
R.J. Sternberg, Successful intelligence: finding a balance. Trends Cogn. Sci. **3**(11), 436–442 (1999)
C.A. Tomlinson, J. McTighe, *Integrating differentiated instruction & understanding by design: Connecting content and kids* (ASCD, Alexandria, 2006)
C.A. Tomlinson, M.L. Kalbfleisch, Teach Me, Teach My Brain: a call for differentiated classrooms. Educ. Leadersh. **56**(3), 52–55 (1998)
S. Totten, T. Sills, A. Digby, P. Russ, *Cooperative learning: A guide to research* (Garland, New York, 1991)
B. Tucker, The flipped classroom. Education Next **12**(1), 82–83 (2012)
N. Waldron, J. McLeskey, An interview with Nancy Waldron and James McLeskey. Intervention and School & Clinic **36**(3), 175 (2001)
M.C. Wittrock, A generative model of mathematics education. J. Res. Math. Educ. **5**(4), 181–196 (1974)
Z.T. Zhu, B. He, Smart Education: new frontier of educational informatization. E-education Research **12**, 1–13 (2012)
Z.T. Zhu, D.M. Shen, Learning analytics: the science power of smart education. E-education Research **5**, 5–12 (2013)