A Framework of Learner Development Ecosystem for Designing a Ubiquitous Educational Informational Infrastructure

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***Abstract*—The methodology of designing ubiquitous learning environments has recently started to attract considerable attention in various disciplines. From the viewpoint of researchers of educational technology, this paper proposes a new framework of a learner development ecosystem for designing a ubiquitous learning environment, which is built on the theory of social constructivism proposed by Vygotsky, the theory of ecology of human development by Bronfenbrenner and the knowledge spiral theory by Nonaka. We argue that a practical ubiquitous learning environment should be regarded as a complex, dynamic ecosystem within which a learner's knowledge is continuously developed in the shape of spiral. Based on this framework, we suggest a technical infrastructure and the implementation of ubiquitous learning in a real world context.**

***Index Terms*—framework, design, ubiquitous learning, learning environment, social constructivism**

I. INTRODUCTION: BACKGROUND AND PROBLEM ANALYSIS

Since Weiser introduced the concepts of Ubiquitous Computing and Calm technology in 1988, technology seems to have matured to a sufficiently high level to bring mobile learning and ubiquitous learning into our lives.

In current research, the terms "mobile learning" and "ubiquitous learning" are often used interchangeably, even though the latter usually involves the concepts of sensor networks and context-awareness. Looking up the definitions of "ubiquitous learning", "mobile learning" and "1:1 learning", we discover that most definitions take technology as the starting point. For example, m-Learning is e-learning through mobile computational devices, such as Palms, Windows CE machines, or even digital cell phones (Quinn, 2000) [1]. The other commonly cited definition is formulated as "anyone can learn anytime, anywhere using a digital device". Also, 1:1 learning (where students use at least one computing device for learning) is closer to education, although it is somewhat unclear with respect to describing the nature of ubiquitous learning (Tak-Wai Chan, et.al. 2005) [2]. Keegan criticizes these definitions by arguing that learning cannot be either 'electronic' or mobile [3]. In the Telenor m-Learning Wap project, Keegan and colleagues provide a definition of m-Learning which attempts to describe the significance of m-learning from a social and cultural point of view (the use of mobile terminals in learning) and attributes its growth to the increasing portability of electronic devices and the growing need for flexible learning.

In practice, researchers have found that techniques for ubiquitous learning involve not only new teaching models and positive influences, but also new problems and negative influences. There is an urgent need for a practical theoretical framework to be developed in order to overcome these obstacles to implementing ubiquitous learning.

When we analyze problems which prevent U-learning from being implemented, we find that with respect to hardware, in contrast to desktop computers, handheld devices have relatively small screens, low resolution, low processing power, limited storage capabilities, low network speed capabilities, follow different enterprise standards, and their battery life and heat dissipation issues limit their usability with respect to intensive streaming media or continuous connection to broadband networks. In addition, the capabilities of handheld devices do not follow the rapid increase in capabilities in accordance with Moore's law. Therefore, in the pursuit of intricate knowledge via social cooperation and communication, handhelds can not yet replace face-to-face discourse and

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videoconferencing even despite their characteristics of high portability, mobility and accessibility.

With respect to learning, many teachers have reported the distractions posed by laptops and mobile phones. Levine (2002) suggested a model of integrating laptops into classrooms which is based on a laptop-up laptop-down system [4]. During lecture time, students are told to close their laptops and pay attention to the lecturer, and they only open their machines when they need to use them. On the other hand, many researchers have reported that U-learning has obvious strengths with respect to quick reminders and alerts, personal knowledge management, peer-to-peer communication and learning for special content, such as language skills, and in particular contexts, such as in museums. Beside these advantages, Fitch (2004) has found that mobile devices can facilitate faculty-student interactions and in-class participation, thus increasing engagement and promoting active learning [5].

Therefore, we argue that, similar to other media, mobile devices have their niche in ICT. Although mobile terminals are categorized as new media, they do not possess extreme capabilities and have limited information transferring channels which are no faster than traditional media. However, they can always be accessed by the learner. There is an urgent need for the development of a new practical theoretical and technical framework in the field of educational technology in order to overcome these obstacles to the effective and efficient implementation of ubiquitous learning.

Based on these works, we believe that by using ubiquitous learning, it is possible to set up ubiquitous connecting channels between different contexts within our lives, as well as to create a ubiquitous dialogue structure within which teachers, capable peers and digital resources can direct, support and communicate with individual learners.

II. NATURE OF KNOWLEDGE, LEARNING AND DEVELOPMENT: VIEWPOINTS OF RESEARCHERS OF EDUCATIONAL TECHNOLOGY

Since the 1980s, researchers of educational technology have been experiencing a shift of paradigms from cognitivism to constructivism. Classical teaching metaphors have shifted from the traditional metaphors of transfer-reception to a new metaphor of knowledge construction. In the new constructivist research paradigm, researchers began to focus on the interaction between learners and their environments, especially the process of interaction, on the basis of a dynamic, historic and cultural approach instead of a static atomistic approach (Sugai,1999) [6]. Essentially, in the mind of a constructivist researcher, “Constructivist conceptions of learning…assume that knowledge is individually constructed and socially coconstructed by learners based on their interpretations of experiences in the world. Since knowledge cannot be transmitted, instruction should consist of experiences that facilitate knowledge construction” (Jonassen, 1999) [7].

As Moore points out, ‘distance education is a subset of the universe of education’ in some way. Distance education and education are similar in connoting “interplay among the environment, the individuals and the patterns of behaviors in a situation” [8]. Therefore, ubiquitous learning should be first considered in a framework of learning theories, not a framework of techniques utilization.

In this paper, we regard knowledge construction as the basic unit in the analysis aimed at explaining individual learning behaviors. We describe knowledge construction as an interaction, a communication, or interplay between the environments, the individuals and the behavioral patterns corresponding to given situations. Also, according to the definition of proximal development zone as proposed by Vygotsky (1978), only under adult guidance or in collaboration with more capable peers do individual learners achieve success in learning or development [9].

A. Dimensions of personal and social knowledge and how the knowledge spiral develops

The social and cultural approach adopted by Vygotsky (1978) was widely accepted by constructivist researchers. He stated that, "Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, between people (interpsychological) and then inside the child (intrapsychological). This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher functions originate as actual relationships between individuals".

In the field of knowledge management, Nonaka developed Vygotsky’s points and adopted a SECI model for knowledge-creating enterprises. As illustrated in Fig. 1, the SECI model describes in detail the dynamics of knowledge evolution as a knowledge spiral: “a dynamic human process of justifying personal belief toward the ‘truth’” [10]. He points out that the process of knowledge creation includes four stages: Socialization, Externalization, Combination and Internalization. At different stages, knowledge transfer occurs in the form of sympathized knowledge, conceptual knowledge, systemic

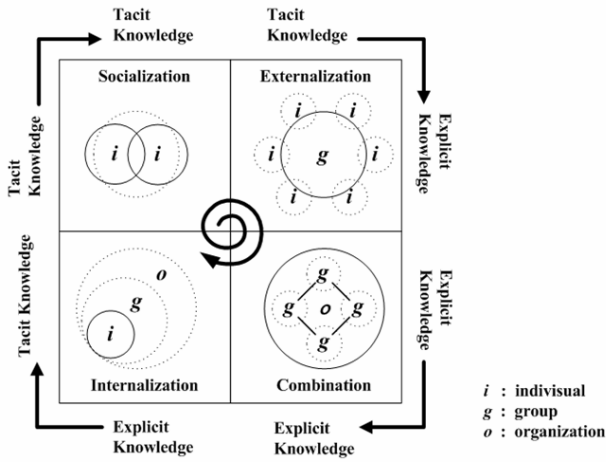

Figure 1. Nonaka’s SECI model of knowledge creation in an enterprise. Source: Nonaka and Konno, 1998.

knowledge and operational knowledge. In order to support different stages of knowledge creation, it is necessary to provide relevant support and environments to workers.

These statements are helpful for us to understand how learning occurs in the real world as well as the behavior of individual learners at every stage of the learning process.

Although Nonaka's model is developed for the purpose of analyzing the learning behavior in an enterprise so that it places emphasis on the transformation of knowledge and group activities, it is essentially applicable when we focus on individuals and regard individual learners as subjects at the center of the model.

The contribution by Nonaka gives us a topological framework for authentic learning, thus uncovering the dynamics of evolutional knowledge and learning mechanics and emphasizing the nature of complex and iterative knowledge and learning in a postindustrial society.

In modifying Nonaka' model, we place emphasis on individual learners instead of on knowledge or enterprises, and we obtain a model for analyzing the actual learning process of an individual learner.

B. Dimensions of well- structured and ill-structured knowledge

In the SECI model, Nonaka uses the terms "explicit knowledge" and "tacit knowledge". These terms have been introduced by Michael Polanyi, who presents two fundamentally different kinds of knowledge: explicit knowledge which can be expressed, transferred and received by using words, numbers, diagrams and other symbols, and tacit knowledge, which he describes as, 'We can know more than we can tell' [11]. Furthermore, Nonaka describes "tacit knowledge" as a kind of knowledge which is difficult to formalize and communicate.

However, although this classification was relevant at the time of its formulation, nowadays it is somewhat outdated. At present, we have access to many types of media for dynamic visualization. With the support of AI techniques, statistics techniques or visualization techniques, users can generate, sometimes even automatically, immense amounts of digital content. However, even the individuals who create the content can not formalize and communicate its meaning.

In order to clearly classify the domains of knowledge, we tend to use terms from the Cognitive Flexible Theory proposed by Spiro et al. The theory suggests that knowledge can be divided into two domains: well-structured knowledge and ill-structured knowledge [12]. This opinion emphasizes the fact that advanced knowledge has multiple aspects, it is complex and ill-defined. Novices always start from well-structured knowledge and progress towards ill-structured knowledge, and when they finally become experts, they arrive at a higher level in both domains of knowledge.

In order to describe our theoretical framework, by performing some modifications to Nonaka's model and developing it, in this paper, we partly use the classification method proposed by Spiro. In our paper, "well-structured knowledge", which is interchangeable with "explicit knowledge", refers to knowledge which is context-free and which can be expressed by using linear media, such as speaking or writing an essay. "Ill-structured knowledge", which is interchangeable with "tacit knowledge", refers to knowledge which is context-specific. Even when it can be expressed, it can only be expressed through nonlinear media, such as face-to-face communication, hypertext, hypermedia or Mashup media.

In the process of learning, in order to solve a problem or achieve a goal, learners interact with both well-structured knowledge including textbooks, and ill-structured knowledge such as dialogues or collaborative work.

We can point out some research findings as evidence which supports our classification of well-structured and ill-structured knowledge. Moore (1993) analyzed a special teaching procedure on two clusters of variables: the dialogue variable, which is used for describing interaction, and the structure variable, which is used for describing structured elements in a course. Moreover, Saba (2003) verified that there is a negative feedback loop between structure and dialogue [13], namely a mechanism where structure increases as dialogue decreases. Based on a project stared in 2000, Zhang, He and Maesako (2008) found that if a lesson plan on a subject of social science is designed to be clearly divided into sections of lectures (teaching based on well-structured knowledge), discussion and writing (learning based on ill-structured knowledge), a considerable improvement is seen in the performance of the students [14].

C. Framework of a learning and development ecosystem for individual learners aimed at designing a learning environment

In the field of pedagogy, Vygotsky (1992) points out that the development of children's experience depends on their learning environments. In the interplay between human and environment, teachers play the roles of organizers, mediators, managers as well as parts of this learning environment [15].

Since Vygotsky, most such theories have viewed the whole environment as a system and have placed an emphasis on interaction. One of the most influencing theories is Kurt Lewin's classic equation: $B = f(PE)$ (Lewin, 1935), which describes the behavior (B) as a function of the interplay between person (P) and environment (E) [16].

Expanding Vygotsky's theory, the Activity Triangle Model proposed by Engeström (1987) offers a systematic method for analyzing learning activities. In his model, designers can focus on learning activities and analyze them from six viewpoints: object, subject, instruments, community, rules and division of labor [17].

The Constructivist Learning Environment Model proposed by Jonassen (1997, 1999) focuses on the workflow of the constructivist instructional design. It is

especially suitable for teachers and e-learning designers [18].

The Conversation Theoretical Model proposed by Laurillard (2002, 2008) provides a dynamic analysis method for the teaching process at university from a bird-eye view, and her newest lecture gives a complete set of tools for the analysis of technology-enhanced teaching and learning from the viewpoint of behaviorists, cognitivists and constructivists. [19][20].

Furthermore, the Systemic Instructional Design Model proposed by He (2002) gives a constructivist instructional design in an authentic context of classrooms in schools. He advises teachers to create an instructional design by using both approaches, namely the teacher-driven and the learner-driven one, in order to adapt to the categories of well-structured knowledge and ill-structured knowledge. When teachers encounter well-structured knowledge, they can turn it into a lecture and subsequently into a resource-based teaching model, and when they encounter ill-structured knowledge, they can turn it into a learner-centered self-learning and activity-based learning model [21]. He's approach has been implemented in over 130 schools, especially in Chinese and English language education in China. Researchers have collected feedback and data from over 3000 pupils, and the results indicate that most pupils have improved their achievements in learning.

Also, Situation Learning Theory, Community of Practice, Cognitive Apprentice, Scaffolding and studies on CSCL, cultural psychology and cultural anthropology gave clues to learners regarding learning strategies through distributive cognition and everyday computing.

However, so far there have been no models which cover such a wide area of space and time in considering authentic learning.

Bronfenbrenner (1979) proposes a theory of learner-centered ecological environment as a set of nested structures, each inside the next [22]. At the innermost level is the developing person and settings such as home, classroom, or other behavioral settings directly influencing the person. Areas located further have less influence on the person. He has argued that when considering learning, all elements, including cultural context, should be considered from a systemic point of view. Considering limited elements separately can not uncover the truth about learning and development. However, Bronfenbenner provides evidence which many other researchers have also found. In this regard, there is a difference between the outcome of experiments in laboratory conditions and in real-life experiments.

In our opinion, Bronfenbrenner's ecosystem model provides a powerful analytical framework for designing a ubiquitous learning environment in a real-world context. Under this framework, it is possible to further refer to works of other researchers, especially ones focusing on learning environments.

Since the argument of Bronfenbrenner regarding the leaner development ecosystem is rooted in many works of theorists from a variety of disciplines, especially researchers focusing on learning environments and constructivists, it is possible to easily blend all kinds of theories of learning environments under Bronfenbrenner's framework.

III. DEVELOPMENT OF A THEORETICAL FRAMEWORK OF A KNOWLEDGE SPIRAL-BASED LEARNER DEVELOPMENT ECOSYSTEM

A. Ubiquitous Educational Information Infrastructure as a Development Ecosystem for Individual Learners

Our theoretical framework of a learner development ecosystem is based on the works of Bronfenbrenner, Sugai and Maesako.

By using the nested structure model of Bronfenbrenner (1979) Ecological system theory, Sugai (2002) describes all kinds of interplay between learners and ICT-enhanced learning environments, especially when the learner is in a real-world context [23].

As illustrated in Fig. 2, in this nested structure, a learner is at the center of the structure. The tools system is closest to the learner. By using tools, such as digital terminals and traditional learning instruments, the learner can interact with the environment through mediated activities. The media tools include desktops, notebook computers, mobile phones, textbooks, pens and notes, and so on. Moreover, the tool system can be divided into a software level and a hardware level.

According to arguments presented by Bronfenbrenner, we should look beyond single behavioral settings to the relations between them. The consideration of these interconnections can be used for analyzing the situation of the learner and providing effective and efficient learning support.

In the core of the nested structure, just next to the tool system, there is the microsystem containing fields in which the learner gains experience by direct involvement. The fields include school, home and social facilities such as museums and libraries. A child learner can directly

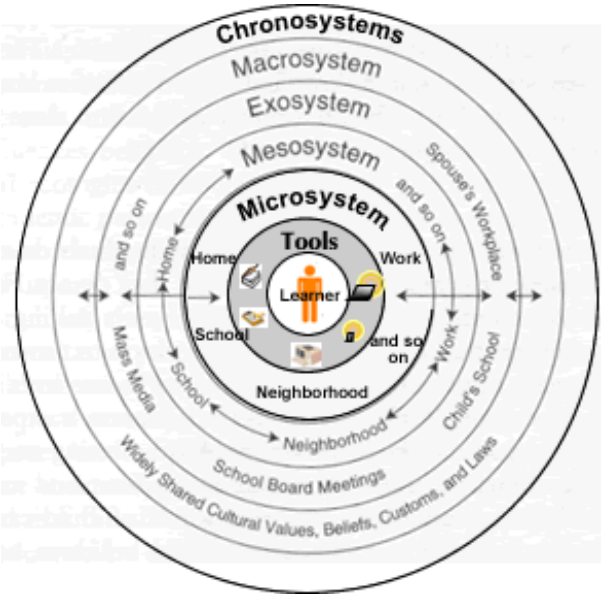

Figure 2. Model of ecosystem of learner development, based on Bronfenbrenner's Ecological system model (Bronfenbrenner, 1979)

interact with teachers and classmates at school, with parents or guardians at home, friends in the neighborhood or at faculties in social educational facilities. An adult learner can directly interact with colleagues at work. At this level, we consider the interrelations between all kinds of learning tools.

The mesosystem comprises the interrelations between two or more settings in which the learner is active. For example, for a child, this can represent the relations between school, home, neighborhood, and social educational facilities; while for an adult these can be the relations between family, work, and social life.

The exsosystem refers to one or more settings which do not directly influence the learner, but in which events affect or are affected by settings in the mesosystem. Settings in this level include mainly mass media, parents' workplace, school board meetings and so on.

On a higher level, the macrosystem contains nationwide shared cultural values, beliefs, customs and laws.

Finally, the chronosystems provide a chronic framework to the analysis of the learner's development in view of a very long history.

This framework can help designers and teachers to analyze the context learners operate in and the learning environment in order to uncover the core needs of the learner and what kinds of events can influence learners in their development.

Based on the nested structure model proposed by Bronfenbrenner, from the viewpoint of technological architecture, Maesako (1997, 2006) suggests a local educational information infrastructure as a human development ecosystem [24][25].

Maesako argues that it is necessary to establish a local wireless educational information infrastructure by equipping schools and social facilities (e.g. museums, science museums, galleries, zoos, ocean aquariums, libraries, media centers, parks, historic sites, net-cafes, stations, airports, adolescent activity centers, lifelong learning centers and citizen centers) with a wireless network and a sensor network. In this infrastructure, by using mobile handhelds, every learner can obtain access to stronger communication and computing capabilities and can immerse in a seamless learning space.

Within the coverage area of access point devices, learners can use wireless LAN at high network speeds for accessing local servers. Outside the coverage area of access point devices, learners can use cell phone networks to perform personal knowledge management, receive quick reminders and utilize peer-to-peer communication. In this framework, using wireless techniques and mobile handhelds, every student can easily access teaching materials and activities in classrooms from home or other places.

Through the utilization of ubiquitous devices and infrastructure, it is possible to create many fluent communication channels to connect different behavior settings around the learner. Just as Bronfenbrenner pointed out, authentic learning is a dynamic ecosystem, and we should analyze the relations between as many elements as possible in order to draw a conclusion regarding learning and development.

B. DynamicMechanism of Knowledge Spiral in the Learner Development Ecosystem

In order to analyze the dynamic mechanism of this ecosystem, we focus on knowledge construction as the basic building block in a complementary relationship. More importantly, the continuous learning and development of an individual learner is a spiral process in which all knowledge construction takes place repeatedly.

According to works of Vygotsky, Spiro and Nonaka, learning is a continuous process, and personal knowledge is constructed through solving authentic problems. In Nonaka's model, the processes of knowledge construction can be divided into four modes: Socialization, Externalization, Combination and Internalization. Through jumping from one of these four modes to another, learners develop knowledge in a way similar to the method based on a spiral curve in an historical and cultural context. Based on the SECI model, we develop a theoretical framework of a dynamic mechanism of learning and development as illustrated in Fig. 3. Indeed, it is necessary to point out that in the spiral of learning and development of a learner can jump steps and can progress in counterclockwise direction.

By taking the two directions of the vertical axis as "well-structured knowledge" vs. "ill structured knowledge" and those of the horizontal axis as "personal learning" vs. "social learning", knowledge construction activities of a learner can be divided into four modes in four quadrants. Then, the learning activities of the learner can be divided into five modes.

Quadrants III and IV are the actual development levels for learners, while quadrants I and II are the potential development levels for learners. Under adult guidance or in collaboration with more capable peers in quadrants I and II, learners obtain a development on the social level, and then, in quadrants III and IV, learners obtain a development on an individual level. There is the zone of proximal development proposed by Vygotsky between quadrants III and IV and quadrants I and II. In the social learning area, more dialogues improve the performance

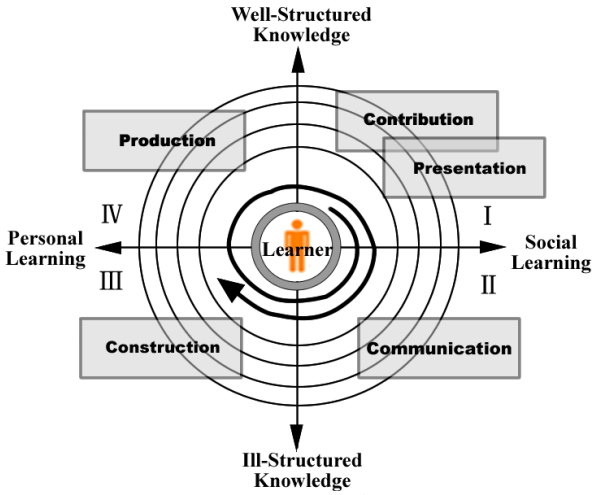

Figure 3. A Theoretical Framework of Knowledge Spiral-based Ecosystem of Learner Development

of learning. Meanwhile, in the personal learning area, less dialogue improves the performance of learning.

According to the kinds of targeted knowledge, owing to natural sciences or social sciences, the methodologies of teaching and learning can be divided mainly into two categories: the teacher-centered, resource-based learning in quadrants I and IV and the learner-centered, activity-based learning in quadrants II and III. The former is more context-free, as the latter is more context-specific. There is a negative feedback loop between quadrants I and IV and quadrants II and III. For example, instructional design or learning design, which are based on well-structured knowledge, hinders the acquisition of ill-structured knowledge.

According to the analysis of everyday teaching patterns, we suggest that there are five modes of learning activities. Following our knowledge spiral and the usual teaching flow, the five modes are Presentation in quadrant I, Communication in quadrant II, Construction in quadrant III, Production in quadrant IV and Contribution again in quadrant I.

Some typical examples of learning activities in the five phrases are provided below. In the Presentation phase, the learner attends lessons at school. In the Communication phase, the learner attends activities in the community, has discussions with peers, and works together with peers. In the Construction phrase, the learner begins to perform self-reflection and activities in a laboratory. In the Production phrase, the learner writes a report or an essay. Finally, in the Contribution phrase, the learner gives a presentation based on his prior knowledge construction experience.

C. Discussion on Guidelines for Desinging a Ubiquitous Learning Environment

Based on the works of Lave and Wenger (1991) and Sugai, Bronfenbrenner and Zhao (2003), we consider the influence of all kinds of contexts on the learner within an ecosystem when we design a learning environment [26][27]. At all levels of the nested structure, the social/cultural context, social support, teacher support, learning environments, and learning tools, as well as the interrelations between them, influence learners and constitute a dynamic complex system.

In order to maintain an existing ecosystem, a learner needs to obey many rules. Designers should first investigate the context in which the learners are situated, where the designer can not make direct use of the so-called “effective design” from a different context. As time goes by, the design of instructional and learning environments must be reconsidered in accordance to changes in the context and the development of the learner. Also, it is necessary to consider five phrases of learning as well as to provide different designs for learning environments and activities in order to adapt to different circumstances as well as to maintain the continuous development of the learner across different phrases.

When we design a ubiquitous learning environment, we should consider the different characteristics of different development quadrants. In quadrants I and IV, teachers should provide more support, such as digital resources, as well as learning scaffolding, such as tasks and reminders. In quadrant II, learners should obtain a higher number and wider communicating channels with peers through creating learner communities, carrying out collaborative learning activities and mediating discussions. In quadrant III, an individual, flexible solution can allow learners to start at any time and to following their own pace according to their personal needs for combining studies with work, family and social life.

TABLE I.
CLASSIFICATION OF EDUCATIONAL MEDIA WITH SUPPORT FOR FIVE MODES OF LEARNING ACTIVITIES

Learning activity support	Kinds of educational media
Presentation	Printed materials, reference books, encyclopedias, dictionaries, Wikipedia, courseware, television, recorders, DVDs, video tapes, projectors, slide projectors, PowerPoint, podcasts, video on demand
Communication	Email, BBS, chat rooms, newsgroups, mail lists, mini-blogs, social bookmarks, teleconferences, video conferences, MOO, network games, SNS
Construction	Labs, virtual labs, drills and practices software, CAI, simulations, mindmaps, logos, digital cameras
Production	Word processors, PowerPoint, Excel, modeling tools, webpage makers, programming tools, image processors, video and audio processors, statistics software, visualization software
Contribution	Blogs, video blogs, storytelling tools, wiki, mashup applications

IV. A TECHNICAL ARCHITECTURE OF UBIQUITOUS LEARNING ENVIRONMENTS UNDER THE THEORETICAL FRAMEWORK OF A LEARNER DEVELOPMENT ECOSYSTEM

A. Classification of Educational Media for Supporting Five Modes of Learning Activities

According to the works of Vygotsky, McLuhan (1932) and Jonassen (1998), media play a very important role in learning as well as in the development of individuals. In their works, media can be viewed as extensions of man or as mind tools. Just as we can not take away a person's glasses, the functions and types of media, together with the skills of using those media, are becoming inseparable parts of a person's abilities [28][29]. Therefore, we place tools/media just around and nearest to the learner.

In order to design a prototype of a ubiquitous learning environment, we need to classify the available educational media for use under different learning contexts. As Table I shows, depending on the kinds of supporting learning activities, educational media can be divided into five categories.

B. System Architecture of a Prototype of a Ubiquitous Learning Environment under the Theoretical Framework of the Learner Development Ecosystem

Under our theoretical framework, by using the respective educational media listed in Table I, we propose a prototype of a ubiquitous environment as illustrated in Fig. 4.

As seen in this figure, at the bottom layer of the system, there are five modules which support five learning activities at different phases of the knowledge spiral: a Presentation module, a Communication module, a Construction module, a Production module and a Contribution module.

At the top layer of the system, learners and teachers can connect to different interfaces through mobile devices with Internet access. Learners can manage their learning progress and activities, and teachers can manage data collected from all learners.

At the middle layer of the system, there are two core modules: the Task management module and the Data analysis module. By using the Task management module, a teacher can open a new lesson and divide the lesson into several tasks. Then, the teacher can divide each task into several activities in the form of a flow chart and share this lesson flow chart and the tasks with other teachers and all learners who select the lesson. The charts are limited to five modes, which we have classified. By clicking on different parts of the flow chart, teachers can enter bottom modules to support learners, while learners can enter bottom modules to join a study program.

The task management module ensures the interrelations between teachers and learners: sharing a common vision, learning objectives and keeping learners on the right route and preventing them from getting lost.

Data is collected and handled from two perspectives: syntactic (quantity) and semantic (meaning). Syntactic data refers to the data from web logs which document all of the learner's activities, such as frequency of login sessions, learning time, frequency and quantity of notes and comments, and so on. Semantic data refer to the comments, feedbacks and assessments from teachers and peers.

The data analysis module handles all the data from both learners and teachers and pushes visual results to both parties. For example, for a learner, the degree of participation in five modes of learning activities can be presented as five progress sheets. Different colors can be used for the learner's progress, the average progress of all learners, the highest progress level achieved by all learners and the progress envisaged by the teachers.

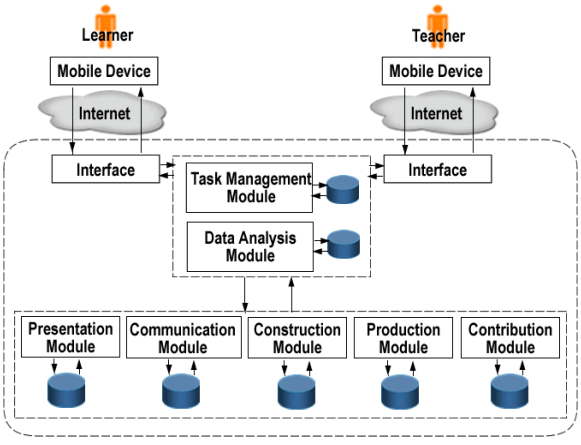

Figure 4. System architecture of the Learner Development Ecosystem Based on the Knowledge Spiral

By checking the learning progress in different modes of learning activities at any time and at any place, learners can acquire learning strategies from teachers and capable peers and revise the learning methods.

By clicking on a progress sheet, learners can enter a bottom module in order to join a study program. They can also package all their learning portfolios in order to share them with others or save to their hard disk. Meanwhile, teachers can check the visual data for all learners.

The data analysis module ensures the interrelations between peers, teachers and learners. In a dynamic complex system, visualization methods are the core methods for turning chaos into order.

V. CONCLUSION

In this paper, we propose a framework of a learner development ecosystem for the purpose of designing an information infrastructure for ubiquitous education. From the viewpoint of pedagogy, we argue that designing a ubiquitous learning environment or any other distance learning environment should place an emphasis on the nature of knowledge, learning and development. In addition, we insist that education should consider the needs of society. In the knowledge-based society we live in, it is necessary to consider the characteristics of the dynamics and the complexity of this society. It appears that education systems face a paradigm shift occurring within a short time period. The constructivist approach and the concepts of ubiquitous learning comprise one of the available methods for solving current education problems. Our framework uses these two approaches. In some pilot studies, our arguments are confirmed to be effective for improving learners' performance.

VI. PROBLEMS AND FUTURE RESEARCH DIRECTIONS

Although we acknowledge the complexity of authentic learning, this complexity is beyond the scope of the present study. The problems related to diversity mainly include the visualization of data for the purpose of improving different learners' performance, the synthesis of all kinds of learning patterns for learners in different subjects, differences in cultural and sub-cultural contexts, the assessment of the learners' performance in such multi-layered contexts, as well as the influence which learners receive under different social network structures. Our next goal is the development of a practical prototype and its verification for the purpose of revising and developing our framework.

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