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From Learning Object to Learning Cell: A Resource Organization Model for Ubiquitous Learning

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ABSTRACT

This paper presents a new model for organizing learning resources: Learning Cell. This model is open, evolving, cohesive, social, and context-aware. By introducing a time dimension into the organization of learning resources, Learning Cell supports the dynamic evolution of learning resources while they are being used. In addition, by introducing a semantic gene (knowledge ontology) into the model, Learning Cell can flexibly describe the internal structure and external relations of learning resources, allowing the evolution of learning resources to occur in an orderly way. Furthermore, by employing a computational model of a social cognition network, Learning Cell enables not only materialized resource sharing but also the sharing of social cognition networks. Finally, by separately deploying resource structures and resource content in the cloud storage model, Learning Cell achieves context awareness of ubiquitous learning (u-learning) resources. Learning Cell represents a resource aggregation model that is different from the learning object model. It makes up for the defects of existing learning technologies in the following areas: the sharing of process information and social cognition networks, the intelligence of resources, and the evolution of content. Learning Cell provides a theoretical framework of u-learning resource organization.

Keywords

Ubiquitous learning, Learning Cell, Learning object, Knowledge relationship network, Aggregation model, Context awareness

Introduction

There have been three generations of resource organization models in the field of e-learning (See Figure 1): Integrable ware (Reusable Learning Unit), Learning Object, and Learning Activity. The Integrable-ware model (Li, 1997) emphasizes the combination and reuse of small learning resource units. A learning object is any digital resource that can be reused to support learning (Wiley, 2000). The main idea of learning objects is to break educational content down into small chunks that can be reused in various learning environments, in the spirit of object-oriented programming. The learning object model (ADL, 2004) provides solutions for data exchange between different learning management systems (LMS), allowing structured and interactive learning objects to be shared between LMS. The learning activity model (Britain, 2004) supports high-level sharing of learning processes and activities by reusing learning methods, learning strategies, and learning activities. The emergence of IMS-LD (IMS Learning Design) (IMS GLC，2003) extended the sharing of learning resources from learning objects to learning activities, signaling a shift in learning-resource sharing from a technological problem to an educational problem.

However, the sharing of learning activity designs is not the ultimate goal of learning resource sharing. New learning technologies aim to cater to ubiquitous learning. Figure 1 also lists questions that need to be addressed in the future development of learning-resource sharing, for instance, how to share generative information during the learning process and how to adapt learning content for personalized learning.

U-Learning's demands on learning resource organization

Pervasive computing creates a seamless computing space encompassing both the real world and the virtual world, where ubiquitous learning (u-learning) is well supported. Generally, u-learning allows people to access learning resources anytime anywhere. Context-aware u-learning is supported by mobile devices, wireless communications, and sensor technologies.

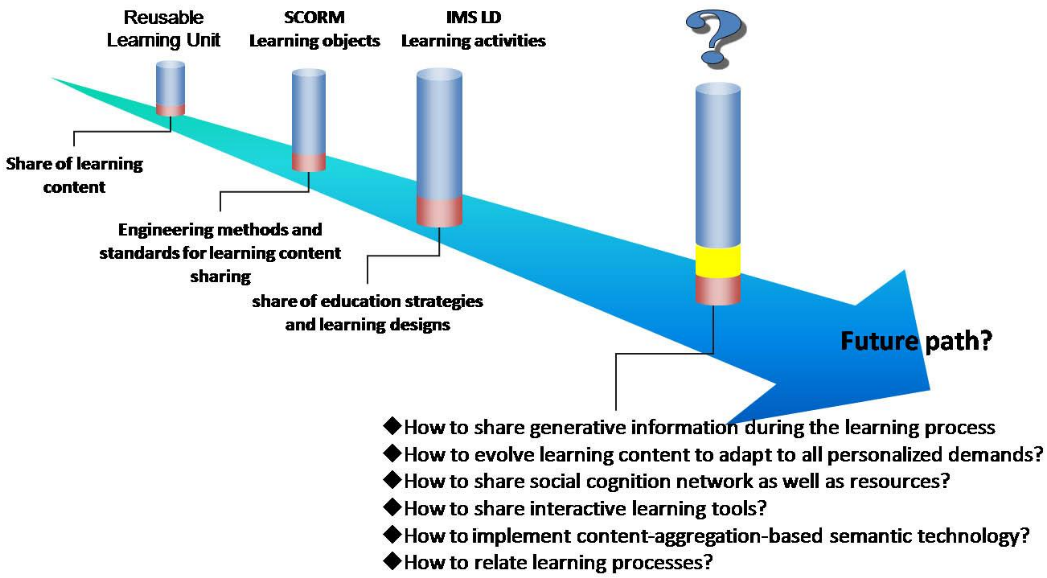


Figure 1. The development of learning resource sharing

As one of the ideal models for future life-long learning, u-learning provides an environment in which learners can access information, communicate and engage in learning activities without temporal or spatial constraints. Learning in such environments has different characteristics than traditional learning (Hwang, Yang, Tsai, & Yang, 2009; Ogata & Yano, 2004; Wong & Looi, 2011; Yu, 2007): (1) u-learning may happen anytime and anywhere; (2) u-learning is personalized, context-aware and problem-oriented, and it provides suitable learning content and services to meet learners' demands; (3) u-learning is embedded into daily life and may be decentralized and fragmented; (4) u-learning is socialized, with social interactions being an important component.

The core motivation behind u-learning is not the ubiquity of devices and connections, but the changes in learning modes brought about by pervasive computing. Traditional, statically hierarchical organizational structures cannot meet the new demands created by these changes. U-learning needs to provide the following new organization modes for learning resources:

- U-learning needs adaptive and contextual learning resources.
- U-learning requires a large number of learning resources, which are created and shared by the learners.
- U-learning needs evolving learning resources. Ubiquitous learning resources should exist in real time, reflect the latest developments in related areas and meet learners' actual real-time needs. Such resources need to keep track of the information generated during the learning process. This information becomes the seed of resource evolution and reflects the history of knowledge construction.
- U-learning needs learning resources that are integrated with learning activities. Learning is not just acquiring information but is a process of effective internalization. This is achieved by providing learners with opportunities to participate in learning activities.
- Above all, u-learning needs the "human" resources that can be created by sharing social cognitive networks. Interaction in u-learning is not merely the interaction between learners and materialized resources, but also among the learners.

Related work

Existing learning resource standards, such as IEEE LOM (Learning Object Model) and SCORM (Sharable Content Object Reference Model) focus on describing and packaging resources, and their primary goal is to enable resource sharing and reuse across different platforms. Existing resource standards that are designed for traditional e-learning are characterized by knowledge transfer tools and are not suitable for new learning methods such as collaborative learning and discovery learning, where resources can be collaboratively developed and shared using social networks. Therefore, some international research groups have initiated work on the next-generation model for sharing learning resources. For instance, the Instructional Management System Global Learning Consortium (IMS) has published the Common Cartridge V1.0 standard (IMS GLC, 2008). In addition, Advanced Distributed Learning (ADL) is working on a standard called SCORM version 2.0 (Allen, 2008).

Common cartridge

Newly proposed by IMS, IMS Common Cartridge is a resource package format specification integrated with IEEE LOM, Dublin Core, IMS Content Packaging, IMS QTI, and IMS Authorization Web Service v1.0. The design concept of Common Cartridge is to integrate learning resources of different types and from different sources to create a learning platform (Cheng, Xu, & Yu, 2009). Resource types include web pages, associated content, QTI tests, QTI question banks, discussion topics, and web links that can be stored in learning platforms or accessed anywhere on the Internet. Access control mechanisms are adopted to protect important content. Figure 2 describes the architecture of Common Cartridge.

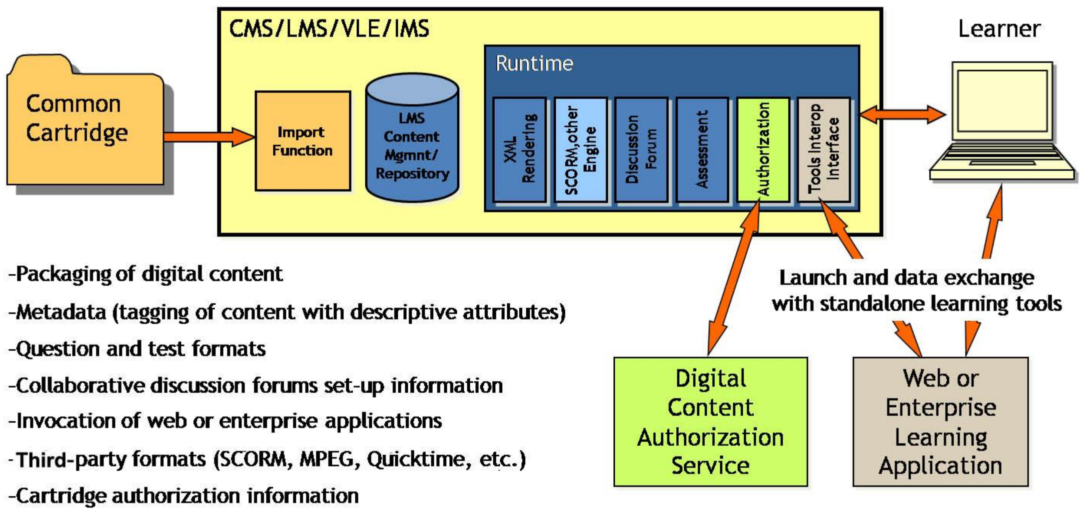


Figure 2. Architecture of Common Cartridge (IMS Global Learning Consortium, 2008)

Compared with SCORM, IMS Common Cartridge represents progress because it expands the types of sharable resources to tests, allows discussions, and provides a mechanism for distributed resource integration. Common Cartridge's package interchange file not only contains metadata descriptions and allows static resources to be organized and sorted but also supports a variety of resources such as external web pages, web links, discussion topics, project assessments, and question banks. In addition, Common Cartridge offers strategies for integrating external learning tools.

SCORM 2.0

SCORM is currently the most widely used learning resource package standard and has significant influence on both industries and academia. However, with the development of new technologies and concepts, many creative and prosperous Internet applications have been created in web 2.0 mode. Therefore, SCORM can no longer satisfy the various needs of e-learning and especially of u-learning. In response, ADL initiated work on SCORM 2.0, which is now overseen by LETSI (Learning, Education, and Training Systems Interoperability). The main goals of SCORM 2.0 are to support existing and emerging technologies, to support multiple teaching and learning modes, and to support multiple learning environments and modes, such as classroom learning, vocational training, distance education, self-learning, etc. (LETSI, 2008).

At present, different organizations and individuals have presented more than 100 white papers on SCORM 2.0. The content of these white papers covers the generic model, architecture, group learning, sequence and navigation, metadata, content integration, and assessments. Many papers suggest that SCORM should be simplified and call for the support of SOA architecture, Web 2.0, external resources and services, and user-defined features. The common suggestion (among 29 papers) is to include the support of SOA architecture and cross-platform integration. In addition, 13 papers emphasize the aggregation of external content, multi-format display, assessments, and 14 papers highlight the importance of learning designs.

Analyses

Both SCORM 2.0 and IMS Common Cartridge indicate that international standardization groups have made significant contributions to the development of learning technologies. However, both resource-sharing methods are not suitable for u-learning, because (1) they fail to plan and design tools that would enable the renewability of these resources, (2) they ignore human factors in resource organization (Yu & Yang, 2007), (3) they are unable to meet informal learners' needs for individualized and diversified learning, and 4) the limited resource-sharing supported by SCORM, IMS learning design standards and Common Cartridge norms prevents resources from being imported and exported between different LMS. Real and accessible model should therefore set a good example for observers. Generative information produced during the learning process is an appropriate object for observation that can promote learners' learning. Thus, this generative information should be included among the sharable learning resources.

An increasing number of researchers and practitioners realize that learning concepts and methods need to be revamped to represent the digital age. Connectivism, considered "the learning theory of the digital age" (Siemens, 2004), suggests that individuals are not able to possess all the knowledge they should because of the rapid change of knowledge bases and the increasing amount of available knowledge. Knowing how to obtain the knowledge we need and the ability to discern the importance of the information we find is now more important than acquiring static knowledge. Thus, learning encompasses not only the individual's intrinsic psychological activities but also a process of linking to inside and outside nodes for storing knowledge and information. The current learning resource technologies focus only on the development and use of materialized resources while neglecting the possibilities of humanized resources—social interpersonal networks and cognitive networks.

Based on the above problems, this study attempts to go beyond learning objects and proposes a new sharable learning resource model for u-learning.

The proposed model: Learning cell

Because they are based on centralized storage and hierarchical directory structures, existing learning resource organizations cannot meet the demands of u-Learning. In this paper, we propose a new learning resource describing and packaging scheme called Learning Cell.

Principles of Learning Cell

Based on connectivism and collaborative knowledge construction theories, Learning Cell features cloud storage, a dynamic structure, and non-static data elements. Learning Cell is a learning resource that is open, generative, evolvable, connected, cohesive, intelligent, adaptive, and social (Yu, Yang, & Cheng, 2009). It is developed from the learning object model and designed for u-learning. The basic idea is to introduce a time dimension and an interpersonal cognition network into learning resources to make the learning resource evolvable. During the evolution process, generative information and the revision history are recorded, an interpersonal network is generated, and humans and knowledge connect with each other to form a knowledge network, which allows students to construct knowledge, understand the context of that knowledge, and share collective wisdom through social cognition networks.

Figure 3 shows how learning cell can support u-learning. To achieve pervasiveness and context awareness, the two important characteristics of u-learning, the learning space needs to be based on an educational cloud platform, which consists of pervasive network connections, content-aware devices, evolvable learning resources, cognition networks, learning designs, and community networks. The platform hosts authentic knowledge and field experts and connects these experts in a social wisdom network, establishing knowledge networking social services (KNS) using collective wisdom-based algorithms. As shown in Figure 3, a seamless learning space for u-learning can be achieved with the coordination of cloud-computing and multi-media technologies.

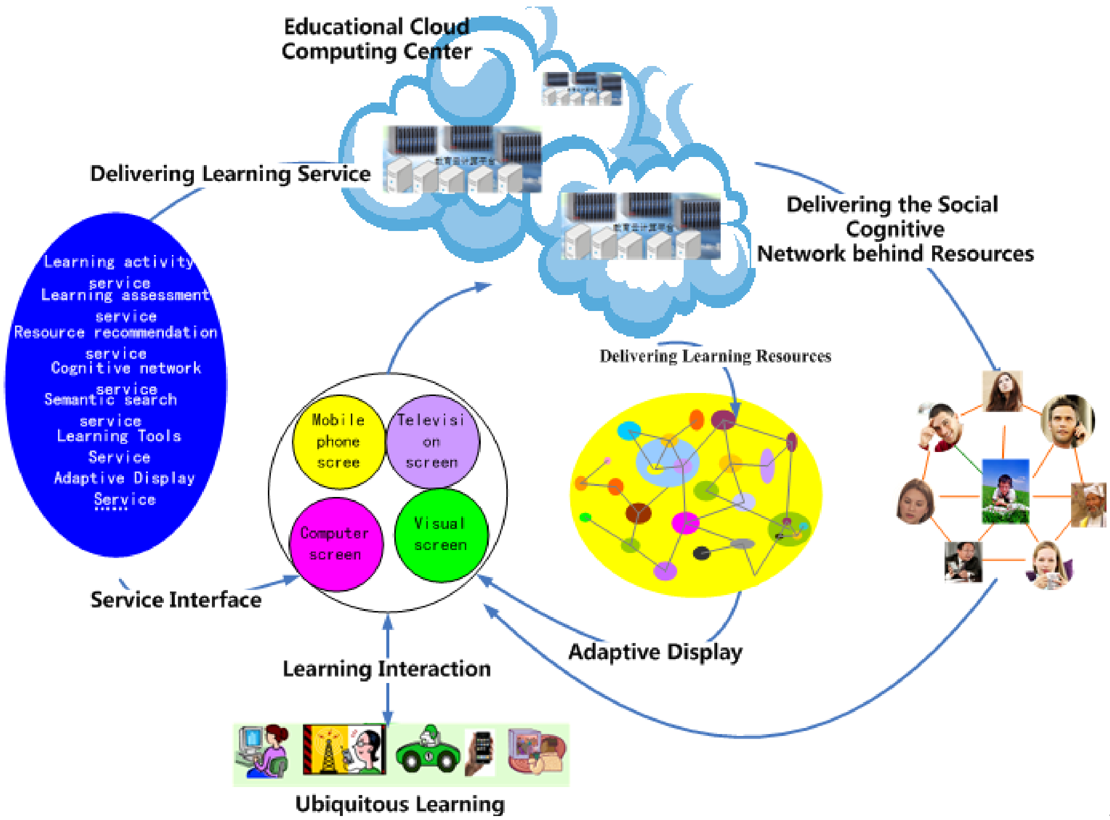


Figure 3. U-learning supported by Learning Cells

When users encounter problems or develop an interest in something, the intelligent terminals can detect their needs and communicate these needs to the educational cloud-computing platforms through pervasive communication networks. Based on users' learning requests, the platforms would perform searches, computations, and transformations to choose the most appropriate learning content for the user and attach the content to learning services and knowledge networks. Learners would be able to contact other learners and experts who are interested in the same content to form learning communities, giving learners access to the most authoritative knowledge in the field and allowing learners to build relationships with experts. Such a learning model does not mimic traditional classroom learning in which there is one teacher and many learners, but is instead a 1:1 or even n:1 model of learning, in which many authoritative experts and collaborators serve as teachers for one learner.

Structural model of Learning Cell

Learning Cell uses the cloud storage model to provide resources for u-learning. Figure 4 shows the learning content and its structure. Learning Cell consists of components such as metadata, ontology, content, activities, assessments, generative information, and multi-formats. All these components connect with education cloud services through a variety of service interfaces (e.g., learning activities and assessments). In education cloud services, there is an immense amount of learning resources and records of learning, including activity records, editing records, evaluation records, usage records, learning communities, and other information generated during the learning process. The learning content itself can be stored in resource servers all over the world. When learners enter u-learning environments, what they access is not unchangeable learning content but the dynamic structure of the learning content. When learning cells are accessed in different contexts, learning content is also aggregated differently to meet the learners' needs.

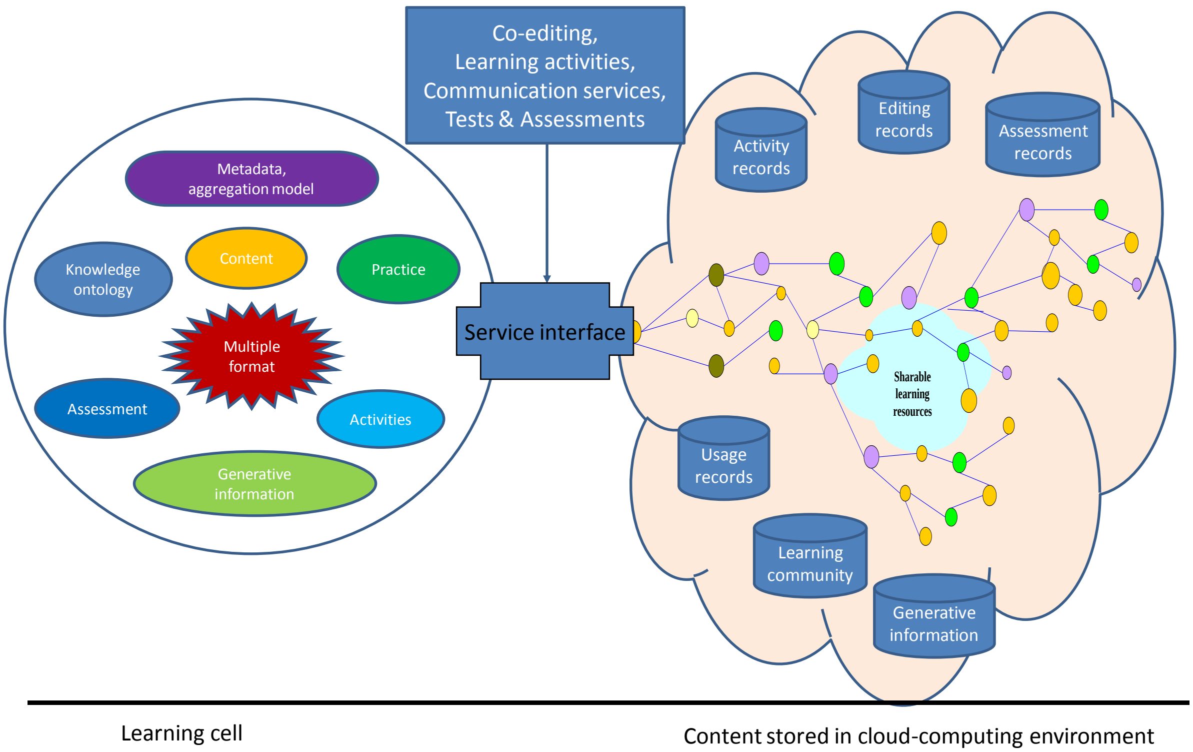


Figure 4. The cloud storage model for ubiquitous learning resources

Learning Cell is a learning service that can be accessed through a URL, which allows it to provide users with context-appropriate learning content and applications. Learning cells are goal oriented and can exist independently or be connected into a personalized knowledge network. The network contains metadata, aggregation models, knowledge ontology, learning content, learning assessments, learning activities, generative information, learning service interfaces and other resources, which are described in detail below.

Metadata is used to describe the attributes of Learning Cells so that they can be easily categorized, indexed, and shared.

Aggregation models prescribe the inner components and connection modes of Learning Cell. In contrast with Learning Object, Learning Cell adopts a semantic-based network aggregation model in which different components dynamically connect with each other to form a network. Different learning resources can be aggregated into one learning cell, and different learning cells can be aggregated into larger-scaled knowledge clouds.
Knowledge ontology describes the basic concepts and inter-concept relationships of related knowledge, which are used to construct effective aggregation models and promote the aggregation of Learning Cell components and the dynamic connection of learning cells containing similar content.

Content is the main component of Learning Cell. Learners use content to obtain learning resources and to build their own knowledge. The content in a learning cell needs to have specific subjects and goals and to be independent and self-contained, even with small granularity. Assessment is used to examine how learners grasp learned knowledge and to adjust learning strategies based on the assessment results. Learning Cell records all of a learner's interactive information and forms assessment reports after performing information analyses. Activities promote deep interactions between learners and content; they are process-oriented and enable the sharing of learning processes, strategies, and activities. Generative information is generated during the process of using Learning Cell. It contains user information, interaction information, Learning Cell revision history, and so on. Multiple formats indicate ways through which learners access a Learning Cell, including http, e-book, knowledge map, and video or audio. These formats allow a learning cell to be displayed on different devices.

Service interface is the primary channel of information exchange between Learning Cell and the cloud-computing environment. It defines the interface both to acquire and update process information when learners perform learning activities through a learning cell and to update the inner components and structure of learning cell. For example, when a learner revises a paragraph of the learning content and submits new related learning resources, this information is labeled and stored in a learning cell and can be shared with other learning systems.

The cloud storage architecture embodies the importance of distributed computing and cloud computing to learning technologies. Future learning resources would not be simply deployed from a centralized inner server but distributed and connected around the world. Learning resources on those nodes would be dynamically connected, based on rich semantics, forming a comprehensive, intelligent network.

Core features of Learning Cell

Learning Cell retains the accessibility, adaptability, affordability, durability, interoperability, and reusability of Learning Object but has, in addition, the following five unique properties (as shown in Figure 5):

Openness

Open-learning resources provide not only open access but also open content. Unlike the traditional static and closed-resource organization model, Learning Cell is built on a dynamic resource structure. Learning Cell allows resources to be updated with usage information, to grow by absorbing valuable online content such as Gadget, to interact with the external learning environment, and to be integrated with learning activity designs. Each learning cell is equipped with a learning system service interface, allowing the learning process to be traced and information to be exchanged between Learning Cell and the runtime environment.

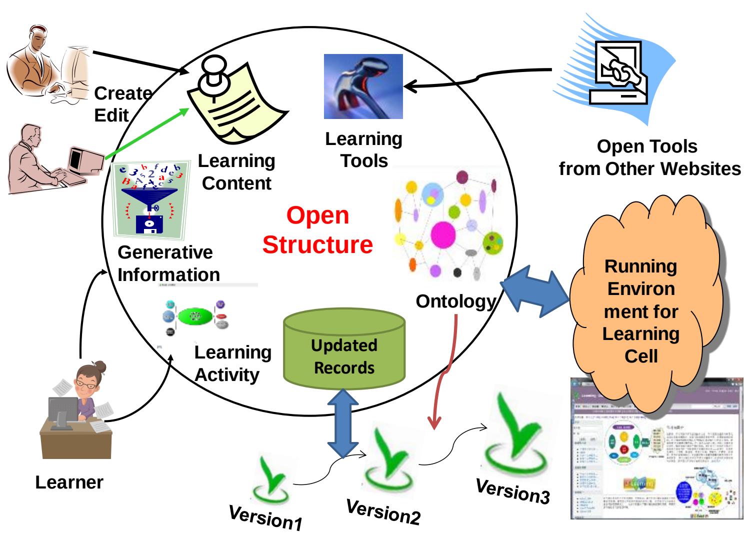


Figure 5. Open-structure model of Learning Cell

Evolvable

Traditional learning content is static and difficult to update. Learning Cell makes learning content evolvable by updating content with the feedback it receives from the learners. Based on the idea of Web 2.0, learning content is no longer generated by a few professionals but is generated and updated by public users who are connected via a network. Unlike Learning Object, Learning Cell saves not only predefined course content, exercises, and activities but also information generated during the learning process, such as submitted work, annotations on learning content, and learning records. Revisions to learning content are also recorded to reflect the evolving process of learners and learning cells.

Users first generate learning resources and invite collaborators to edit the open content. As the content evolves, more users familiarize themselves with the content and add comments and annotations to it. With time, as the users' collective wisdom grows, the content will grow to meet learners' needs. At present, the evolution of most open content is achieved by collaborative editing, and a version-control mechanism protects the content.

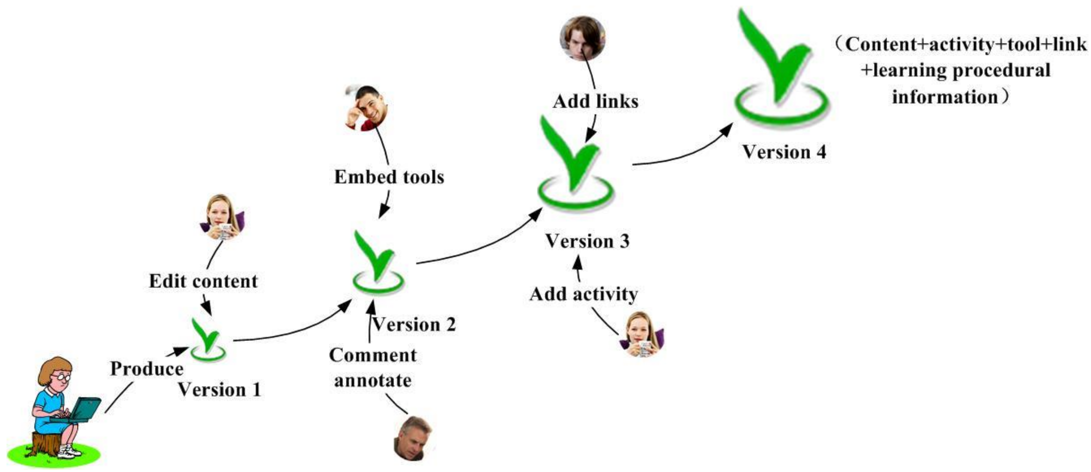


Figure 6. Content evolution of learning resources

During the evolving process, learning resources are manually (users generate inter-resource relationships through an editor) or automatically (the system creates semantic relationship mining using semantic correlators) connected via semantic relationships, including similar relationships, hyponymy relationships, precursor relationships, inclusive relationships, and equivalence relationships. As the connections among resources strengthen, similar resources form subject resource groups, from which learners access the subject's knowledge relationships. Meanwhile, users can organize semantically related resources into structured courses according to the inner-logic relationships of the knowledge. In the end, all resources become nodes in the resource network and are enhanced by forming dynamic connections with other resources. In addition to connections with materialized resources, human resources are also important. Interpersonal networks are formed when users perform various learning-related activities on the resource.

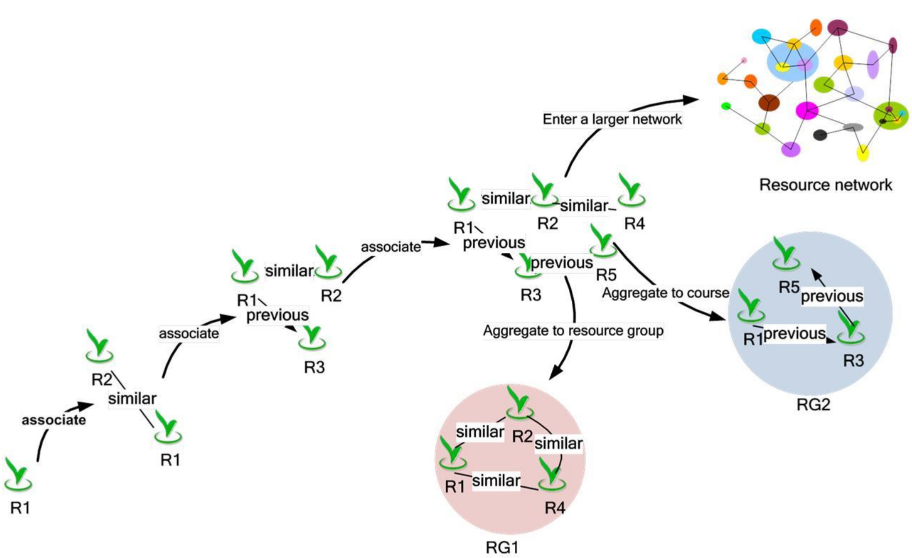
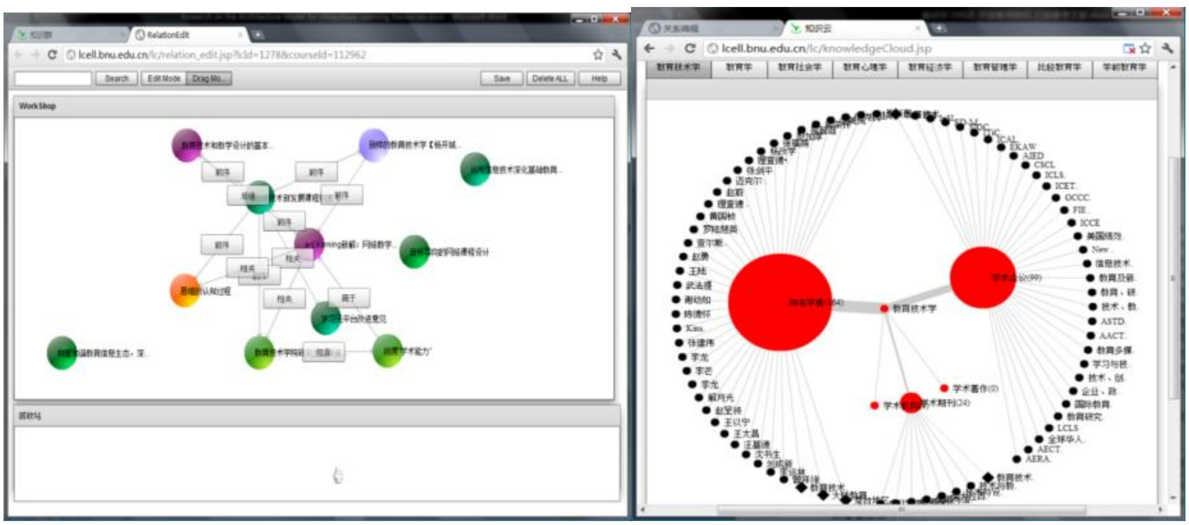


Figure 7. Relationship evolution of learning resources (R and RG stand for resource and resource group, respectively)

Cohesive

Learning Cell is cohesive, organizing all elements of the learning process into an orderly whole. The “gene” of a learning cell is formed according to an ontology-based knowledge structure and aggregation model, which controls the evolution and development of each learning cell. This structured learning resource organization is distinctive from loosely organized web resources such as blogs and BBSs. The network generated by Learning Cell is not a simple accumulation of learning resources, but a dynamic knowledge network.

The most important distinction between Learning Cell and Learning Object or SCORM-based online courses is the application of semantic network and ontology technology, which makes Learning Cell resemble an organism that grows and evolves under the control of an internal gene. Except when it exists as an independent and complete learning unit, each learning cell could serve as a node in resource networks and could connect with other nodes based on certain rules.



(a) (b)

Figure 8. (a) Visualized editing of semantic relationships between learning cells; (b) semantically based visualized navigation

Social

Because learning content is infused with the wisdom of all learners, the combination of physical resources and people would create a dynamically evolving and developing social cognitive network. Learners could acquire not only existing knowledge but also learning methods and knowledge acquisition channels.

Therefore, the social characteristics of future learning resources should be gradually strengthened. In u-learning, learning resources should serve as the bridge to connect learners in addition to communicating knowledge. The cognitive network attached to learning resources is an indispensable attribute of future learning resources. Aligning with this concept, learning cells include not only materialized learning resources but also interpersonal networks generated during the evolution process. Learning cells can be regarded as intermediaries between learning channels and social wisdom. Learning cells connect humans through learning content and generate a social cognition network in ubiquitous learning space.

Unlike the common conception of social networking, a social cognition network consists of knowledge, humans, and the interactions between them. In a social cognition network, a learning resource can be an independent learning unit connected to another resource via semantic relations. Through the social cognition network, learners can not only access materialized resources, but they can also find related people. For example, a learner can find subject-related experts and learning partners through learning content and access knowledge or promote learning activities from the experts or other learning partners.

Context-Aware

The core feature of u-learning is its context awareness. It can adapt the learning services to the learning contexts; in other words, it can perceive users' demands using intelligent learning devices and offer the most suitable learning modes and services. To realize such a learning model, we must improve the adaptability of learning devices and re-design the aggregation model to make learning resources more adaptable to these devices.

The context awareness of learning resources lies in the following two aspects: (1) intelligent adaption to learning terminals and 2) adaptability of learning content. The context awareness of Learning Cell arises from three features：1) the predefined multi-formats (including different file types, resolutions, and code rates) of resources, through which Learning Cell can adapt learning resources to different learning terminals; (2) the addition of semantic information to resources, through which Learning Cell allows learning resources to be easily recognized and processed by intelligent devices so they can be indexed, matched, connected, and assigned; (3) the dynamic structure through which resources can be adjusted. To realize the dynamic aggregation and self-adaptation of learning content, we must change the static structure model so that all learning content is organized in a process-oriented, logical structure and is dynamically generative.

Implementation of Learning Cell

The success of Learning Object relies on SCORM-supported learning management system and IMS-LD-supported learning platform. In comparison, Learning Cell operates independently of a specific supporting environment.

Runtime environment architecture (REA)

Figure 9 shows the architecture of the Learning Cell runtime environment. Key components include the message transfer controller, resource locator, repository, learning cell runtime engine, active adaptor, and learning service interface. A u-network is a ubiquitous network that supports u-learning; it is accessible via the Internet, wireless communications, and digital TV networks, to which users can easily connect with a device. A u-network manages the data transfer and device communication that are necessary to transfer content among learning cells. Various display devices, the u-network, and the Learning Cell runtime environment work collaboratively, forming a Learning Cell-based, seamless learning environment.

The message transfer controller receives user request information from the ubiquitous network (u-network), analyzes the information, and decides where to send the information. The resource locator manages resource indexes, searches learning resources at users' requests, and locates the resources in the repository. The repository stores learning cells and other resources, including generative information, semantic relationships, user information, and information about various devices. The Learning Cell runtime engine manages the information exchange between learning cells and the external environment; it consists of a series of APIs, including the Learning Cell grow API, the Learning Cell divide API, and the Learning Cell track API. Through this engine, learning cells content can evolve, resources can be aggregated based on semantics, and the learning cells themselves can divide and grow. The active adaptor receives device information from the message transfer controller; analyzes device types, screen sizes, and screen resolutions; and transforms the content into the most appropriate format for display on devices. The Learning Service interface provides users with a series of learning services, including learning tools, learning communities, learning content, learning activities, learning assessments, learning records, and semantic associations. Learners can use these interfaces in the u-network and access learning support services from any location and at any time.

The Learning Cell runtime environment is based on Java 2 Platform Enterprise Edition (J2EE) and Service Oriented Architecture (SOA) and can be divided into four layers: the repository layer, the service layer, the application layer, and the display layer.

The repository layer stores various data from the runtime environment and includes (1) a resource repository, which stores all of the resources, including learning cells and knowledge groups; (2) an ontology repository, which stores all of the knowledge ontology in the environment, including predefined ontology and user-generated ontology; (3) a user-information repository, which stores information like user portfolios and trust degrees; (4) an activity repository, which stores information like discussions, voting patterns, and reflections; (5) a tool repository; and (6) a log repository, which stores logs from learning cells, knowledge groups, learning activities, and user operations. There are mainly two ways to generate knowledge ontologies. One is to import external ontologies applied widely in many organizations directly. The other is to build a collaborative ontology-creating environment for any user participating in producing different knowledge ontologies. In the latter, a strict mechanism should be provided to guarantee the quality of ontologies. After time testing, these ontologies could be exported to Web Ontology Language (OWL) file for public sharing in other organizations.

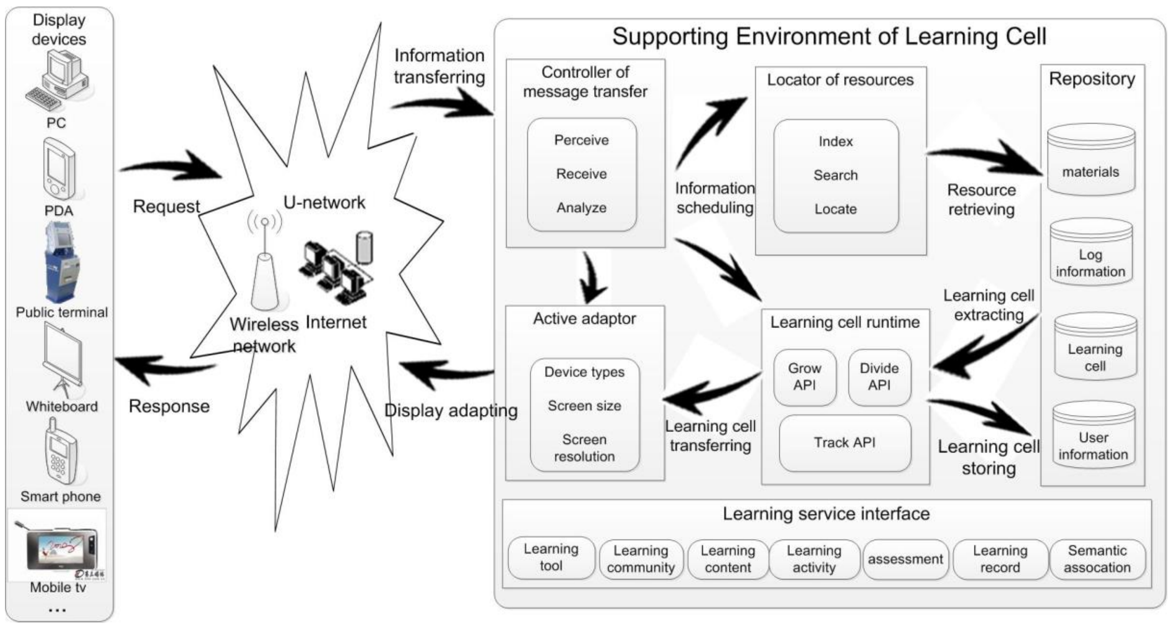


Figure 9. Architecture of the Learning Cell runtime environment

The service layer provides various services based on data from the repository layer, including learning activities, learning assessments, learning tools, version controlling, collaborative content editing, resource management, resource aggregation, resource indexing, format matching, and learning activities. During the process of collaborative content editing, we can not only adopt Wikipedia's content audit mechanism, but also use semantic technology and trust evaluation technology (Yang, Qiu, Yu, & Hasan, 2014) to realize automatic content checking (Yang & Yu, 2013). Resource aggregation can be implemented by counting semantic similarities among resources and human selection and reorganization.

The application layer provides applications for users by calling services from the service layer. The applications include learning cells, knowledge groups, knowledge clouds, learning tools, personal space, and learning communities, all of which offer varied learning experiences.

The display layer automatically converts the format of learning cells according to the information provided by the display devices, which could include digital TVs, computers, smart phones, public information terminals, and live telecasts so that learning cells can be properly displayed on different devices. We should provide a variety of content format templates, so as to adaptively display the content on different devices.

Functions of the application layer

Figure 10 shows the functional model of the application layer. Its main functions are knowledge group (KG), knowledge cloud (KC), learning cell (LC), learning tool (LT), personal space (PS), and learning community (LC).

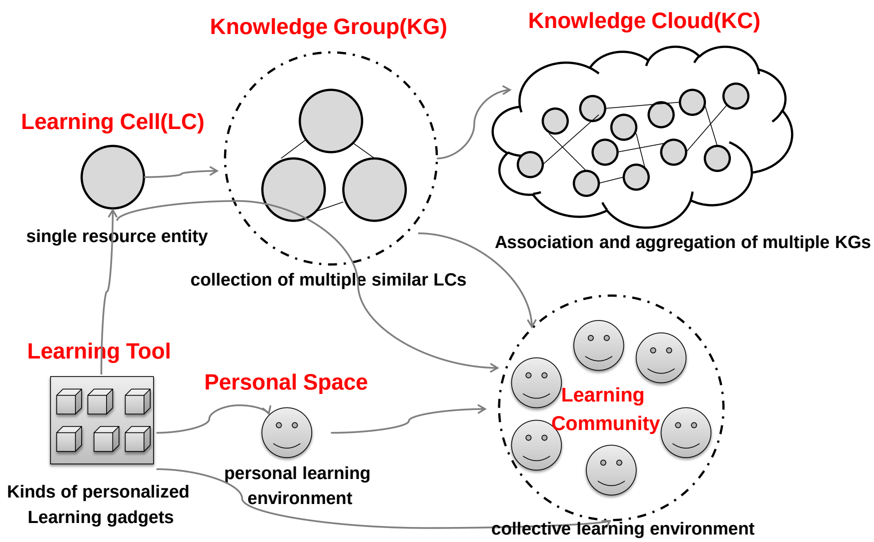


Figure 10. Functional model of the application layer of the Learning Cell runtime environment

The Learning Cell function assembles all of the learning cells in the environment. Each learning cell is a resource entity; it can be a lesson or a knowledge point. A learning cell contains not only learning content but also learning activities, KNSs, semantic information, and generative information. Learning cells are available in multiple formats, such as web pages, e-books, concept graphs, and 3D models. Learning cells can introduce related assistant learning tools to support u-learning.

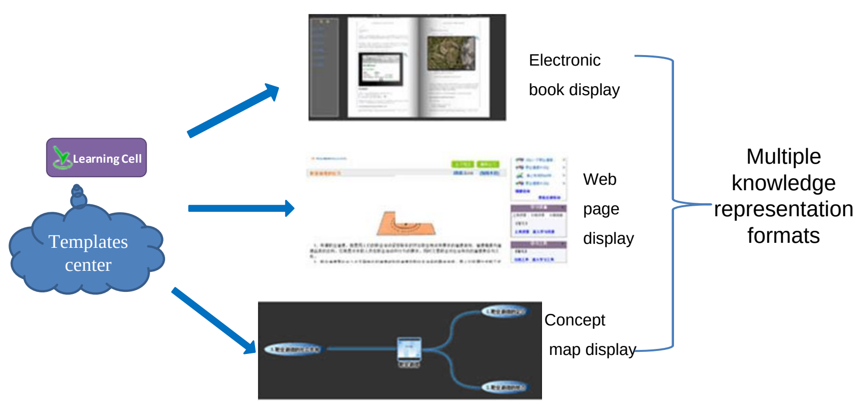


Figure 11. Multiple formats of learning cells

The knowledge group (KG) function assembles all of the knowledge groups in the environment (see Figure 12). Each knowledge group consists of learning cells on related subjects. For example, a course can be a knowledge group and each lesson or knowledge point in the course can be a learning cell. When users access the knowledge group, they can find all of the learning cells related to the course.

The knowledge cloud (KC) function aggregates multiple knowledge groups. Different knowledge groups are connected via semantic relationships. In a knowledge cloud, users can easily find all of the knowledge groups related to their subject.

The learning tool (LT) function assembles all of the personalized learning gadgets. In LT, users can not only preview or save gadgets but also upload gadgets. All gadgets conforming to open social standards can be integrated into LT. These gadgets can be used by learning cells, knowledge groups, personal space, and learning communities. For example, to enhance learning efficiency, some gadgets, such as translating gadgets, can be integrated into the learning content during the content creation or editing process.

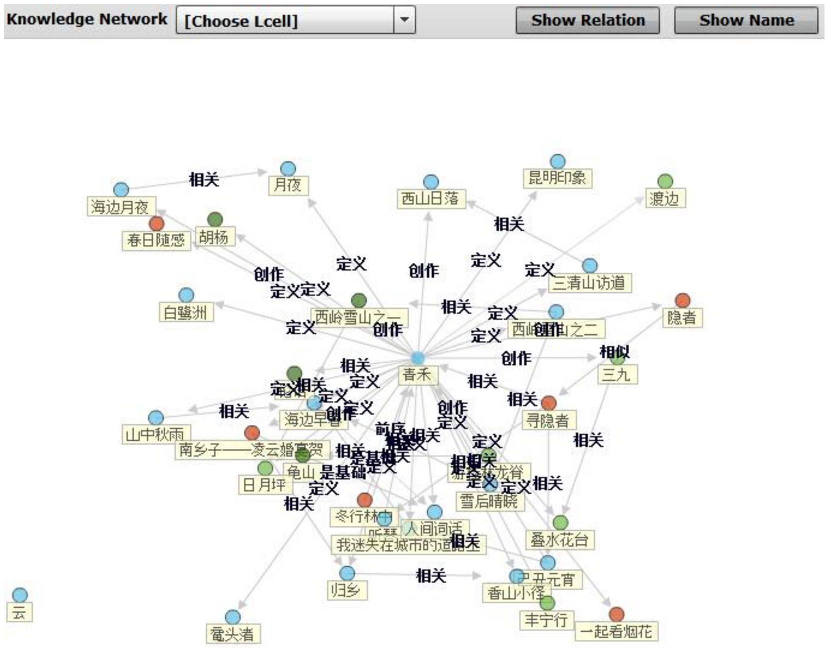


Figure 12. A knowledge group consisting of multiple semantically related learning cells

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The learning community (LC) function assembles all of the learning communities in the environment. A learning cell is a collective learning environment (CLE) in which community members communicate, collaborate, or share with each other. Community members can publish a notice, initiate a discussion, share interesting resources, and initiate learning activities. Learning communities are related to LC, KG, and LT, and related learning cells, knowledge groups, and knowledge tools can be introduced into learning communities. In addition to learning communities, all users have their own personalized learning environment.

Personal space (PS) is the personal learning environment (PLE) of each user, containing functions for personal resource management, friend management, schedule management, gadget management, and personalized learning recommendations. In personal space, users can post basic personal information, manage (create, collaborate, and subscribe to) interesting learning cells and knowledge groups, and select recommended learning resources.

Applications and evaluations

As a proof of concept, our lab created the Learning Cell System (LCS), an open-knowledge community developed for u-learning. It supports collaborative knowledge editing, knowledge aggregation and evolution, multiple-level interaction, and multi-dimensional communication. Specifically, LCS allows the orderly evolution of resources, facilitates shared cognition networks and the collaborative construction of ontologies, and provides open-service tools. LCS can be accessed at http://lcell.bnu.edu.cn. Since its launch in May 2011, 8,851 users have registered, 15,793 learning cells have been created, 80 learning applets have been generated, and 1,507 knowledge groups and 116 learning communities have been formed (as of July 23, 2013).

Case study

We carried out two practical applications of LCS. The first application was designed to support e-learning for graduate students (formal learning), and the second one was to support regional collaborative teaching research for primary and secondary school teachers (i.e., informal learning). In the first e-learning case study, a course was offered to 25 graduate students through LCS (see Figure 13). The teacher created teaching content that allowed students to collaboratively edit them. The teacher designed all kinds of learning activities (discussion, test, vote, etc.) for students to participate. Students could use smart phones or tablet PCs to view learning content and interact, commenting, rating, and taking notes (See Fig. 14). In order to promote deep communication and knowledge sharing, the teacher created a course community. In this community, teachers could publish course information, put up some questions to guide students to in-depth thinking, assign individualized homework, and keep a watchful eye on students' learning process. Students could upload their work, share course materials, and attend course discussions.

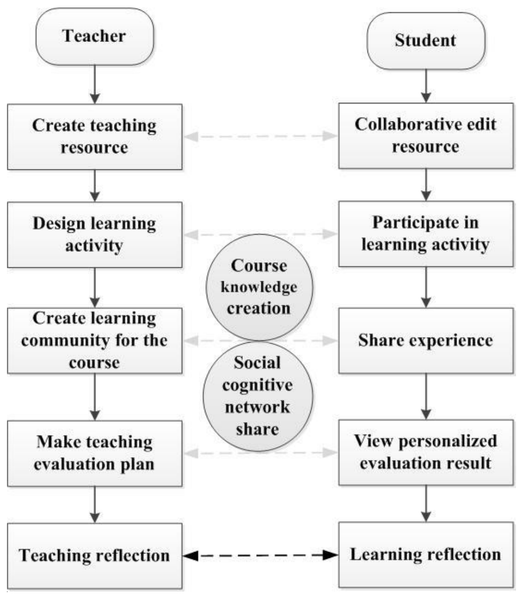

Figure 13. E-learning process based on LCS

Figure 14. Students using tablet PCs (left) and a smart phone (right) to learn on LCS

The case study was performed in Feixi County, Anhui Province, with 50 participating teachers in 10 schools. The collaboration process is shown in Figure 15. In the regional collaborative teaching research case study, teachers shared experiences through LCS. The director established several knowledge groups for the focus subjects and invited teachers to collaborate on the research. Meanwhile, learning communities were set up to encourage teachers to share their resources, knowledge, and experiences. Any teacher can create, edit, and comment on lesson plans anytime, anywhere with the mobile client APP of LCS (See Figure 16). Teachers could also publish their own teaching thoughts in a timely manner and communicate with others to improve together.

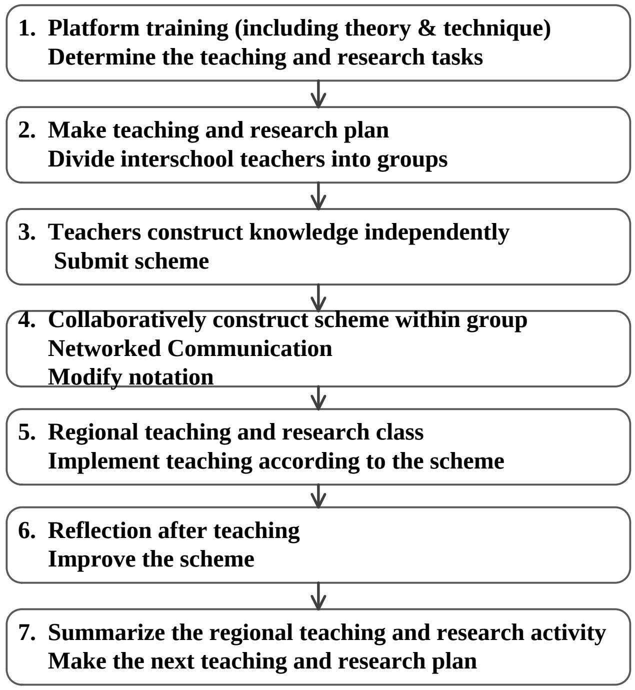

Figure 15. Regional collaborative teaching research process based on LCS

Figure 16. Screenshots of mobile APP of LCS

Evaluations

In the above two case studies, investigations were carried out to determine the LCS's usability and user attitudes. The usability investigation was based on an SUS tool developed by John Brooke (Brooke, 1996), and the questionnaires were published using a professional investigation platform (http://www.sojump.com/). Fifty users participated in the investigation; the results are shown in Figure 17.

The results show that 68% of the users felt confident using LCS, 26% of the users were neutral, and 6% of the users were not willing to use the system due to their lack of confidence with it. In general, most users had positive attitudes toward LCS. Further investigations reveal that the non-confident users felt that LCS was too complicated.

The first group of user attitude investigations was carried out with the teachers involved in the collaborative research case study. Twenty-five questionnaires were sent out by email and 23 (92%) were returned. The results are shown in Figure 18.

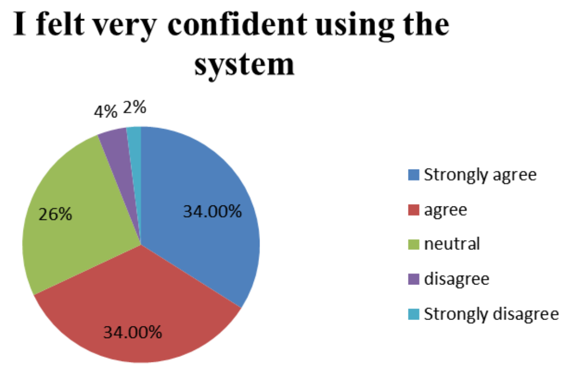

Figure 17. LCS usability investigation results

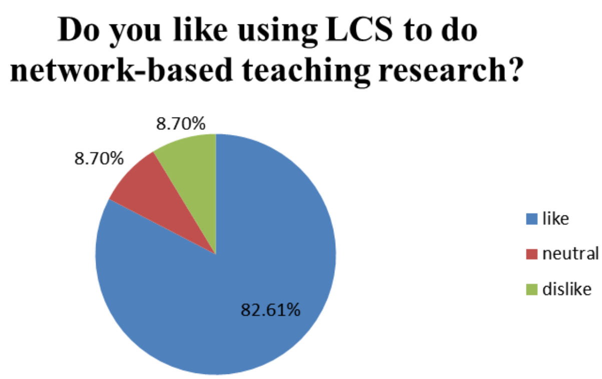

Figure 18. Investigation results of LCS-supported collaborative teaching research

Figure 18 shows that 82.61% of the teachers liked LCS-supported collaborative research, and 8.7% of teachers disliked it. Further investigations indicated that some teachers felt LCS was too complicated to use without additional usage guidance.

The second group of user attitude investigations was carried out with the graduate students who participated in the e-learning course. Twenty-five questionnaires were distributed, and all of them were returned. The results of the general feedback are shown in Table 1, and the results of feedback about specific LCS functions are shown in Table 2.

Table 1. User feedback about LCS-supported e-learning (25 users)

Options	Number	Proportion
Functions are rich and practical	17	68%
Helpful for collaborative learning	20	80%
Resource organization is innovative and practical	19	76%
LCS compensates for the deficiencies of existing learning platforms and conforms to the development direction of learning technologies	17	68%

Table 1 shows that 68% of students approved the system functions and technologies, 80% of students liked LCS-supported collaborative learning, and 76% of students believed LC was innovative and practical. Overall, most students have a positive attitude towards LCS-supported learning.

Table 2. User feedback on LCS functions (25 users)

Options	Number	Proportion
Content is open to generative information, such as comments and annotations, and helpful for KNS construction.	23	92%
Learners can obtain the updated information on demand.	13	52%
Learning Cell is evolvable, dynamic, and open.	21	84%
Learning Cell provides multiple formats to choose from.	22	88%
Content, activities, and tools are integrated.	20	80%
Participating in collaborative editing helps me absorb others' wisdom.	23	92%
KNS helps me find knowledge-related learners and experts.	19	76%
KNS promotes learning by helping me communicate with related learners and experts.	16	64%
Semantic-based resource organizations (knowledge groups) are flexible and help me find resources on demand.	19	76%
Knowledge semantic networks within knowledge groups allow users to contribute to strengthening the relationships among different knowledge points.	18	72%

Table 1 shows that 92% of students liked the features of openness and collaborative editing. More than 80% of students liked the features of evolution, multiple formats, and integration. More than 70% of students enjoyed using the features of knowledge semantic network, semantic-based resource organizations, and KNS. In addition, half of students were able to obtain the updated information on demand, and 64% of students believed KNS can promote learning.

Valuable user comments about the system include: (1) the system is somewhat complicated, and user experience can be improved; (2) the adaptability of LC to multiple devices is advantageous, but more formats should be supported; (3) Learning Cell updates can be synchronized with micro blogging.

The above investigations reveal that LCS is functioning but there are some problems. In the future, we will simplify LCS operations and perform more and deeper investigations on LCS application.

Conclusion

Effective learning requires an intelligent, seamless learning space. Compared with other learning environments, seamless learning space accommodates high immersion and mobility. The construction of such a learning environment cannot be achieved without communication networks; context-aware, intelligent terminals; learning resources; and education cloud centers. Without the proper organization of learning resources, the appearance of new technological environments will not create ideal learning effects. The organization of learning resources is a fundamental factor of seamless learning environments. Based on Learning Object, this paper proposes a new learning resource organization model, Learning Cell, which provides a theoretical and practical basis for resource organization in future u-learning. Learning Cell is open, generative, evolvable, connected, cohesive, intelligent, adaptive, and social.

Our research team has successfully developed the Learning Cell System (LCS), a runtime environment for Learning Cell and used the basic ideas of Learning Cell to support learning. LCS can provide technical support for the following four aspects of the application: (1) In school context, teachers and students can create an online course together. The system can save all the learning procedural information, so as to generate standard courses in conformity with the SCORM standard. Teachers can also collaborate to build the school-based resource center and share teaching experience with each other. (2) Users can achieve personal knowledge management and organizational knowledge management in PS. (3) When used in industries, employees can be attracted to actively participate in learning by designing rich activities. They can also use the learning community to aggregate network and wisdom to promote collaboration and communication. (4) In higher educational institutions, LCS can support the smooth implementation of blended learning.

Pilot testing reveal the initial success of the Learning Cell Model and the Learning Cell System. In the future, we will carry out further research on evolution control, contextual cognition, personalized resource recommendation, application modes, and ecology-based knowledge construction. We believe that Learning Cell can greatly contribute to the resource design and sharing mechanisms of u-learning's development.

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References

ADL (2004). SCORM 2004 3rd edition. Retrieved June 22, 2008, from http://www.adlnet.org

Allen, C. (2008). SCORM 2.0 project. Retrieved November 30, 2010, from https://letsi.org/index.php?option=com _content &view= article&id=82&Itemid=9

Britain, S. (2004). *A review of learning design: Concept, specifications and tools.* Retrieved June 22, 2008, from http://www.jisc.ac.uk/uploaded_documents/ACF1ABB.doc

Brooke, J. (1996). SUS-A quick and dirty usability scale. Retrieved April 11, 2015, from https://rickvanderzwet.nl/trac/personal/export/72/liacs/hci/docs/SUS-questionaire.pdf

Cheng, G., Xu, J., & Yu, S. Q. (2009). New progress in learning resources standards and development trend of learning resources. *Distance Education Journal, 4,* 6–12.

Hwang, G. J., Yang, T. C., Tsai, C. C., & Yang, S. J. H. (2009). A context-aware ubiquitous learning environment for conducting complex science experiments, *Computers & Education, 53*(2), 402–413.

IMS Global Learning Consortium (2008). IMS common cartridge. Retrieved January 8, 2009, from http://www.imsglobal.org/commoncartridge.html

IMS Global Learning Consortium (2003). IMS learning design specification. Retrieved June 25, 2008, from http://www.imsglobal.org/learningdesign

LETSI (2008). *SCORM 2.0 white paper solicitation.* Retrieved July 22, 2013, from http://scorm.com/ tincanoverview/the-letsi-scorm-2-0-white-papers/

Li, J. H. (1997). From courseware to integrable-ware: The new development of CAI in Chinese school classes. *China Educational Technology*, *4*, 12–16.

Siemens, G. (2004). *Connectivism: A learning theory for the digital age.* Retrieved February 3, 2010, from http: //www. Elearnspace.org/Articles/connectivism.htm

Ogata, H., & Yano, Y. (2004). Context-aware support for computer-supported ubiquitous learning. *Proceedings of the 2nd IEEE International Workshop on Wireless and Mobile Technologies in Education* (pp. 27–34). Los Alamitos, CA: IEEE Computer Society. doi: 10.1109/WMTE.2004.1281330.

Wiley, D. A. (2000). *Connecting learning objects to instructional design theory: A definition, a metaphor, and a taxonomy.* Retrieved November 18, 2013, from http://reusability.org/read/chapters/wiley.doc

Wong, L. H., & Looi, C. K. (2011).What seams do we remove in mobile-assisted seamless learning? A critical review of the literature. *Computers & Education, 57*(4), 2364–2381.

Yang, X. M., & Yu, S. Q. (2013). Research on the intelligent control of learning resource content evolution in the open environment. *E-education Research, 9*, 83–88.

Yang, X. M., Qiu, Q., Yu, S. Q., & Hasan, T. (2014). Designing a trust evaluation model for open-knowledge communities, *British Journal of Educational Technology, 45*(5), 880–901.

Yu, S. Q. (2007). From knowledge transfer to cognitive construction, and finally situated cognition: Development and prospect of three generation of mobile learning. *China Educational Technology, 6*, 7–18.

Yu, S. Q., & Yang, X. M. (2007). Discrimination among integrable-ware, learning object and learning activity: Discussion on new directions of educational resources' sharing. *China Educational Technology, 12*, 60–65.

Yu, S. Q., Yang, X. M., & Cheng, G. (2009). Learning resource designing and sharing in ubiquitous learning environment: The concept and architecture of Leaning Cell. *Open Education Research, 1*, 47–53.