# Chapter 18
# Facilitating Complex Learning by Mobile Augmented Reality Learning Environments

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**Abstract** The widespread ownership of mobile devices has lead to an increased interest to ubiquitous learning that is supported by a wide range of mobile devices. Mobile learning (m-learning) is referred to as when the process of learning and teaching occurs with the use of mobile devices anywhere and anytime. These developments have led to new research challenges in integrating formal and informal learning opportunities in technological supported environments. Therefore, this chapter is intended to provide an overview on how complex learning may be facilitated by mobile augmented reality learning environments and discuss technological, theoretical, and assessment challenges that must be addressed by future research for mobile augmented reality learning environments to fulfill its potential.

## 18.1 Introduction

An increasing number of researchers in the fields of instructional design, learning sciences, and educational psychology argue that complex knowledge domains present the most challenges, both for designing effective learning environments and for determining factors which contribute to learning (see, for instance, Dörner 1987, 1996; Funke 1991; Jacobson 2000; Sabelli 2006; Spector et al. 2001).

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Challenges involved in learning in complex knowledge domains, such as Science, Engineering, Mathematics, Technology (STEM) domains, are two folds. First, learning in complex knowledge domains requires understanding complex systems. The heart and the brain are two examples of complex physiological systems. Such systems are complex in both their composition—typically many different kinds of components interacting simultaneously and nonlinearly with each other and their environments on multiple levels—and in the rich diversity of behavior of which they are capable. Future scientific and technological developments in many complex knowledge domains depend upon coming to grips with complex systems (Sabelli 2006; Kelso 2009). Recent years has witnessed an increasing emphasis towards this direction. The international workshop on complex dynamics of physiological systems is a recent example. It brought together more than 100 researchers from various fields including physics, mathematics, biology, and medicine to model the complex functions of the brain and the heart by using computer-based simulation systems to advance the fields of medical science and physiology (Dana et al. 2009). Hence, learning in complex knowledge domains is challenging; yet it is a continuous, life-long enterprise as these fields evolve and redefine themselves.

A second challenge of learning in complex knowledge domains, i.e., complex learning, is due to its situativity (cf. Greeno 1998) in real-life contexts. Complex knowledge domains are characterized by large numbers of non-recurrent skills, that is, skills that have to be applied differently and flexibly from situation to situation (van Merriënboer 1997). In contrast, simpler domains are characterized by large numbers of recurrent skills, which are performed similarly from situation to situation, thus, can be automated. This ability to flexibly apply previously learned knowledge and skills to solving new problems under novel situations requires that learners should be able to recognize the situational conditions and far-transfer their learning (Mayer and Wittrock 1996). Thus, complex learning involves the integration and coordination of qualitatively different knowledge, skills, and attitudes that constitute real-life task performance (van Merriënboer et al. 2002). Hence, rather than teaching relevant domain knowledge and skills in isolation, effective teaching in complex knowledge domains should simulate real-life, authentic practices. Yet, creating educational activities that allow students to engage in authentic practices is challenging within the boundaries of a classroom (Chinn and Malhotra 2002). For example, medical students have to learn about forensic medicine in order to differentiate between everyday injuries and wound patterns of trauma due to assault. However, ethical problems may arise when integrating real-life cases into the classroom. Additionally, the quality of available real-life cases may differ and not all relevant findings during a demonstration may be presented (Albrecht et al. 2011). As a possible solution, mobile augmented reality learning environments (MARLE) combine the benefits of mobile learning, virtual learning environments, as well as augmented reality and allows a realistic presentation of various forensic findings (Albrecht et al. 2011).

The widespread ownership of mobile devices has lead to an increased interest to ubiquitous learning that is supported by a wide range of mobile devices (e.g., Tablet-PC, smart phones). Mobile learning (m-learning) is referred to as when the process of learning and teaching occurs with the use of mobile devices anywhere and anytime (Traxler 2009). A virtual learning environment (VLE) models phenomena of the real world by integrating a set of equivalent virtual learning objects and instructional components such as materials, tests, and multimedia objects (Winn 2003). Augmented reality learning environments (ARLE) are considered as an extension of VLE. Generally, ARLE bring virtual learning objects into the real world and allow learners to virtually interact with the combined (real and virtual) world (Haller et al. 2007). MARLE integrates the instructional potential of mobile learning, virtual environments and augmented reality.

These developments have led to new research challenges in integrating formal and informal learning opportunities in technological supported environments. Therefore, this chapter is intended to provide an overview on how complex learning may be facilitated by mobile augmented reality learning environments and discuss technological, theoretical, and assessment challenges that must be addressed by future research for MARLE to fulfill its potential.

## 18.2 Complex Learning

Consider two medical doctors who are asked to diagnose two patients with the same illness. Now imagine that time travel is possible and one of these doctors and the patient are in 1600s; while the other one is in 2011. For the doctor in 1600s, diagnosing this patient's illness would be a simple problem of determining which of the four humors (blood, phlegm, black bile, and yellow bile) is imbalanced and the treatment options would include interventions like bleeding the patient or inducing vomiting to restore the balance of the four humors; and the required surgical skills would include using very basic instruments like drill, saw, or forceps. Fortunately, as our understanding of the human anatomy and physiology increased medical professionals moved away from defining human body based on the ancient Greek view of the four humors. Due to the technological advancements in the field of medicine, competent doctors of today have a better understanding of the complex physiological systems governing human physiology and the dynamic interactions among various system elements. Hence, they are better equipped to diagnose and treat a variety of illnesses. On the other hand, it is also due to these technological advancements that medical diagnosis in today's world would constitute a very complex and ill-structured problem that require an in-depth understanding the interrelationships among very complex physiological systems and finding the optimum treatment option among a number of possible treatment options, each with pros and cons. So, choosing the optimum solution would highly depend on situational factors. As new discoveries are made in the field of medicine, new drugs, new treatment options, new surgical techniques require competent doctors to adapt to the ever-changing requirements of their field.

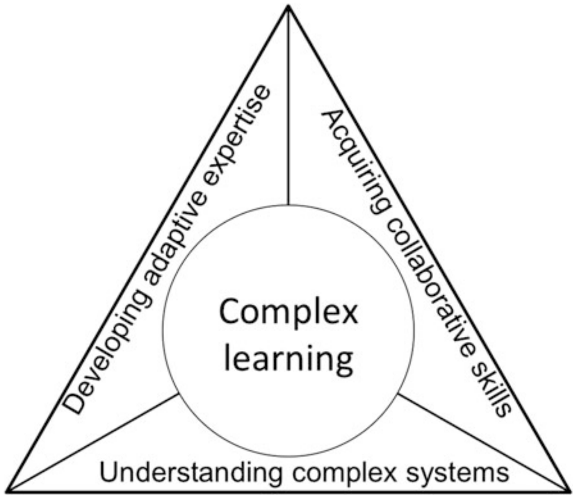


**Fig. 1** Conceptual framework for complex learning

Similarly, the knowledge and skills required for the competent professionals in many scientific domains has increased in their complexity. As a result, the fields of education, training, instructional design, and learning sciences have become more conscious of the demand to prepare individuals to be competent professionals in complex knowledge domains. Hence, a core research agenda of interest shifted their attention to designing learning environments to facilitate complex learning.

As depicted in the example from the field of medicine, complex learning involves (1) in its knowledge base, the requirement of understanding complex systems; (2) in its hard-skills base, the requirement to flexibly apply large numbers of non-recurrent skills that call for adaptive expertise; and (3) in its soft-skills base, the requirement for collaboration, communication, task coordination with others, and other profession-specific attitudes (see Fig. 18.1). In the remainder of this section, we briefly discuss each of these requirements.

## *18.2.1 Understanding Complex Systems*

An important attribute of complex learning is that it calls for understanding complex systems. Complex systems are best characterized by interconnected components whose behavior is not explained exclusively by the properties of their components. Rather the behavior emerges from the interconnectedness of the components. Complex systems depend on feedback, respond to multiple causes and effects, involve multiple interconnected levels, and operate at multiple time scales.

Understanding complex systems is fundamental to learning in many complex knowledge domains such as physics, physiology, environmental biology, and ecology. For example, to develop a proper conceptual understanding in ecology, students must be able to understand the dynamic interrelationships among different organisms within and across species. However, prior research suggests that humans have difficulty in understanding and monitoring complex systems, which calls for complex, and sometimes also ill-structured, problem solving (Dörner 1996). Dörner and Wearing (1995) and Funke (1991) identify a number of reasons for this difficulty. First of all, any given complex problem solving situation may involve multiple goals and it is very difficult to define goals operationally. Often, this requires decomposing the global goal into many subgoals but this leads to another difficulty: As time is always limited it is necessary, not only for one action to serve more than one goal, but also to order the priority of these goals. However, as the most important and urgent goal is being addressed the variables in the system may interact in such a way that lead to the requirement of reconsidering the overall system goal (MacKinnon and Wearing 1980). Nevertheless, in some cases, it may not be necessary to act at all to reach one's goals as the system's development may produce the goal state independently. If, however, the system does not move autonomously in the desired direction, it is necessary to act, taking into account the autonomous developmental tendencies of the system (Frensch and Funke 1995). In any event it is necessary but challenging to predict what will happen to the system as some of the goals may be contradictory which require reasonable trade-offs.

Rumelhart et al. (1986) argue that this type of complex problem solving calls for the interplay between *schemata* and *mental models*, which fulfill the basic cognitive functions of *assimilation* and *accommodation* as described in Piaget's epistemology (Fig. 18.2). Schemata assimilate new information into cognitive structures and constitute the fundamental basis for constructing mental models that aid in the process of accommodation (Ifenthaler and Seel 2011; Seel 2001). During complex problem solving, the solver's mental model takes as input "the specifications of the actions intended to be carried out and produces an interpretation of what would happen if the solver did that" (Rumelhart et al. 1986, p. 41). Part of

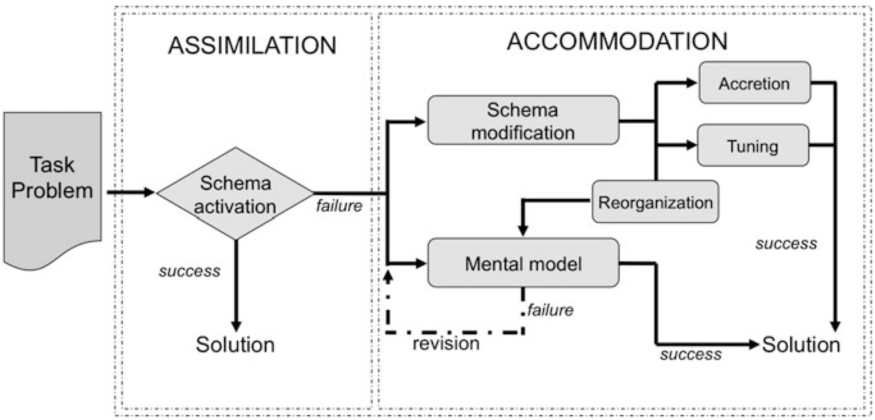


**Fig. 2** Cognitive processes during complex problem solving (Ifenthaler and Seel 2011)

this specification might be a specification of what the new stimulus conditions would be like. Thus, the activated schemata takes input from the phenomena to be explained and produces relevant reactions, whereas the mental model help predict how the input would change in response to these reactions. In other words, during complex problem solving, a *mental simulation* “runs in the mind’s eye” (Seel 2001, p. 407) to imagine the events that would take place if a particular action were to be performed. In this way, mental models allow one to perform entire actions internally and to judge the consequences of actions, interpret them, and draw appropriate conclusions. Accordingly, the learner makes a mental effort to understand complex systems and in doing so constructs appropriate mental representations to model and comprehend these systems.

This kind of learning involves the construction of causal explanations with the help of appropriate mental models (i.e., causal reasoning skills), hence, it aids in accumulation of domain-specific knowledge (i.e., structural knowledge). Stated in the terminology of Piaget’s epistemology, it is a mode of accommodation rather than assimilation. Consequently, the construction of a mental model in the course of learning often necessitates both a restructuring of the underlying representations and a reconceptualization of the related concepts (Seel 2006).

Prior research point out a number of learning difficulties due to the challenges associated with constructing a mental model of the complex system to be managed (Hogan and Thomas 2001; Putz-Osterloh and Lemme 1987). In large part, these challenges are due to the intransparency of the complex systems. Complex systems typically involve large number of variables with high-degree of connectivity. Changes in one variable may affect a number of other variables, making it very difficult to anticipate all possible consequences of a given situation. Therefore, it is not possible to directly observe all of the variables involved or the relationships between them. Furthermore, not every action shows immediate consequences. Some of the effects may occur with time delay. All of these factors cause excessive demands on working memory and make it very challenging for building the mental model of the complex systems necessary for complex problem-solving and effective decision-making.

Studies by Brehmer (1980) show that people can generally detect linear, positive correlations given enough trials if the outcome feedback is accurate enough. However, they have great difficulty in the presence of random error, nonlinearity, and negative correlations, often never discovering the true relation. Similarly, experiments of Plous (1993) showed that people tended to assume each effect has a single cause and often cease their search for explanations when a sufficient cause is found ignoring situational factors. Studies by Axelrod (1976) and Dörner (1980) also conclude that people tend to think in single strand causal series and have difficulty in systems with side effects and multiple causal pathways. It is possible to argue that part of this inadequacy lies in the assumptions and practices of current educational system: Classroom problems are usually well-structured story problems, in which the problem given and problem goal are well-defined and there is only a single solution path to reach the goal. Therefore, students are trained to view all problems in a similar vain and look for a single solution (see, for a discussion, Jonassen 1997; Frederiksen and White 1992). On the other hand, complex ill-structured problem solving calls for causal reasoning skills that would allow the solver to view the complex problem space in its entirety as a complex system of interrelated components. This would allow the solver to *visualize* the outcome of all possible solution alternatives by mental simulation and choose the most appropriate solution approach while being able to justify the decision.

### *18.2.2 Developing Adaptive Expertise*

A second important attribute of complex learning is that it requires mastery and coordination of a range of qualitatively different constituent skills. Van Merriënboer (1997) distinguishes between two types of constituent skills that make up the skill base in complex knowledge domains: (1) *recurrent skills*, which are performed similarly from situation to situation, thus, can be easily automated via repetitive exercises; and (2) *non-recurrent skills*, which have to be applied differently and flexibly from situation to situation. Furthermore, he argues that constituent skills are not merely subskills, which can be added together to make up the *Big Skill; hence,* teaching subskills separately does not guarantee that the learner would transfer the performance of the *Big Skill* in real life professional environment (van Merriënboer 1997).

Recent research also confirms that in complex knowledge domains, traditional instructional design approach of breaking down the overall complex skill into a cluster of subskills (that are easy to teach and assess) and training learners for mastering each subskill separately is ineffective and does not result with transfer of what is learned to real-life performance settings (Perkins and Grotzer 1997; Spector and Anderson 2000; van Merriënboer et al. 2002; Wightman and Lintern 1985). This approach is only effective if little or no coordination is required among the different skills during the real-life performance of the whole skill (Naylor and Briggs 1963). In contrast, real-life performance in complex knowledge domains are characterized by numerous interactions between the different aspects of overall task performance with very high demands on the coordination of non-recurrent skills (van Merriënboer et al. 2002).

A recent evidence of this realization comes from medical education research, which showed that 86 % of the medical students, who passed the standardized medical licensing examination by correctly answering questions regarding indicators of a certain illness, were not able to correctly *diagnose* the same illness when presented by patient in a real-life simulation (Jonassen 1997). So, being a *doctor* who can correctly diagnose a patient's illness (which is a complex problem solving task) is more than the sum of its subtasks (e.g., 'which illness cause which symptoms' + 'what type of scans are required to check for possible symptoms' etc.). Thus, an important aspect of complex learning is developing the ability to flexibly apply previously-learned knowledge and skills to solving new problems under novel situations in a way to recognize the situational conditions and far-transfer learning (Mayer and Wittrock 1996).

In their study of the expertise in complex knowledge domains, Hatano and Inagaki (1986) distinguished between the experts who can effectively and efficiently solve typical professional problems that are routinely faced in the workplace (i.e., *routine expertise*) and those who can develop innovative solutions to novel professional problems and adapt easily to the changes that occur in professional practice (i.e., *adaptive expertise*). They further argued that an important aspect of preparing professionals for complex knowledge domains should be to place them on a trajectory to develop adaptive expertise (Harris and Cullen 2007; Hatano and Oura 2003; Schwartz et al. 2005). This idea highlights that complex learning involves more than the integration and coordination of non-recurrent skills. Complex learning also involves (1) complex problem solving skills so that learners can flexibly adapt existing knowledge and skills to novel goals; (2) metacognitive and self-regulation skills so that learners can successfully monitor their understanding, thinking, and problem-solving; and (3) epistemological beliefs so that learners conceive of domain knowledge as dynamic in nature and that it will change as the field evolves so they continuously inquire for new learning in their domain expertise.

### *18.2.3 Acquisition of Collaboration, Communication, and Task Coordination Skills*

The third important attribute of complex learning is that it calls for mastery of collaboration, communication, and task coordination skills. In complex knowledge domains, the complexity and expertise needed accomplish real-life professional tasks typically requires a team of individuals. In some cases, the team may comprise of individuals with similar expertise; in others the team may comprise of individuals who possess different but complementary expertise and roles. For example, in one project, the design of the nuclear power plant structure alone required about 200 civil engineers to collaborate together while the whole nuclear power plant project required collaboration among approximately 2,500 engineers with different specializations (Bechtel Power Corporation, n.d. 2011).

Hence, successful execution of real-life professional tasks in complex knowledge domains heavily relies on the collaboration, communication, and task coordination skills of the team members (cf. Hung 2011). In the cases where the collaboration requires individuals with different expertise and roles, communication and task coordination skills become even more crucial since different roles and expertise may bring with themselves different sets of vocabulary, protocols, requirements, and way of working, and so on. For instance, the professionals in the built environment disciplines often have to work together on design projects. For architects and interior designers, the design problem may be simply stated as:

Design a general office building with 65,000 square feet, three stories high, with green systems and materials for a location in downtown Dallas, Texas. Constraints may include such things as the building orientation allowed on the site, budget, or the desired level of sustainability. To solve this problem, architects and designers begin by executing their spatial perceptions about typical activities in the building and visualization techniques. Mental images form then from the spatial visualizations as room locations and features are represented. From this point the architects and designers begin the visual reasoning process as they ask questions about alternatives. Alternatives, for instance, about the design features that meet green building criteria. The architect may ask, “What are the options available for reducing heat gain anticipated by the building’s orientation to the west?” Visual reasoning provides the architect with multiple possibilities to solve this complex problem. On the other hand, the process of design problem solving for engineers and engineers and constructors are quite different than that of the building architectural and space designers. They typically receive a set of 2–dimensional drawings for a building. The first task for engineers and constructors involves interpreting the symbols and graphical representations to develop some perception about the interior and exterior building space and their relationships. Once that is complete and they have their ‘bearings’, they can begin to mentally rotate the representation from a flat 2–dimensional representation (X,Y coordinates) to a 3-dimensional representation in which the Z–axis adds mass by adding volume to the form. It is at this point a clear mental image of the overall building and individual rooms is formed. Once the engineers and constructors have a valid mental image they can begin to process of reasoning about the optimal means and methods for transforming the building from paper and model to a real structure. Selecting the optimal means and methods by which to construct a building requires professionals ask questions about alternatives, such as: What happens if another pipe is added to a vertical chase in one area of the building? To answer this question, the engineer and constructor must consider the enclosure materials and impact on the space. They must understand more than just the functional aspects but also the changes to the horizontal and vertical space. Given the differences in the way these different professionals—who have to work together—approach the same design problem solving, building effective cross-communication would be more challenging and require an in-depth understanding of the *ways* of the others to develop a common vocabulary and an effective communication using multiple channels (written, verbal, visual, and so on).

The crucial importance of requirement of complex learning to include effective collaboration and communication skills is evident in the Institute of Medicine’s 1999 publication, *To Err is Human: Building a Safer Health System,* which exposed troubles with the quality and safety of patient care in the United States, including the determination that between 44,000 and 98,000 lives were lost each year due to medical errors, most of which were attributed to collaboration and communication problems among doctors, nurses, ancillary staff, medical students, and other health care team members, who are integral components of the health care environment (Kohn et al. 1999).

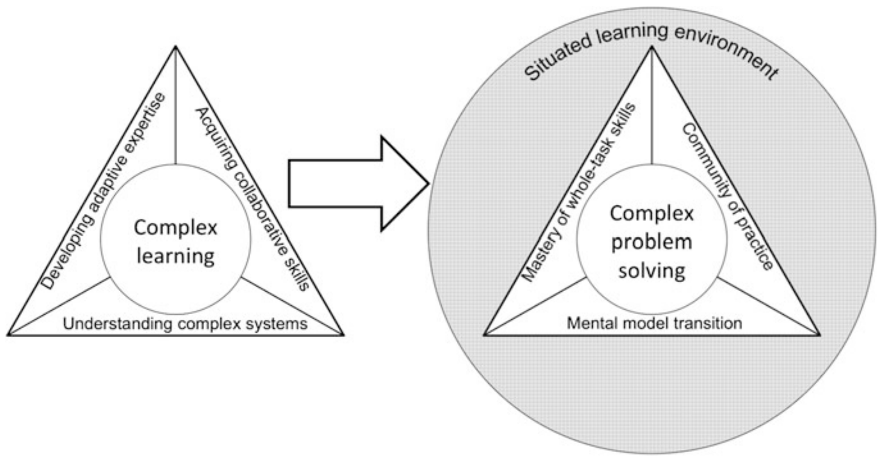


**Fig. 3** Requirements for learning environments to facilitate complex learning

## 18.3 Designing Learning Environments to Facilitate Complex Learning

In previous section, we discussed three attributes of complex learning that should be targeted in an effective learning environment for complex knowledge domains: (1) understanding complex systems; (2) developing adaptive expertise; and (3) acquisition of collaboration, communication, and task coordination skills. Each of these attributes lead to the specification of different requirements for designing learning environments (see Fig. 18.3).

A common denominator underlying all three attributes is the requirement for situating the learning experience in a complex, ill-structured problem that is representative of the authentic, real-life professional work in the targeted complex knowledge domain. In Greeno's (1998) terminology, it is the *situativity* that affects learners' problem space, which he described as, "the understanding of a problem by a problem solver, including a representation of the situation, the main goal, and operators for changing situations, and strategies, plans, and knowledge of general properties and relations in the domain" (p. 7). Hence, situated learning theorists argue that there is no such thing as context-independent thought and behavior. Learning is always fundamentally about *doing* something for some purpose in a social context (Wertsch 1998). Thus, it is argued that the environment plays an important role during learning; effective action is always situated within environmental constraints and affordances (Dewey 1938; Peirce 1992; Salomon 1993). From this perspective, learning is understood as the ongoing transformation of identity (cf. Wenger 1998) and mark of developing domain expertise is one's ability to *see* the environment in particular *ways* ordained by the profession (cf. Glenberg 1997; Goodwin 1994).

Instructional approaches that emphasize situated learning include cognitive apprenticeship, problem-based learning, project-based learning, inquiry learning, guided discovery learning, case method, learning by design, anchored instruction, and so on. Regardless of the variances among the interpretations and applications of these approaches in the literature, we argue that the design of the situated learning environment should fulfill three requirements in order to facilitate complex learning as suggested in Fig. 18.3.

First, learning environments to facilitate complex learning should support learners in their understanding of complex systems. In the earlier section, we contended that learning in many complex knowledge domains, like science, calls for understanding complex systems. Self-organizing and adaptive biological systems such as cell biology; physiological systems such as those based on various multifunction organs including the brain and the immune system; ecological systems such as a lake ecosystem are all examples of complex systems. Understanding complex systems require students to build an accurate mental model of the complex system depicting the causal interrelationships among system components. The proponents of inquiry learning and guided discovery learning argue that these instructional approaches effectively assist students in their construction of accurate mental models of the complex systems and learn the deep principles that govern them (Bransford et al. 2000; Cavalli-Sforza et al. 1994; Eisenhart et al. 1996; McGinn and Roth 1999; Palincsar and Magnusson 2001). In inquiry or guided discovery methods, students were asked to solve a complex problem situated in an authentic activity. Students often start their inquiry or guided discovery learning investigations with an incomplete or incorrect mental model, which dictates the construction of their very first hypothesis to test the causality between the variables. Through multiple cycles of investigations, they are expected to infer from their findings the dynamic interrelationships among components of the complex system. The desired process of mental model transition is depicted in Fig. 18.4. Scaffolding is an critical aspect of designing such learning environments

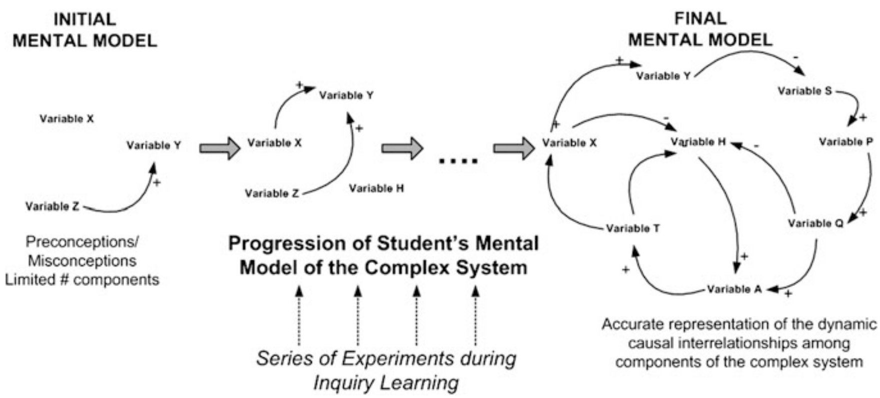


**Fig. 4** Mental model transition

(de Jong and van Joolingen 1998; Kirschner et al. 2006); especially when the system under investigation is a complex system. Students are then required to conduct a multivariable analysis, which is very challenging since they have to simulate in their mind's eye a large number of system components and dynamic interrelationships among them (Eseryel and Law 2010). Given the limited information processing capacity (Miller 1956), this places an extraneous cognitive burden on students. Based on their findings Law and Eseryel (2011) further argue that unless students possess strong cognitive regulation skills, they would not be able to conduct the kind of multivariable analysis required for successful mental model transition. Hence, scaffolding cognitive regulation appears to be an important aspect of facilitating students' mental model transition in promoting their understanding of complex system.

Second, learning environments to facilitate complex learning should involve authentic and meaningful whole complex tasks presented in learning trajectories—not just the part tasks or subskills that make up the whole task. Given the high cognitive load imposed by whole complex tasks, they should be offered in such a way that learners are not cognitively overloaded by their complexity. That is, learners should be given the opportunity to practice simplified but increasingly complex versions of authentic whole tasks that will eventually place them on a trajectory for adaptive expertise. An appropriate model to support this type of instructional design is the 4C/ID Model (van Merriënboer 1997), which details the task analysis, sequencing, and scaffolding methods to assist with the design of holistic learning environments to support complex learning. The model is based on the idea that placing learners on a trajectory to adaptive expertise is accomplished when they are presented with multiple whole tasks that are of the same level of complexity but differ in amount of instructional support offered (from high to low support as the expertise of the learners increase); once the learners can successfully complete the first set of whole tasks without any external support providing them with the next set of whole tasks a higher level complexity, and so on until the desired level of learning and expertise is achieved.

While the 4C/ID model provides effective guidelines to design the learning activities, it mainly focuses on developing individual expertise and pays little attention to collaborative aspect of real life professional work in complex knowledge domains. Hence, as the third requirement, learning environments to facilitate complex learning should include authentic, whole task performances that require collaboration among learners replicating real life professional work. Depending on the nature of the targeted complex learning domain, learners could either assume different professional roles to solve complex problems together as a team; or they could all assume the same professional role to collaborate together to solve complex problems with guidance from expert modeling, mentoring, and legitimate peripheral participation (cf. Lave and Wenger 1991). Such an environment promotes the advancement of collective learning and support the growth of individual learning, in addition to addressing collaboration, communication, and task coordination skills (cf. Scardamalia and Bereiter 1994; Vygotsky 1978). This is in accordance with learning through participation in communities of practice perspective (cf. Lave and Wenger 1991), which emphasizes building learning communities to support shared repertoire of knowledge to be continuously developed and refined through the engagement of multiple community members in a joint enterprise, such as working together to solve complex professional problems. Shaffer (2006) further argues that through their involvement in communities of practice novices learn the structure, grammar, and ways of working of any particular profession, which he calls *epistemic frames* and include (Shaffer 2006):

- Skills: the abilities and competencies that community members are able to perform and demonstrate.
- Knowledge: the facts and information shared by community members.
- Identity: the social and cultural roles assumed by community members.
- Values: the opinions and beliefs held by community members that define what is important (and conversely, not important).
- Epistemology: the justifications and methods of proof that legitimize actions and claims within the community.

To connect this to Lave and Wenger's work (1991), new members who are at the periphery of a community of practice would have underdeveloped and loosely-linked frame elements in their epistemic frame, while expert members of the community in full participation would have well-defined epistemic frames with dense connections between and among the different frame elements. However, as the new members grow and learn in the ways of the profession, their understanding of the individual frame elements—and the relationships among them—will increase, resulting in an increasingly more sophisticated epistemic frame. In a study on instructional design expertise, Law et al. (2011) documents how building learning communities that simulate professional community of practice of instructional designers support novice designers to develop epistemic frames of the instructional design profession while collaboratively solving authentic instructional design problems.

In this section, we discussed the characteristics of situated learning environments to support desired complex learning outcomes that are representative of real-life task performance. Unfortunately, classroom-based learning environments are seldom appropriate to fulfill the required characteristics of situated learning environments discussed in this section because arranging complementary, tacit, relatively unstructured learning in complex real-world settings is difficult within the boundaries of classroom. For example, several investigators (Griffin 1995; Hendricks 2001) developed curricular activities in an attempt to validate situated learning theory but were forced to modify their research designs due to the difficulty of implementing situated learning within the constraints of a K-12 classroom. As an alternative to practices located within a school, taking students to actual professional contexts might provide an authentic, meaningful, and motivating context for students to master complex learning. For instance, Clarke and Dede (2007) attempted to bring students to a local hospital to work with epidemiologists and doctors to study an outbreak of whooping cough; yet, they found that this is not feasible for a myriad of reasons including prohibitive cost and managerial challenges.

With the advancements of computer-based technologies, the characteristics of virtual learning environments provide affordances for supporting the kinds of situated learning environments intended to facilitate complex learning. For instance, digital-game based environments such as educational massively multi-player online games (MMOG) or virtual worlds like Second Life have the potential to serve as a situated learning environment that can provide a completely immersive experience by enabling digital simulation of authentic problem-solving communities, in which learners interact with other virtual entities (both participants and computer-based agents) who have varied levels of skills. Hence, virtual worlds has the potential to provide the learners the subjective impression that one is participating in a comprehensive, realistic experience if they are willing to suspend their disbelief (Dede 2009). However, designing such realistic virtual learning environments that can provide actional, symbolic, and sensory immersion require extensive resources. In addition, students' initially high-level motivation tend to subside quickly while they are challenged with complex problem solving tasks (i.e., the novelty effect wears out quickly) in totally-immersive educational environments like massively multiplayer online games (Eseryel et al. 2011). On the other hand, augmented reality, which bridges virtual and real world environments, has the potential to open up new opportunities for supporting complex learning.

## 18.4 Mobile Augmented Reality and Complex Learning

The beginning of the twenty-first century sees a technological shift and a continuous progress towards powerful mobile and handheld computer devices as well as intelligent software applications. Most of these systems are GPS-enabled, location-aware, and provide wireless access to the Internet. High quality video cameras and audio functions provide the basis for future learning and instruction. Additionally, intelligent software applications can semantically interpret the learners' interactions and combine virtual objects with the real world. These new technologies are and will be shaping how people learn in the beginning of the twenty-first century in formal and informal settings (Ifenthaler 2010).

One of the most powerful technological developments within the last decade is augmented reality learning environments, which enable learners to use virtual objects in the real world. However, a consistent definition of augmented reality does not exist (Mehler-Bicher et al. 2011). In order to define augmented reality, the reality-virtuality continuum is used for clarification, which postulates a steady transition between real and virtual environments (Milgram et al. 1994). The left side of the continuum defines the real environment that contains solely real objects. The right side defines the virtual environment that contains exclusively virtual objects. Within the continuum, *mixed reality* is defined where real and

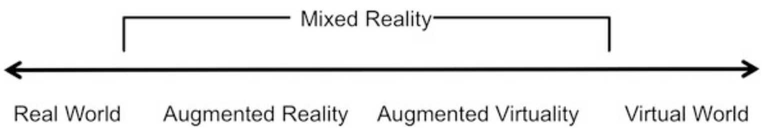


**Fig. 5** Reality-virtuality continuum (Milgram et al. 1994)

virtual objects are combined arbitrary (see Fig. 18.5). For augmented reality, the real objects are predominating. Virtual objects are dominating the augmented virtuality.

Accordingly, an augmented reality learning environment features the following characteristics (Azuma 1997):

- Combines real objects and virtual objects
- Real objects are predominating
- Uses sensory input such as sound, video, graphics, or GPS-data
- Includes high interactivity
- Runs in real time
- Enables spatial registration (in any sensory dimension)

Key technologies of augmented reality (AR) include: (1) spatial augmented reality, (2) visual overlay augmented reality, and (3) self-locating augmented reality. *Spatial AR* uses digital projectors to display virtual objects and information on real objects. The key benefit is that the learner does not need to wear a head-mounted display in order to see the virtual object in the real world. This enables for a collaborative environment for multiple learners and an expanded display area (Bimber and Raskar 2005).

*Visual overlay AR* uses visual markers to generate visual overlays on real objects (see Fig. 18.6). A visual marker (a) is registered in the applications

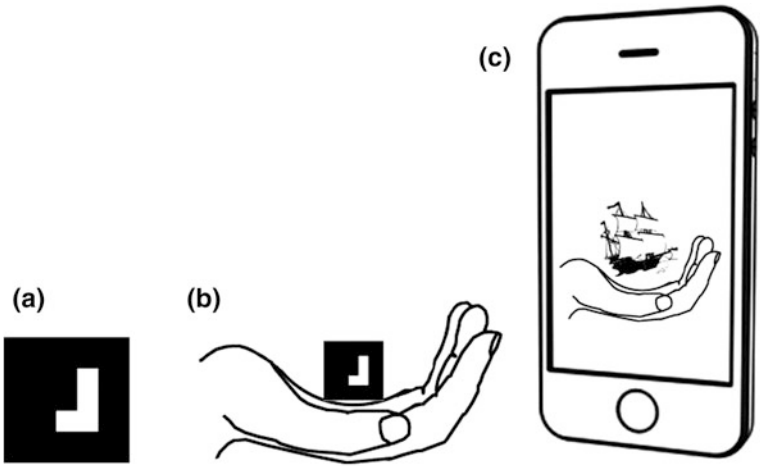


**Fig. 6** Visual overlay AR process

database and connected to corresponding digital information (e.g. picture, text, etc.). The marker is placed in a real world setting (b). Through the video stream of a mobile device, the information of the registered marker is processed and transformed into a virtual object (c). Finally, the learner is able to see the ship sailing in his hand. *Self-locating AR* use the mobile devices' GPS-data and visual sensory data to calculate its spatial orientation (Ellaway 2010). This technology enables the learner to orientate within a complex environment (e.g., museum, factory) as well as locate resources and people within that environment (Ellaway 2010). Finally, mobile augmented reality learning environments (MARLE) bring virtual learning objects into the real world and allow learners to virtually interact with the combined (real and virtual) world on their mobile devises.

The potentials of AR for learning and instruction have been studied accordingly (Dunleavy et al. 2009; Haller et al. 2007; Ma and Choi 2007; Martín-Gutiérrez et al. 2010; Nischelwitzer et al. 2007). AR facilitates positive learning experiences and enhances the learner's motivation (Freitas and Campos 2008; Saforrudin et al. 2011). Other studies show potentials for formal education in biology (Gillet et al. 2004), chemistry (Fjeld and Voegtli 2002), geography (Shelton 2003), as well as informal education such as astronomy (Sin and Badioze Zaman 2009) or reading (Abas and Badioze Zaman 2011). However, the link between AR and complex learning has not been discussed in educational technology so far.

### *18.4.1 Facilitating Complex Learning by MARLE*

Humans are good at manipulating their environments. Especially important here is the ability to manipulate the environment so that it comes to represent something by means of artifacts of technology (Seel et al. 2009). These abilities are dependent on two interacting sets of units of the cognitive system (Rumelhart et al. 1986). The *interpretation network* is concerned with the activation of schemata, and the other one is concerned with constructing a *model of the world*. It takes as input some specification of the actions we intend to carry out and produces an interpretation of what would happen if we did that. Part of this might be a specification of what the new stimulus conditions would be like. Thus, the *interpretation network* (i.e. an activated schema) takes input from the world and produces relevant cognitive (re-)actions, whereas the second module, i.e. the *model of the world*, predicts how the input would change in response to these reactions. In cognitive psychology it is common to speak of a *mental model* that would be expected to be operating in any case, insofar as it is generating expectations about the state of the world and thus *predicting* the outcomes of possible actions. However, it is not necessary for world events to have really happened. In the case that they have not, the cognitive system replaces the stimulus inputs from the world with inputs from the *mental model* of the world. This means that a *mental simulation* runs to imagine the events that would take place in the world if a particular action were to be performed. Thus, *mental models* allow one to perform entire actions internally and to judge the consequences of actions, interpret them, and draw appropriate conclusions.

In complex learning contexts, mental models have to adapt to represent each new state of the problem due to changes over time. Since mental models are ad hoc representations, they show their benefits in situations where no schema is available. Being able to monitor changes of mental models over time provides us with the necessary insight into complex problem solving—and into the representations of complex problems (Ifenthaler et al. 2011; Ifenthaler and Seel 2011). Accordingly, crucial to learning in complex domains is how learners' general and domain-specific model building skills develop and how their mental models and schemata change (Ifenthaler et al. 2007; Ifenthaler and Seel 2005). Thus, instant feedback on semantic and structural aspects of the learner's progression at all times during the learning process is a significant component for complex learning environments (Ifenthaler 2009). Such dynamic and timely feedback can promote the learner's self-regulated learning (Zimmerman and Schunk 2001). Moreover, situated learning environments require the embeddedness of learning tasks within the real world (Brown et al. 1989; Greeno 1989). Technology-mediated learning environments have the capabilities to facilitate the above-described complex processes by mediating between virtual and real world actions (Gee 2003). MARLE integrate the instructional potential of mobile learning, virtual environments and augmented reality and therefore provide a unique prerequisite for complex learning environments (Dunleavy et al. 2009).

In a resent K-12 project, iPads were handed out to over 100 students and their teachers for a daily classroom use (Ifenthaler 2011b). iPads are used in multiple ways in class:

- Digital textbooks including animations, films, and audio
- Learning management e.g., turning in homework assignments
- Corresponding with teachers and students
- Developing digital portfolios throughout a school year
- Experiments, games, and simulations
- Foreign language training (English, French)
- Instant feedback and help through teachers, peers, and technology

When using these instructional features on a daily basis, iPads are regarded as powerful and versatile tools. Moreover, this individual technology is providing multitude possibility for learning without changing the classroom setting. Yet, the project is driving the classroom beyond the four walls by integrating MARLE into teaching and learning. In a Biology class, students explore their surroundings (e.g., plants, soil) by using the camera of the iPad and visual markers (distributed all over the school campus). For example, students explore the annual rings of a tree by using visual overlays and augmenting the real tree with a simulation of the growth process. The Biology MARLE includes further instructional information about trees (e.g., habitat, plant family) and quick knowledge tests for *assessment on the fly* (Ifenthaler 2011b). In a Mathematics class, students explore practical problems of trigonometry and geodesy through topographical surveying on the school campus. Using the iPad, students can augment the school's building, the classroom, as well as the schoolyard with virtual line segments and calculate angles or solid measures. The MARLE for Mathematics includes scientific calculators, virtual surveying instruments, and quick knowledge tests for *assessment on the fly* (Ifenthaler 2011b). Within the iPad project, the acceptance of the new technology in class is currently empirically investigated Ifenthaler & Schweinbenz (in press). Further, the benefits of MARLE for complex learning will be investigated through an experience sampling technique implemented on the iPad (Ifenthaler 2011b).

## 18.5 Future Directions

Facilitating complex learning by mobile augmented reality learning environments (MARLE) is a challenge for researchers and practitioners in the fields of instructional design, educational technology, and computer science. This interdisciplinary field of research is facing (1) technological, (2) theoretical, and (3) assessment challenges.

First, the rapid development of information and communication technology (ICT) has strongly influenced advances and implications for learning and instruction. Most of these systems are GPS-enabled, location-aware, and provide wireless access to the Internet. High quality video cameras and audio functions provide the basis for future learning and instruction. Additionally, intelligent software applications can semantically interpret the learners' interactions and combine virtual objects with the real world. These new technologies are and will be shaping how people learn in the beginning of the twenty-first century in formal and informal settings. The development of Web 3.0 has now been coined to describe the coming wave of innovation (Yu 2007). Accordingly, Web 3.0 will go a step further and understand or rather learn what the learner wants and suggests the information that fits to the learners' needs. This requires that all information which is available in the Internet is accessible by a certain standard and that the technology is able to *understand its meaning*. Thus, Web 3.0 is intelligent offering a data network consisting in a collection of structured data records published in the Internet in repeatedly reusable formats (e.g., XML, RDF). Besides the service-oriented architecture, Web 3.0 will be the realization and extension of the concept of the Semantic Web (Lassila and Hendler 2007; Yu 2007). Web 3.0 operations will be designed to perform logical reasoning using a multitude of rules, which express logical relationships between semantic meaning and information available in the Internet (Ifenthaler 2012).

Second, questions concerning the development of complex problem solving are still being scrutinized, even though the functions of complex problem-solving processes has attained general acceptance over the past decades (Dörner 1987, 1996; Funke 1991; Jacobson 2000; Sabelli 2006; Jonassen 2000, 2004, 2011; Spector et al. 2001). However, one of these questions has to do with Snow's (1990) verdict that theoretical constructs must be defined precisely and assessed exactly if they are to be used effectively in cognitive and instructional science. Hence, complex learning and problem solving as well as the different types of problems, interindividual and intraindividual differences among problem solvers, as well as the domain and context of problems need to be empirically investigated in laboratory and classroom settings (Ifenthaler 2011a; Ifenthaler et al. 2011; Ifenthaler and Seel 2011; Jonassen 2011).

Third, closely linked to the demand of new approaches for designing and developing up-to-date learning environments in Web 3.0 is the necessity of enhancing the design and delivery of assessment systems (Spector 2010). However, studies exploring the assessment of new technologies in the field of educational technology are rare (Dunleavy et al. 2009; Heinecke et al. 2001; Ifenthaler 2012; Ifenthaler & Schweinbenz (in press); Means and Haertel 2004). Methodologies for measuring the learning-dependent progression of mental models or inferential schemata in complex learning are still being developed and critically investigated (Seel 1999; Ifenthaler and Seel 2011). Ifenthaler and Seel (2005) also stressed the importance of measuring subjects repeatedly over extended periods of time to understand the continuous progression of learning and thinking. This suggests that measuring complex learning continuously or repeatedly during transitional stages is more effective than only measuring them before and after instruction, which is how they are typically measured in most research studies (Ifenthaler et al. 2011).

To sum up, MARLE has yet to be taken out of the laboratory and into the classroom and implemented on an everyday teaching basis. However, the potential of powerful educational interfaces will only facilitate complex learning and problem solving if the building blocks of problem solving learning-environments are understood and implemented entirely.

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