Smart Environments for Smart Learning

Peter Mikulecký
Department of Computer Science, Faculty of Natural Sciences,
Constantine the Philosopher University in Nitra, Slovakia
pmikulecky@ukf.sk

Abstract

Smart environments for learning, as one of the results of intensive research in the area of Ambient Intelligence (AmI), can be naturally considered to be a new degree in the evolution of computer enhanced learning. The challenging exploitation of smart environments for learning together with new technologies and approaches as ubiquitous learning, mobile learning, etc. could be naturally named the smart learning. The purpose of the paper is to map the recent state of the art in the area of ubiquitous and context aware learning (smart learning) in a special type of smart environments, restricted on the case of smart workplaces. On the basis of our ongoing research we wish to present a view on the recent research of smart workplaces enhanced by advanced smart learning possibilities. The results are related to some recent activities in the area of smart offices and other intelligent workplaces. We shall focus here on smart learning possibilities enabled by the recent research results in the smart workplaces area.

Keywords

Computers and education. Ubiquitous computing. Artificial intelligence. Adaptive hypermedia. User interfaces.

Introduction

Smart environments for learning, as a result of intensive research in the area of *Ambient Intelligence* (*AmI*), deserve also attention of the large community oriented on e-learning and technology enhanced learning. Smart environments could be naturally considered to be a new degree of computer enhanced learning, with a considerable number of new facilities. Related to this, the area of *Ambient Intelligence* can be studied from several perspectives. As Bureš, Čech and Mls (2009) pointed out, besides its technological perspective, social perspective, or ethical perspective, we can also identify an educational perspective of *Ambient Intelligence*. The educational perspective deals with problems and challenges related to proper education in relevant *AmI* areas

Besides other intensively investigated and developed applications we may consider *Ambient Intelligence* also being a suitable technology for developing intelligent workplaces of various types.

An intelligent workplace can be, among its other features, helpful in managing knowledge which can be usefully needed by the users working in the workplace. Such knowledge can be used not only for solving various problems requiring some expert knowledge to be properly solved, but also for learning related knowledge at the workplace when creating decisions or looking for solutions of difficult tasks.

In the paper we intend to map the recent state of the art in the area of smart environments oriented on learning. On the basis of our on-going research we wish to present a view on the research of smart environments, related to some recent activities in the area of smart offices and other intelligent workplaces. We shall focus on smart learning possibilities enabled by the recent results of smart workplaces area research.

Problem formulation

Smart offices and other workplaces

Today different appliances have successfully become integrated to our daily life surroundings to such an extent that we use them without consciously thinking about them. Computing devices have transformed during last period of about 50 years from big mainframes to small chips that can be embedded in a variety of places. This has allowed various industries to silently distribute computing devices all around us, often without us even noticing, both in public spaces and in our more private surroundings. According to (Augusto, Nakashima and Aghajan, 2010), these computing devices will have to be coordinated by intelligent systems that integrate the resources available to provide an intelligent environment. This confluence of topics has led to the introduction of the area of *Ambient Intelligence* as a digital environment that proactively, but sensibly, supports people in their daily lives. All we have in the definition, that is

- digital technology,
- proactive but sensible support of people's activities,
- support of daily lives of people,

can be also utilized for further contemplations about supporting people in their working environments by recent *AmI* technologies.

According to (Cook, Augusto and Jakkula, 2009) the idea of *Ambient Intelligence* is not new, but what is new is that we can now seriously think about it as a reality and as a discipline with a unique set of contributions. The basic idea behind *AmI* is that by enriching an environment with technology (e.g., sensors and devices interconnected through a network), a system can be built such that acts as an *"electronic butler"*, which senses features of the users and their environment, then reasons about the accumulated data, and finally selects actions to take that will benefit the users in the environment. Therefore the features that are expected in *AmI* technologies have to be sensitive, responsive, adaptive, transparent, ubiquitous, and intelligent, as it is stressed by Cook, Augusto and Jakkula (2009).

One of most interesting and useful applications of *AmI* seems to be *Smart Offices* and *Smart Decision Rooms* (Ramos, Marreiros, Santos and Freitas, 2010). As mentioned already in various papers, decision making is one of the noblest activities of the human being. The topics as smart offices and intelligent meeting rooms are well studied and they intend to support the decision making activity, however, they have received a new perspective from the *AmI* concept. This concept enables a different way to look at traditional offices and decision rooms, where it is expected that these environments support their inhabitants on a smart way, promoting an easy management, efficient actions and, most importantly, to support the creation and selection of the most advantageous decisions.

Le Gal (2005) defines a smart office as an environment that is able to help its inhabitants to perform everyday tasks by automating some of them and making the communication between user and machine simpler and effective.

A bit broader definition of smart offices can be found in (Marsá-Maestre, de la Hoz, Alarcos and Velasco, 2006). They characterize smart office as an environment that is able to adapt itself to the user needs, release the users from routine tasks they should perform, to change the environment to suit to their preferences and to access services available at each moment by customized interfaces. Smart offices handle several devices that support everyday tasks. They may anticipate user intentions, doing tasks on his behalf, facilitating other tasks, etc.

Freitas, Marreiros and Ramos (2007) pointed out, that the aim today is to develop systems that support distributed and asynchronous meetings, naturally allowing a ubiquitous use that can add flexibility to the global organizational environment of today. Such orientation in software development was followed by the design and building of rooms with specific hardware and software that could empower the decisions makers' actions, supporting them with knowledge and driving their attention to the problem and avoiding their minds from wandering on needless issues. This kind of rooms is commonly named as *Intelligent Meeting Rooms* (*IMR*), and can be considered as a sub domain of Smart Rooms for the workplace context. The goal of *Intelligent Meeting Rooms* is to support multi-person interactions in the environment in real time, but also they can be considered as a system that is able to remember the past, enabling review of past events and the reuse of past information in an intuitive, efficient and intelligent way. *IMR* should also support the decision making process considering the emotional factors of the intervenient participants, as well as the argumentation process. These ideas are in a more detail elaborated in (Freitas, Marreiros and Ramos, 2007). However, the *IMR* concept can directly lead to an intelligent support of smart learning.

Smart learning

The context aware and ubiquitous learning as being naturally close to the educational perspective of *AmI* as well as to the idea of smart learning environments, was defined and studied by several authors. Winters, Walker and Rousos (2005) pointed out that ubiquitous computing has tremendous potential for framing learning, particularly in informal and socially constructed contexts. To reach this potential it is necessary for the current desktop-focus development of technology in education to be challenged through the design, development and testing of new ubiquitous prototypes for learning.

Based on (Yang, Okamoto and Tseng, 2009), context-aware and ubiquitous learning is a computer supported learning paradigm for identifying learners' surrounding context and social situation to provide integrated, interoperable, pervasive, and seamless learning experiences. The objective of context-aware and ubiquitous learning is to enhance *Web-based learning* a step further from learning at anytime and anywhere to learning enabled at the right time and the right place using right resources and right collaborators. Alternatively, according to (Hwang, Yang, Tsai and Yang, 2009) context-aware ubiquitous learning is an innovative approach that integrates wireless, mobile, and context-awareness technologies to detect the situation of learners in the real world and provide adaptive support or guidance accordingly.

Yang, Okamoto and Tseng (2008) summarize the characteristics of context-aware and ubiquitous learning in the following eight aspects: mobility, location awareness, interoperability, seamlessness, situation awareness, social awareness, adaptability, and pervasiveness. More detailed descriptions of these aspects are as follows:

- *Mobility*: The continuousness of computing while learners move from one position to another.
- *Location awareness*: The identification of learners' locations.

ISBN 978-80-558-0092-9

- *Interoperability*: The interoperable operation between different standards of learning resources, services, and platforms.
- *Seamlessness*: The provision of everlasting service sessions under any connection with any device.
- *Situation awareness*: The detection of learners' various situated scenarios, and the knowledge of what learners are doing with whom at what time and where.
- *Social awareness*: The awareness of learners' social relationship, including what do they know? What are they doing at a moment? What are their knowledge competence and social familiarity?
- *Adaptability*: The adjustability of learning materials and services depending on learners' accessibility, preferences, and need at a moment.
- *Pervasiveness*: The provision of intuitive and transparent way of accessing learning materials and services, predicting what learners need before their explicit expressions.

On the other hand, Bomsdorf (2005) considered ubiquitous learning as the next step in performing e-learning and by some authors it was expected to lead to an educational paradigm shift, or to new ways of learning. The potential of ubiquitous learning results from the enhanced possibilities of accessing learning content and computer-supported collaborative learning environments at the right time, at the right place, and in the right form. Furthermore, and this is close to the ideas of *AmI* presented by ISTAG (Ducatel et al., 2001), it enables seamless combination of virtual environments and physical spaces. Ubiquitous computing leads to ubiquitous learning that allows embedding of individual learning activities into everyday life. As it was already stressed, the fundamental issue in a ubiquitous learning environment is how to provide learners with the right material at the right time in the right way. Context aware adaptation is therefore indispensable to all kinds of learning activities in ubiquitous learning environments.

In addition to the context-aware ubiquitous learning characteristics by Yang, Okamoto and Tseng (2008) mentioned earlier in this chapter, Hwang, Tsai and Yang (2008) formulated the potential criteria of a context-aware ubiquitous learning environment as follows:

- it is context-aware; that is, the learner's situation or the situation of the real-world environment in which the learner is located can be sensed, implying that the system is able to conduct the learning activities in the real world.
- it is able to offer more adaptive supports to the learners by taking into account their learning behaviours and contexts in both the cyber world and the real world.
- it can actively provide personalized supports or hints to the learners in the right way, in the right place, and at the right time, based on the personal and environmental contexts in the real world, as well as the profile and learning portfolio of the learner.
- it enables seamless learning from place to place within the predefined area.
- it is able to adapt the subject content to meet the functions of various mobile devices.

As it is pointed out in (Hwang, Yang, Tsai and Yang, 2009), researchers have different views of the term *"ubiquitous learning"* till now. A popular view is *"anywhere and anytime learning"*, which is a very broad-sense definition of ubiquitous learning. With this definition, any learning environment that allows students to access learning content in any location at any time can be called a ubiquitous learning environment, no matter whether wireless communications or mobile devices are employed or not. From this viewpoint, the mobile learning environment which allows students to access learning content via mobile devices with wireless communications is a special case of the broad-sense definition of ubiquitous learning. However, if we took into account the ISTAG scenario *Annette and Solomon in the Ambient for Social Learning* (Ducatel et al., 2001) that could serve as an ideal

case for a smart learning environment, which was undoubtedly context-aware as well as ubiquitous at the same time, the popular view of *"anywhere and anytime learning"* should be considered as impractically broad. According to ElBishouty, Ogata, Rahman and Yano (2010), the challenge in the information-rich world is not to provide information at anytime and at anywhere but to say the right thing at the right time in the right way to the right person.

This approach is supported also by Yang (2006) stating that a ubiquitous learning environment provides an interoperable, pervasive, and seamless learning architecture to connect, integrate, and share three major dimensions of learning resources: learning collaborators, learning contents, and learning services. Therefore ubiquitous learning is characterized by providing intuitive ways for identifying right learning collaborators, right learning contents and right learning services in the right place at the right time.

The main characteristics of ubiquitous learning are permanency, accessibility, immediacy, interactivity, and situating of instructional activities. The ubiquitous environment should be personalized according to the learner's situation. Personalization is defined in (ElBishouty, Ogata, Rahman and Yano, 2010) as the way in which information and services can be tailored in a specific way to match the unique and specific needs of an individual user. While a learner is doing learning task or activity, she usually looks for some knowledge. In a ubiquitous learning environment, it is very difficult for a learner to know who has this knowledge even though they are at the same place. In this case, the learner needs to be aware of the other learners' interests that match his request (ElBishouty, Ogata, Rahman and Yano, 2010).

There are only a few studies that have attempted to induce the educational affordances of context-aware ubiquitous learning environment. Liu and Chu (2009) devoted attention to the problem of what educational affordances can be provided by a context-aware ubiquitous learning environment. They proposed a system named *EULER* that can provide eight educational affordances: knowledge construction, apply, synthesis, evaluation, interactivity, collaborative learning, game-based learning, and context-aware learning. Moreover, they stressed that ubiquitous learning provides context-aware information and self-learning opportunities for learners. Therefore, it not only enables students to achieve learning goals anytime and anywhere, it is also cultivating their ability to explore new knowledge and solve problems. This should be considered to be one of most important characteristics of ubiquitous learning.

Interesting ideas about learning in smart environments can be found in (Winters, Walker and Rousos, 2005). According to it, learning is no longer viewed only as a form of delivered instruction, undertaken within the confines of traditional educational environments. It is now understood as a social process that happens at a time and place of the learner's choosing, continuing throughout one's life. It is collaborative, evolving and informed by a process of self-paced development.

Winters, Walker and Rousos (2005) define a smart environment as any space where ubiquitous technology informs the learning process in an unobtrusive, social or collaborative manner. Thus a smart environment can be an 'aware' room or building, capable of understanding something about the context of its inhabitants or workers; it can be a digitally enhanced outdoor space – park, cityscape or rural environment; or it can be the environment created when peoples' meetings or interactions are augmented by wearable devices. These ideas are very close to that of original Scenario 4: *Annette and Solomon in the Ambient for Social Learning* from the well known ISTAG Report (Ducatel et al., 2001).

Possible solutions

There is already a number of interesting applications and other results in the area of smart workplaces that tackle various important problems necessary for further development of this important field. We try to mention some of them in this chapter.

An important problem in each smart environment is the problem of how the environment evaluates users' needs and how it assigns preferences to them. Actually, when many users are involved in a ubiquitous environment, the decisions of one user can be affected by the desires of others. This makes learning and prediction of user preference difficult. To address the issue, Hasan, et al. (2006) propose an approach of user preference learning which can be used widely in context-aware systems. The approach based on *Bayesian RN-Metanetwork*, a multilevel Bayesian network to model user preference and priority is used here.

With a somehow similar aim our papers (Tučník, 2010) and (Tučník and Mikulecký, 2010) are focused on decision making of agents in multi-agent environments, with a special accent on multi-agent based modeling of smart environments. The ongoing research related to that is oriented on further study of Multi-Criteria Decision Making in autonomous decision making, especially when multiple entities (users or agents) are present at the same time. Solution of conflicts, negotiation, settings of user preferences, multiple objectives, setting priorities, etc. are the main areas of interest in our further research.

When the necessity of user preferences appears, usually new location-based services can be adapted to accomplish this task. For this the ubiquitous system needs to know user profiles, likings, and habits. But in the case when the user moves, this information must be made available at the new location of the user. Either the user carries the data on wearable or portable computers or the smart environment takes responsibility for transporting them. Related to this, it is proposed in (Bagci et al., 2007) that a smart environment takes care for storing and sending the personal information. The person in this approach is always accompanied by a mobile virtual object in the smart environment. So location based services adapted to personal profiles can be offered. The paradigm of mobile agents, used in this approach, ideally fits into the decentralized approach. The mobile agent constitutes a virtual reflection of the user and carries personal information which enables the agent to perform various services for the user. Additionally the mobile agent can use the environmental information which is provided by the local ubiquitous system. Moreover, the movement of the mobile agent should be in this approach faster than the movement of the person. This fact helps to solve a couple of related problems.

An idea of recognition of a current situation and behavior of a user, as well as an unobtrusive satisfaction of his needs underlies the *Ambient Intelligence*. Integration of diverse computation, information and communication resources into a united framework is one of the important issues at design of ambient intelligence and it identifies the modern tendency to transition from smart devices to an ambient intelligent space. Multimodal interfaces provide natural and intuitively comprehensible interaction between a user and intellectual devices, which are embedded into the environment. All the means should be hidden, thus the user can see only the results of intellectual devices activities and concentrate attention on her/his work. Rondzhin and Budkov (2009) describe a development of an intelligent meeting room as a distributed system with the network of intelligent agents (software modules), actuator devices, multimedia equipment and audio-visual sensors. The main aim of the room is providing of meeting or lecture participants with required services based on analysis of the current situation. Awareness of the room about spatial position of the participants, their activities, role in the current event, their preferences helps to predict the intentions and needs

of participants. Context modeling, context reasoning, knowledge sharing are stayed the most important challenges of the ambient intelligent design of this kind of rooms.

One of challenging applications is without any doubts any *AmI* application bringing new ideas and approaches into educational process at every level of education. Educational environment certainly is a rather specific workplace deserving a special attention and focus. One of these applications is the *Smart Classroom* project (Shi, Qin, Suo and Xiao, 2010). It aims to build a real-time interactive classroom with tele-education experience by bringing pervasive computing technologies into traditional distance learning. The goal of *Smart Classroom* project is to narrow the gap between the teacher's experience in tele-education and that in the traditional classroom education, by means of integrating these two currently separated education environments together. The used approach was to move the user interface of a real-time tele-education system from the desktop into the 3D space of an augmented classroom so that in this classroom the teacher could interact with the remote students with multiple natural modalities just like interacting with the local students.

There is a number of interesting attempts to propose ubiquitous learning environments of the type discussed in previous chapters. For instance, a wireless communication based network called *GroupNet* is proposed in (Chen, Kinshuk, Wei and Yang, 2008). It is a *Group Area Network* that is proposed on the basis of P2P wireless network connection to fit with this type of mobile scenario. *GroupNet* consists of a set of interconnecting handheld devices with wireless access, carried by a group of people within proximity.

GroupNet works with wireless modules of the handheld devices to achieve the best of ubiquitous networking. Ubiquitous networks enable secure access to data from everywhere on multiple devices to achieve the ubiquitous learning environment. The ubiquitous learning environment can connect, integrate and share learning resources in the right place at the right time by an interoperable, pervasive and seamless learning architecture. P2P networking used in *GroupNet* is one approach of creating ubiquitous networks for supporting ubiquitous learning.

Another interesting proposal of intelligent learning environments was published by Mhiri and Ratté (2009). The authors proposed an intelligent environment for human learning (called the *AARTIC* project) that assists software engineering students in their assignments. The system resolve real problems: for the students, too much time to complete each assignment, for the teacher, too many students to offer any personalized help. Moreover, because students find themselves in a precarious situation (the concepts are new and complex), they rely on old primary reflexes: zero collaboration or planification. The proposed system aims to help the student in the understanding of concepts by suggesting examples. Two pedagogical agents compose the adaptive aspect of the system. The first monitors students' activities in the environment. The second allows the teacher to observe the performance of each student and of the class as a whole. The environment also emphasizes collaboration.

ElBishouty, Ogata, Rahman and Yano (2010) presented a model of personalized collaborative ubiquitous learning environment in order to support learners doing learning tasks or activities. It utilizes RFID tags to detect the surrounding physical objects and provides personalized recommendations based on the detected objects. It provides the learner with social knowledge awareness map for the peer helpers. The map visualizes the learners' surrounding environmental objects, peer helpers and the strength of the relation in the social network perspective. The learner can contact, interact, and collaborate with the peer helpers to address the learning goal.

Another example of a different approach towards intelligent learning environments can be found in (Winters, Walker and Rousos, 2005). They defined an intelligent environment as any space where ubiquitous technology informs the learning process in an unobtrusive, social or collaborative manner. In their paper, two ubiquitous devices for use in such an environment were presented: the

ISBN 978-80-558-0092-9

Experience Recorder and the *iBand*. The *Experience Recorder* is an embedded system that records the paths travelled by users – i.e. trails – in a particular place, for example at a museum or trade fair. It then recreates this visit in digital form, for example as a personalised website, enhanced for learning. The *iBand* is a wearable bracelet-like device that exchanges information about its users and their relationships during a handshake. Winters, Walker and Rousos (2005) stressed that the challenge of ubiquitous computing was to design and build systems for augmenting human capabilities rather than to replace them. In the context of learning, any ubiquitous computing tool cannot be viewed as deskilling the user. It must encourage skills development in a manner in which the learner is comfortable and engaged with. We cannot agree more.

The last example of a smart environment is the system *ISABEL* described in (Garruzzo, Rosaci and Sarné, 2007). The *ISABEL* is a new sophisticated multi-agent e-learning system, where the basic idea is in partitioning the students in clusters of students that have similar profiles, where each cluster is managed by a tutor agent. When a student visits an e-learning site using a given device (say, a notebook, or a smart phone), a teacher agent associated with the site collaborates with some tutor agents associated with the student, in order to provide him with useful recommendations. Generally, these systems use a profile of the student to represents his interests and preferences, and often exploit software agents in order to construct such a profile. More in particular, each student is associated to a software agent which monitors her Web activities, and when the student accesses an e-learning site, his agent exploits the student's profile interacting with the site. In this interaction, the site can use both content-based and collaborative filtering techniques to provide recommendations to the student's agent by adapting the site presentation.

The problems and works mentioned above are just a collection of some applications and approaches which are somehow interesting and important for our further research direction. The collection certainly is not complete and a lot of other important problems could be extracted from the literature. However, we hope that some inspiration for focusing research work can be found here. We think that at least the importance of the area for common practice has been exhibited.

Conclusion

Quoting Weiser (1991), "*the most profound technologies are those that disappear*. *They weave themselves into the fabric of everyday life until they are indistinguishable from it".* As a matter of fact, smart learning at smart workplaces could be a good example of such a technology.

Bureš and Čech (2007) argue that the achievement of ambient intelligence postulates an adequate shift in thinking. The shift in thinking concerns also managerial work. The paper therefore presents on field experience on how to test the meaningfulness of teaching systems thinking for managers and increasing thus the level of acceptance of new technologies.

One of our earlier papers (Mikulecký, 2007) pointed out that managers, in order to be able of producing the best possible strategic decisions, should have the right information in the right time. However, without having the appropriate knowledge the production of good decisions would not be easy, if not impossible. It is, therefore, quite sensible to think about such a managerial workplace, where the manager would have the best possible working conditions in various meanings of this formulation.

A more general overview of the *AmI* possibilities in education brings our recently published book chapter (Mikulecký, Olševičová, Bureš and Mls, 2011).

The ISTAG scenario *Annette and Solomon* (Ducatel et al., 2001) was considered in the time of its origin as a long term future. However, we presented a lot of examples and arguments in favour of

the idea, that the scenario can be nowadays implemented, as the relevant technology has matured enough. So, smart learning can be today used at smart workplaces as their integrate part.

Acknowledgement

The research has been partially supported by the Czech Scientific Foundation project No. P403/10/1310 SMEW - Smart Environments at Workplaces.

References

Augusto, J.C., Nakashima, H., Aghajan, H., 2010. *Ambient Intelligence and Smart Environments: A State of the Art, Handbook of Ambient Intelligence and Smart Environments.* Berlin: Springer Science+Business Media.

Bagci, F., Schick, H., Petzold, J. , Trumler, W., Ungerer, T., 2007. The reflective mobile agent paradigm implemented in a smart office environment, *Pers Ubiquit Comput*., 11, pp. 11–19.

Bomsdorf, B., 2005. Adaptation of Learning Spaces: Supporting Ubiquitous Learning in Higher Distance Education, Mobile Computing and Ambient Intelligence: The Challenge of Multimedia, Dagstuhl Seminar Proc. 05181, [online] Available at <http://drops.dagstuhl.de/opus/volltexte/2005/371/pdf/05181.BomsdorfBirgit.Paper.371.pdf> [Accessed 15 February 2012].

Bureš, V., Čech, P. 2007. Complexity of Ambient Intelligence in Managerial Work, Inclusive Education in Computer Science, ITiCSE 2007, New York: ACM, p.325.

Bureš, V. Čech, P., Mls, K., 2009. Educational Possibilities in the Development of the Ambient Intelligence Concept, *Problems of Education in the 21st Century*, 13(13), pp. 25-31.

Chen, N.S., Kinshuk, Wei, C.W., Yang, S.J.H., 2008. Designing a Self-contained Group Area Network for Ubiquitous Learning. *Educational Technology & Society,* 11 (2), pp. 16-26.

Cook, D.J., Augusto, J.C., Jakkula, V.R., 2009. Ambient Intelligence: Technologies, Applications, and Opportunities. *Pervasive and Mobile Computing* 5, pp. 277-298.

Ducatel, K., et al., 2001. Scenarios for Ambient Intelligence in 2010: Final report. Seville, Spain, Information Society Technologies Advisory Group, [online] Available at <ftp://ftp.cordis.lu/pub/ist/docs/istagscenarios2010.pdf>, [Accessed 7 June 2011].

El-Bishouty, M.M., Ogata, H., Rahman, S., Yano, Y., 2010. Social Knowledge Awareness Map for Computer Supported Ubiquitous Learning Environment. *Educational Technology & Society*, 13 (4), pp 27–37.

Freitas, C., Marreiros, G., Ramos, C., 2007. IGTAI - An Idea Generation Tool for Ambient Intelligence, In: 3rd IET International Conference on Intelligent Environments, pp. 391–397.

Garruzzo, S., Rosaci, D., Sarné, G.M.L., 2007. ISABEL: A Multi Agent e-Learning System That Supports Multiple Devices. In: IEEE/WIC/ACM International Conference on Intelligent Agent Technology, New York: IEEE, pp. 485-488.

Hasan, Md. K., Anh, K., Mehedy, L., Lee, Y.-K., Lee, S., 2006. Conflict Resolution and Preference Learning in Ubiquitous Environment, In: International Conference on Intelligent Computing, ICIC 2006, LNAI 4114, Heidelberg: Springer, 2006, pp. 355 – 366.

Hwang, G.J., Tsai, C.C., Yang, S.J.H., 2008. Criteria, Strategies and Research Issues of Context-Aware Ubiquitous Learning. *Educational Technology & Society*, 11 (2), pp 81-91.

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, pp 402-413.

Le Gal, C., 2005. *Smart Environments: Technology, Protocols and Applications*, Chichester: Wiley.

Liu, T.Y., Chu, Y.L., 2009. Educational Affordances of Ubiquitous Learning Environment for Natural Science Learning. In: IEEE ICALT 2009, New York: IEEE Press, pp 290-292.

Marsá-Maestre, I., de la Hoz, E., Alarcos, B., Velasco, J.R., 2006. A Hierarchical, Agent-based Approach to Security in Smart Offices. In: International Conference on Ubiquitous Computing: Applications, Technology and Social Issues. Madrid, Spain, CEUR Workshop Proceedings No. 208.

Mhiri, F., Ratté, S., 2009. AARTIC: Development of an Intelligent Environment of Human Learning, In: ITiCSE 09, New York: ACM Press, p. 359.

Mikulecký, P., 2007. Ambient Intelligence in Decision Support. In: Strategic Management and Its Support by the Information Systems, VSB Tech. Univ. Ostrava, pp. 48-58.

Mikulecký, P., Olševičová, K., Bureš, V., Mls, K., 2011. Possibilities of Ambient Intelligence and Smart Environments in Educational Institutions." In: *Handbook of Research on Ambient Intelligence and Smart Environments: Trends and Perspectives* (Mastrogiovanni, F., Nak-Young Chong, eds.), Chap. 29, pp. 620-639, Information Science Reference (IGI Global).

Ramos, C., Marreiros, G., Santos, R., Freitas, C.F., 2010. Smart Offices and Intelligent Decision Rooms, In: *Handbook of Ambient Intelligence and Smart Environments*, Berlin: Springer Science+Business Media, pp. 851-880.

Ronzhin, A.L., Budkov, V.Yu., 2009. Multimodal Interaction with Intelligent Meeting Room Facilities from Inside and Outside. In: *Smart Spaces and Next Generation Wired/Wireless Networking*, LNCS 5764, Berlin: Springer, pp. 77–88.

Shi, Y., Qin, W., Suo, Y., Xiao, X., 2010. Smart Classroom: Bringing Pervasive Computing into Distance Learning. In: *Handbook of Ambient Intelligence and Smart Environments*, Berlin: Springer Science+Business Media, pp. 881-910.

Tučník, P., 2010. Multicriterial Decision Making in Multiagent Systems – Limitations and Advantages of State Representation of Behavior. In: Data networks, communications, computers (DNCOCO 2010), Athens: WSEAS Press, pp. 105-110.

Tučník, P., Mikulecký, P., 2010. Multicriteria Adaptation Mechanism of Agent Environment Behavior in Ambient Intelligence Services, In: Proc. of the International Conference on Applied Computer Science, Athens: WSEAS Press, pp. 401-405.

Weiser, M., 1991. The computer for the twenty-first century. Scientific American, September 1991, pp. 94-104.

Winters, N., Walker, K., Rousos, D., 2005. Facilitating Learning in an Intelligent Environment. In: The IEE International Workshop on Intelligent Environments. London: Institute of Electrical Engineers, pp. 74-79.

Yang, S.J.H., 2006. Context Aware Ubiquitous Learning Environments for Peer-to-Peer Collaborative Learning. *Educational Technology & Society*, 9 (2), pp. 188-201.

Yang, S.J.H., Okamoto, T., Tseng, S.S., 2008. Context-Aware and Ubiquitous Learning (Guest Editorial), *Educational Technology & Society*, 11 (2), pp. 1-2.