Adaptive context-aware pervasive and ubiquitous learning

Anastasios A. Economides

Information Systems Department,
University of Macedonia,
156 Egnatia Avenue, Thessaloniki, 54006, Greece
E-mail: economid@uom.gr

Abstract: In pervasive and ubiquitous learning, a learner should be able to freely perform an educational activity possibly cooperating and/or collaborating with others using multiple devices and networks as he moves in an environment. The educational activity should be able to be performed by various types of learners and to operate on various devices, networks and environments. Correspondingly, the devices and the networks should be able to support various types of learners and to operate various educational activities in any environment. In order to provide adaptive context-aware pervasive and ubiquitous learning, an adaptation engine senses the context and produces adapted educational activity and infrastructure. This paper defines the context to consist of the learner state, the educational activity state, the infrastructure state and the environment state. Furthermore, it comprehensively describes each one of the states.

Keywords: adaptation; adaptive learning; context-aware; educational activity; learner profile; learner model; mobile learning; personalised learning; pervasive learning; ubiquitous learning.

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Biographical notes: Anastasios A. Economides received his DiplEng in Electrical Engineering from Aristotle University of Thessaloniki. Holding a Fulbright and a Greek State Fellowship, he received his MSc and his PhD in Computer Engineering from the University of Southern California, Los Angeles. Currently, he is an Associate Professor and Chairman of the Information Systems Department at the University of Macedonia, Thessaloniki, Greece. His research interests include networking techno-economics, e-learning and e-services. He has published over 150 peer-reviewed papers. He has been the Plenary Speaker in two international conferences.

1 Introduction

Mobile phones are extensively used in every day life, mostly for phone calls and short message service (SMS) (Economides and Grousopoulou, 2008). Educational institutes are also starting to exploit mobile devices and networks for learning and management. As most students already possess handheld devices, several educational institutes are using wireless technology to deliver and support mobile learning (Davies, 2003; Waycott and

Kukulska-Hulme, 2003; Sung et al., 2005; Economides and Nikolaou, 2008). The intersection of online learning and mobile computing – called mobile learning – holds the promise of offering frequent, integral access to applications that support learning, anywhere, anytime (Tatar et al., 2003). Mobile learning would help the development of the knowledge society. The objective is a society with access to knowledge and learning for everyone (Lytras and Sicilia, 2005). The mobile learner will carry multiple heterogeneous wearable and handheld devices. He will be able to continually learn wherever he is moving without any mobility, time and other restrictions. He will move and interact unrestricted with other learners, hardware and software resources in his neighbourhood or on remote locations via networks. Collaborative learning at outdoors (e.g., educational trips to an archaeological site or a national forest, collaborative game-based learning) would be supported by multicast mobile ad hoc networks (Vasiliou and Economides, 2007a, 2007b, 2008).

Many researchers called for personalisation of knowledge according to the characteristics of the learner (e.g., Lytras, 2007) and integrating the variety of perspectives on personalised and adaptive learning (e.g., Wolpers and Grohmann, 2005). They also stressed the value of educational resources' interoperability in order to share and reuse them (e.g., Wolpers and Grohmann, 2005). The necessity of personalised learning has been well recognised since every learner has different characteristics. The educational activities and the provided infrastructure would be auto-configured tailored to the learner's needs, interests and abilities. Multiple sources of information would be used to adapt the educational activities and the infrastructure to every situation and condition. Most of the physical objects in the environment will be equipped with some embedded sensing and communication capabilities. They will sense, track and monitor the surrounding environment and transmit this information to those interested for that. This information would be used to make dynamic adaptation decisions for the benefit of the learner. In such pervasive and ubiquitous computing environments, a comprehensive and accurate description of the context is important.

Several previous studies on pervasive and ubiquitous computing provided various definitions of context. Location, identity, time and activity have been suggested as primary types of context (Schilit et al., 1993). Computing context (e.g., network connectivity, communication costs, communication bandwidth, nearby resources such as printers, displays and workstations), user context (e.g., user's profile, location, people nearby and current social situation) and physical context (e.g., lighting, noise levels, traffic conditions and temperature) have been also proposed as main context categories (Schilit et al., 1994). In addition to location (Becker and Durr, 2005), identities of nearby people and objects, as well as changes to those objects have been included in the context (Schilit and Theimer, 1994). Context-aware has been defined as 'the ability of the computer to sense and act upon information about its environment, such as location, time, temperature or user identity' (Ryan et al., 1998). Context has been also described across three dimensions:

1 environment (physical and social)

2 self (device state, physiological and cognitive)

3 activity (behaviour and task) (Schmidt et al., 1999).

Any information that can be used to characterise the situation of an entity (e.g., person, place or object) would be considered as context (Dey and Abowd, 2000). Different types

of information about a user can simultaneously be relevant to a given adaptation decision (Tamminen et al., 2004). Context can be externally-imposed, externally-induced or internally-induced (Hill, 2007). An ontology-based context model considered time, place, user knowledge, user activity, user environment and device capacity (Bouzeghoub et al., 2007). In parallel, a situation model gave a view on the context model describing temporal properties. It was argued that the following context parameters should be taken into consideration: variety, priority, granularity, implementation and cost-effectiveness (Bayoumi, 2007). An essential issue in pervasive computing is related to data gathering techniques about the context (Roibas, 2007). Furthermore, it has been argued that a context-aware mobile learning system should also take into consideration the learner's willingness to participate in the proposed learning activity (Bhaskar and Govindarajulu, 2008).

Several architectures for context-aware applications have been proposed (Dey, 2001; Jameson, 2001; Petrelli et al., 2001; Indulska and Sutton, 2003; Lonsdale et al., 2003; Biegel and Cahill, 2004). However, implementing such systems on a large scale is not free from obstacles (Raisinghani et al., 2004). Building adaptive educational systems that adapt to different learning characteristics is not an easy task (Kay, 2001). Open research questions include on how to identify the relevant learning characteristics, to model the learner or to change the learning environment for users with different learning characteristics. It is known that learner's characteristics (e.g., cognitive style of learning) actually influence his performance (e.g., navigational behaviour in the training module) (Souto et al., 2002). Educational, socio-cultural, economical and technical requirements for mobile learning applications have been defined (Economides, 2008a). Contract-based adaptive software architecture (CASA) provided a framework for the development of adaptive applications that were able to adapt their functionality and/or performance dynamically in response to runtime changes in their execution environments (Mukhija and Glinz, 2004). A mechanism to support adaptation in m-learning systems proposed activities to a user depending on:

1 the user's features, learning style, preferences or previous actions

2 his partners' features, learning styles, preferences or previous actions

3 his specific context at that time (location, idle time, devices)

4 the specific context of his partners at that time (Martin et al., 2006).

An ontology-based framework for context-aware mobile learning has been proposed by Berri et al. (2006). A rule-based ontology is driven by the learner's profile to contextualise learning content accordingly. Then, a search agent searches a set of learning objects for feasible learning objects. Context-aware social presence mechanisms would support a learner in formal locations (e.g., classroom, scheduled computer laboratory sessions), semi-formal locations (e.g., libraries, walk-in laboratories) and informal locations (e.g., residences) (Kekwaletswe and Ngambi, 2006). Instant messaging would provide the learner with continuous access to social networks. A three-tier web-based architecture has been proposed for context-aware m-learning (Basaeed et al., 2007). The client tier corresponds to the learning device which supports a web browser and internet connectivity. The middle tier consists of context sensing, context reasoning and context-aware delivery. It is connected to resources using web services. The third tier consists of the learner profile, device profile, connectivity profile, ontologies and learning

objects. Similarly, 'SmartContext' was an ontology based context model which included a standardised context template, a context reasoning ontology and a context middleware (Hu and Moore, 2007). The following types of context were considered: personal, task, role and spatio-temporal.

Several standardisation efforts have been undertaken regarding learner models and learning objects: IEEE personal and private information (PAPI), IEEE WG1 learning technology systems architecture (LTSA), IEEE learning object metadata (LOM), ADL Sharable Content Object Reference Model (SCORM, http://www.adlnet.org) and IMS learner information package (LIP). The IEEE PAPI (http://ltsc.ieee.org) consists of the following six categories of information about a learner: personal, relations, security, preference, performance and portfolio information. The IMS LIP (http://www.imsglobal.org) consists of the following 11 categories of information about a learner: identification, goal and qualifications, certifications and licenses (QCL), activity, interest, competence, accessibility, transcript, affiliation, security key and relationship. In the IEEE 1484.12.1 standard, the LOM includes multimedia content, instructional content, learning objectives, instructional software and software tools and persons, organisations or events referenced during technology supported learning (IEEE LOM, http://ltsc.ieee.org). LOM groups the elements that are used to describe a learning object into nine categories: general, lifecycle, meta-metadata, technical, educational, rights, relation, annotation and classification.

Most previous studies on adaptive learning proposed to adapt the interface, the learning flow or sequencing, the content (Burgos et al., 2006) or even the exams (Economides and Roupas, 2007; Triantafillou et al., 2008a, 2008b). The learner would choose the learning tools and companion learners, on-demand learning of various types, control over the elements of the systems and the possibility of controlling the amount of control (Kay, 2001). Next, previous studies on learning adaptation are briefly presented.

Content and course adaptation has received much attention (e.g., Vassileva, 1998; Healey et al., 2002; Brusilovsky and Vassileva, 2003; Tretiakov and Kinshuk, 2004; Yau and Joy, 2007a, 2007b). Dynamic course generation (DCG) allowed automatic generation of individualised courses according to the learner's goal and previous knowledge and adapted the course according to the learner's success in acquiring knowledge (Vassileva, 1998; Brusilovsky and Vassileva, 2003). Content was adapted to the device and modality of a user's preference (Healey et al., 2002). Content was adaptively structured for access via mobile devices, accounting for variations in communication channels, end-user device capabilities and user profiles (Tretiakov and Kinshuk, 2004). The architecture of a context-aware schedule tool for learning Java was proposed (Yau and Joy, 2007a). The appropriate learning objects were selected according to the learner's preferences (e.g., learning style, learning priorities and knowledge level) and contextual features (e.g., level of concentration, location and time). A context-aware system consisting of three components was proposed by Yau and Joy (2007b). A learning schedule supported the student's daily routines. A learning style adaptation module adapted the activities to the student's learning style. A context adaptation module identified the current student's context (e.g., location, time available and noise level) and then recommended appropriate learning activities accordingly.

Presentation adaptation has also received some attention (e.g., Vassileva, 1998; Kurzel et al., 2002; Wang et al., 2004; Klett, 2005; Kelly and Tangney, 2006). Generic tutoring environment (GTE) adapted the presentation of the content (Vassileva, 1998). Content was presented in a variety of ways based on both student prior competencies

(pre-requisite knowledge and skills) and preferences (Kurzel et al., 2002). The presentation was adapted to facilitate learners' spatial reasoning on geometric topics (Wang et al., 2004). Multiple representations of complex or hidden subjects were also used (Klett, 2005). Different adaptive presentation strategies were used for students with different learning activities (Kelly and Tangney, 2006).

Navigation and sequencing adaptation reasonably received much attention (e.g., Eklund and Brusilovsky, 1998; Brusilovsky et al., 1998; Weber and Brusilovsky, 2001; Herder and van Dijk, 2002; Carchiolo et al., 2002; Brusilovsky and Vassileva, 2003; Faraco et al., 2004; Albano et al., 2006, 2007). Link annotation was adapted to the individual user in order to help him find an appropriate path in a learning space (Eklund and Brusilovsky, 1998). Guidance and navigation in InterBook (an authoring tool for developing adaptive electronic textbooks on the web) were adapted to the user (Brusilovsky et al., 1998). Episodic learner model-adaptive remote tutor (ELM-ART) provided adaptive navigation support, course sequencing, individualised diagnosis of student solutions and example-based problem-solving support (Weber and Brusilovsky, 2001). Navigation support was adapted to device characteristics (such as screen size, interface design and means of interaction) and its context of use (Herder and van Dijk, 2002). The knowledge path that a student should follow was adapted according to his needs and capabilities (Carchiolo et al., 2002). Concept-based courseware analysis (CoCoA) checked the consistency and quality of a course at any moment of its life and assisted course developers in some routine operations (Brusilovsky and Vassileva, 2003). A learning companion agent type was chosen according to the student profile to support him in the conceptual maps navigation (Faraco et al., 2004). CoCoA checked the consistency and quality of a course at any moment of its life and assisted course developers in some routine operations (Brusilovsky and Vassileva, 2003). A flexible e-learning model would take into consideration the learner's knowledge state and learning preferences (Albano et al., 2006) to create personalised learning paths (Albano et al., 2007).

Assessment adaptation is an important area and several high stakes test organisations use computerised adaptive testing techniques. In computer adaptive testing (CAT), if the examinee answers correctly a question, then the next question is harder. Otherwise, the next question is easier (e.g., Economides and Roupas, 2007). Material for self-assessment was adapted to the needs of the individual learner (Georgouli, 2004). The examinee's confidence in answering the question was also incorporated in adaptive testing (Lamboudis and Economides, 2004). It would be useful for the examinee to know his current status. The amount and timing of this orientation information revealed to the examinees would be adapted to his learning characteristics (Economides, 2005b). A CAT system on mobile devices was also developed and evaluated (Triantafillou et al., 2008a, 2008b).

Adaptive feedback would be provided to the examinee tailored to his needs (Economides, 2006b). The system would try to reduce the student's fear during a test (Economides and Moridis, 2008). A model to measure the student's mood during a test was proposed (Moridis and Economides, 2008a) and validated using experimental data (Moridis and Economides, 2008b).

Adaptive communication and collaboration would support learners from diverse cultural origins (Economides, 2008c). Other adaptation approaches considered the users preferences for informal communication and learning (Groth et al., 2007). Adaptive tools

based on teacher's model for authoring, curriculum setting, co-teaching and privileges setting, reward setting, assessment setting and information sharing setting were proposed (Lin et al., 2005).

Although there are many studies on learner's models, learning objects and context, none provides an integrated adaptive decisions framework based on a comprehensive description of the relevant parameters. This paper tries to fill this gap by proposing adaptive pervasive and ubiquitous learning based on a holistic context model. A common framework would enable interoperability among various systems and applications.

The key ingredients of the system are the input (context), the adaptation engine and the output (adaptations). The context is explicitly described by comprehensive models of the learner's state, the educational activity's state, the infrastructure's state and the environment's state. The adaptation engine acquires input data and produces the adaptation results. Input data into the adaptation engine is the context. Output results of the adaptation engine are the adapted educational activity and infrastructure. The output would be produced either deterministically or probabilistically (Economides, 2006c). Learning automata would be employed as probabilistic adaptation engines. The quality of the adaptation engine would be evaluated with respect to various criteria (Economides, 2007).

In Section 2, the context is defined. Section 3 describes the phases of a context-aware adaptive pervasive and ubiquitous learning system. Section 4 presents the adaptation engine. Section 5 explicitly describes the context on which the adaptations are based. Finally, conclusions and directions for future research are given.

2 Context definition

We define the context to consist of the learner's state (L), the educational activity's state (A), the infrastructure's state (I) and the environment's state (E). Furthermore, every state consists of various dimensions and every dimension consists of various variables (see Section 5). During a given moment, multiple learners would perform educational activities (possibly, cooperatively and/or collaboratively) using various infrastructures in multiple environments. Thus, the full description of the context would incorporate these learners' states, educational activities' states, infrastructures' states, environments' state and their interconnections: L2L, L2A (A2L), L2I (I2L), L2E (E2L), A2A, A2I (I2A), A2E (E2A), I2I, I2E (E2I) and E2E.

3 Phases of an adaptive context-aware pervasive and ubiquitous learning system

An adaptive context-aware pervasive and ubiquitous learning system would sense data related to the context, estimate the real current state of these data, manage these data (e.g., prioritise), use these data (e.g., decide adaptations) and predict the future state of these data. Thus, the phases of the system's operation are the following:

1 sense, detects, monitor, track, measure and record the context parameters

2 estimate the context

3 organise and manage the context (e.g., classify it, filter it, order its variables, prioritise its variables, compare it to others and evaluate it)

4 use the context (e.g., apply it, infer from it, adapt the educational activity and/or the infrastructure, guide the learner)

5 predict future context.

A context-aware system collects information about the learner, the educational activity, the infrastructure and the environment by sensing, detecting, monitoring, tracking or measuring them. For example, vision and speech would be monitored (Porta, 2007). After storing this raw information, the system refines it and estimates the 'true' context. The third phase is to organise and manage the context. The system would classify the context based on relevance, accuracy, validity, security and other criteria. It would filter the context to extract the most useful information for the particular educational activity. It would order the context parameters according to some criteria and priorities. It would compare the context to similar situations' context or to past situations' context for the same learner or similar learners or an average learner or an expert.

The fourth phase is the usage of the context. The system would apply the context or infer from the context (for example, about the learner's performance and achievements). The system would be adapted according to the states of the learner or/and the educational activity or/and the infrastructure or/and the environment. For example, if there is not enough communication capacity, then multimedia communication would be substituted by text communication. On the other hand, the system would adapt the educational activity or/and the infrastructure to the context. For the previous example, it would buy communication capacity from other networks. Also, the system would guide the learner based on the context (for example, suggest him alternative educational material).

Finally, in the last phase, the system would predict the future context and take appropriate steps. For example, it would pre-fetch advanced educational material by predicting the learner's progress.

4 Adaptation engine

The adaptation engine 'reads' the context and 'produces' the adapted educational activity and the adapted infrastructure:

$$\begin{aligned}\text{Output}(t+1) &= [A(t+1),\ I(t+1)] = \text{Function\_C}(\text{Context}(t)) \\ &= \text{Function\_C}(L(t),\ A(t),\ I(t),\ E(t))\end{aligned}$$

- adapted educational activity: $A(t + 1) = \text{Function\_A}(L(t), A(t), I(t), E(t))$
- adapted infrastructure: $I(t + 1) = \text{Function\_I}(L(t), A(t), I(t), E(t))$.

Thus, the educational activity is adapted to the learner, the infrastructure and the environment. Similarly, the infrastructure is adapted to the learner, the educational activity and the environment. As we will show later, the learner's state also incorporates the states of the other learners.

When an adaptation is performed at a given moment, either the most appropriate item is selected among a variety of alternatives (e.g., a more difficult question) or a real-time conversion is performed (e.g., zooming, text-to-speech, WAV-to-MP3, GIF-to-JPEG).

Let us give an adaptation example:

If

$$\text{Context}(t) = [L_1, A_1, I_1, E_1],$$

then

$$A(t+1) = A_{101}$$
$$I(t+1) = I_{101}$$

...

If

$$\text{Context}(t) = [L_n, A_n, I_n, E_n],$$

then

$$A(t+1) = A_{nik}$$
$$I(t+1) = I_{nlm}$$

Many explanatory adaptation examples are given in Economides (2008b). In case the information about the context is not very accurate, probabilistic adaptation decisions would be employed. Instead of deciding definitively about the adaptations, a more soft decision would be done. For example, the adapted state of the educational activity or/and the infrastructure would be selected probabilistically among a set of candidate states (Economides, 2006c). Multiple criteria for evaluating the quality and effectiveness of an adaptation engine are also proposed in Economides (2007).

5 Context model

Having defined the Context = [L, A, I, E], let us further describe the dimensions and variables of each one of the learner's state (L), the educational activity's state (A), the infrastructure's state (I) and the environment's state (E). It is obvious that the more information is available about each state, the more accurate but complicated the model becomes.

The variables would be estimated according to the following ten ways:

1 the learner declares some variables (e.g., demographics)

2 the teacher declares some variables (e.g., learning theory)

3 the parents declare some variables (e.g., costs and pricing limits)

4 the participants collaboratively decide for some variables (e.g., assessment type)

5 others (e.g., doctors, psychologists, educators, peers, authors, school administrators, developers, manufacturers, network providers, etc.) declare some variables

6 the learner takes some pre-tests in order to evaluate some variables (e.g., learning styles)

7 some variables are transferred from other hardware and software systems (e.g., transcripts, health, weather, location and maps)

8 data mining techniques are used to extract information (e.g., favourites, device characteristics and media conversion) from online or offline databanks (e.g., social networks, government data and manufacturers)

9 the computer monitors and measures some variables (e.g., current status, emotions and feeling, results and achievements)

10 sensors track and record some variables (e.g., mobility, environmental conditions).

For example, the learner's mood during a self-assessment test would be estimated (Economides and Moridis, 2008; Moridis and Economides, 2008a, 2008b). Furthermore, some variables (e.g., religion) may be useful for some cases (e.g., food to avoid, schedule/holidays), but inappropriate for other cases (e.g., privacy and confidentiality).

5.1 Learner's state

We define the learner's state to consist of the following dimensions: 'demographics, education and profession, results and achievements, preferences, favourites, interests, objectives and aims, health, current biological and physiological needs, physical abilities, cognitive abilities, social abilities, cultural abilities, emotions and feelings, motivation and conation, learning styles, cognitive styles, intelligence, personality, people, time and schedule, location, mobility, restrictions and constraints, and current status' (Table 1). Each one of these dimensions is described by many variables. Regarding cultural abilities, we adopted the models of Trompenaars and Hampden-Turner (1997) or Hofstede (1980). The dimensions of learning styles, cognitive styles, intelligence and personality are interrelated and various models have been proposed to describe them. We choose to describe them independently adopting the Felder and Silverman (1988) or Kolb (1984) models regarding learning styles; the Gardner (1983, 2006) model regarding intelligence; the Witkin et al. (1977) model regarding field dependence-independence; and the big five model regarding personality, among others. Regarding the feelings and emotions dimension, we adopt Economides (2006a) model to describe the learner's emotional state.

The learner's model communicates with other learners', the educational activity's, the infrastructure's and the environment's states via the 'current status' dimension.

Table 1 Dimensions of learner's state

Dimensions of learner's state	*Variables of each dimension*
Demographics	ID, name, access rights, e-mails, telephone numbers, websites, blogs, profiles in communities, addresses, age, gender, languages, nationality, ethnicity, religion, culture, customs, income, marital status, affiliations and memberships (in educational, professional, sports, etc., organisations, communities, social networks and other groups), habits, hobbies, travel, etc.
Education and profession	Level of knowledge, educational and professional background, professions and jobs, computer experience, informal education
Previous results and achievements (formal and informal)	Transcripts (schools, courses, syllabus, teachers, assignments, grades, etc.), certifications, licenses, awards and prizes, fellowships and scholarships; educational activities completed, portfolio, projects, case studies, papers, reviews, tasks, exams and results, performances, experiments, simulations, constructions, presentations, knowledge transfer, tutoring, teaching, participations (engagement) and contributions (e.g., to blogs, forums, Wikis, social networks), collaborations, sharing, negotiations, conflict resolutions, management, supervision, guiding, organising and planning
Preferences	Autonomy and control (choices: by self, by teacher, collaboratively, etc.); preferable input and output means (choices: speech, text, keyboard, mouse, pen, handwriting, graphics, animation, video, etc.); preferable environment conditions: temperature, light, noise, etc.; preferable physical space (choices: around table, amphitheater, out-doors, walking, etc.), cognitive space, emotional space, social space, etc.; preferable media (choices: audio, text, photos, graphics, animation, video, 3D, etc.); aesthetics, lifestyle, etc.; preferable educational activities, assessment types; preferable communication mode: 1. synchronous (choices: face-to-face, phone, chat and video conference) – 2. asynchronous (choices: e-mail, SMS, MMS, IM, podcast, forums and social networks), people to communicate and/or collaborate, communication frequency, group population, group homogeneity; privacy, non-intrusion, confidentiality; etc.
Favourites	Educational subjects, teachers, mentors, tutors, partners, scientists, artists, famous persons, educational resources, books, songs, websites, blogs, social networks, etc.
Interests	Interests regarding education, art, profession, etc.
Objectives, goals and aims	Objectives, goals and aims regarding learning, career and life
Health	Level of fitness, vision (clear vision, loss of centralised vision, tunnel vision, partial/poor vision, poor acuity, night blindness, colour blindness, complete blindness, etc.), hearing, speech, blood, heart, chronic and temporal illnesses, prescribed drugs and medicine, etc.
Current biological and physiological needs	Urgent needs regarding air, food, drink, shelter, warmth, sleep, etc.
Physical abilities	Weight, height, level of physical abilities and disabilities (hand or arm movements' problems, muscle weakness or involuntary movement, tremor, loss of fine motor control, etc.)

Table 1 Dimensions of learner's state (continued)

Dimensions of learner's state	*Variables of each dimension*
Cognitive abilities	Level of cognitive abilities: working memory capacity; sub audition, writing, logical; mathematical; critical thinking; inductive reasoning; associative learning, reflective thinking, organising, space orientation, perceptiveness, etc.
	Level of cognitive disabilities: dyslexia; attention deficit disorder; intellectual and memory impairments, etc.
Social abilities	Level of communication skills (written and oral), knowledge transfer, negotiation, conflict resolution, management, supervising, etc.
	Level of active (extrovert, social and expressive) – passive (introvert, loner and shy); cooperative (sharing, helpful, altruist and generous) – competitive (selfish, individualistic and greedy); leader (dominating and influential) – follower (dependent); open (equitable, fair, accepting and tolerant) – discriminating (biased and rejecting); adaptable – inflexible; responsible (reliable, honest, trustworthy and trustable) – careless (unreliable and liar); friendly (positive, conflict avoidance and polite) – hostile (negative, disagreeable and impolite)
Cultural abilities	Level of power distance; collectivism – individualism; femininity – masculinity; uncertainty avoidance; long-term – short-term orientation, OR
	Level of universalism – particularism; communitarianism – individualism; neutral – emotional; defuse – specific culture; achievement – ascription; human-time relationship; human-nature relationship
Feelings and emotions	Level of enthusiasm (fascination, excitement, passion and involvement) – boredom (apathy); happiness (joy, delight, pleasure and amusement) – sadness (melancholy, sorrow and depression); satisfaction (fulfillment); calmness (tranquility, serenity, peacefulness, comfort and relaxation); anger (irritation, indignation and upset); anxiety (stress and nervousness); frustration (despair, hopelessness and panic); fear (concern, worry and doubt); confusion; hope (optimism) – pessimism (defeatism and self-pity); expectancy (anticipation, certainty, assurance and acceptance) – astonishment (amazement and negative surprise); sympathy (love) – disgust (aversion); hate; pride (honour) – shame (guilt, humiliation, embarrassment and dishonour)
Motivation and conation	Level of self-awareness (self-consciousness) – self-ignorance; interest (will and volition) – disinterest; self-efficacy (self-esteem, confidence) – self-doubt (insecurity); motivation – discouragement; self-direction (goal-orientation) – disorientation (distraction, un-focusing and inattention); commitment (dedication, determination and persistence) – reluctance (hesitance); self-regulation – disorganisation

Table 1 Dimensions of learner's state (continued)

Dimensions of learner's state	*Variables of each dimension*
Learning styles	Level of active – reflective; sensing – intuitive; visual – verbal; sequential – global, OR
	Diverger (concrete experiencer/reflective observer); converger (abstract conceptualiser/active experimenter); accommodator (concrete experiencer/active experimenter); assimilator (abstract conceptualiser/reflective observer)
Cognitive styles	Level of field dependent (global) – field independent (analytic); left brain (logical, sequential, rational, analytical, objective, look at parts) – right brain (random, intuitive, holistic, synthesising, subjective, look at whole)
Intelligence	Level of visual (spatial); verbal (linguistic); bodily (kinesthetic); logical (mathematical); musical (rhythmic); interpersonal; intrapersonal; naturalist
Personality	Level of extraversion – introversion; confidence – sensitive; detail-conscious – unstructured; tough-minded – agreeable; conforming – creative
People (related to), their roles and relationships	Family, relatives, friends, partners, classmates, colleagues, associates, teachers, mentors, tutors, neighbours, social networks' peers, etc.
Time and schedule	Calendar, time table, agenda, scheduled activities, to-do-list, bookings, reservations, acceptable variations (+/– time), low and upper time limits, deadlines, etc.
Location	Position [measurement choices: satellite (e.g., GPS, Galileo)], cellular (e.g., cell-ID), indoor [e.g., radio frequency identification (RFID), infrared beacons], etc.; elevation; type (choices: classroom, library, computer laboratory, home, café, corridor, street, outdoors, etc.)
Mobility	Choices: sitting, standing, waking and stopping, walking on a path, looking/searching for something, wondering around, running, bicycling, driving car, etc.; speed, acceleration, direction, orientation, etc.
Restrictions and constraints	Costs and pricing, privacy, non-intrusion, confidentiality, safety, accessibility (special needs persons), time (upper and lower limits, deadlines), locations to avoid, geography (boundaries), people to avoid, activities to avoid, food to avoid, etc.
Current status	Availability [choices: online and available, online and busy (not available), offline until 'time/date', on vacations, etc.]; location; mobility; educational activities' progress; connected people, devices, etc.

5.2 Educational activity's state

The educational activity (A) would be either a 45 minutes class composed from several modules (e.g., motivation, example, theory, application and discussion) or a single module. The educational activity's state is defined to consist of the following dimensions: 'identification, subject, keywords, educational level, requirements and prerequisites, technical requirements, type, participants, purpose, expected educational outcomes,

learning theory, instructional design, management, content, presentation and media, sequencing, feedback, communication and collaboration, assessment, resources and connection, pricing and costs, and current status' (Table 2). Each one of these dimensions consists of variables. Some of these dimensions and variables are fixed, some can change (being adaptable) and some can be either fixed or adaptable (depending on the design). For example, fixed variables would be declared by the authors. Attractive candidate dimensions for adaptations include the type, participants and teams, management, presentation and media, sequencing, feedback, communication and collaboration, assessment and resources.

Table 2 Dimensions of the educational activity's state

Dimensions of educational activity's state	*Variables of each dimension*
Identification	ID, title, authors, languages supported, owner, administrator, address (e.g., url), size, date created, dates modified, usage history, evaluations (reviews, ratings, popularity, recommendations, usefulness, learners' satisfaction, etc.), users, access rights, etc.
Subject	Specific subject, relevant subjects, follow-on subjects, super-subject where it is included, sub-subjects that includes, etc.
Keywords	Classification according to various formal indexes, tags (social tagging) by users (teachers, learners, etc.)
Educational level	Appropriate for learners at given educational level
Requirements and prerequisites	Educational level requirements; prerequisite subjects; age requirements; abilities (cognitive, social, affective, conational and physical) requirements; difficulty level; time requirements; etc.
Technical requirements (*would be adaptable*)	*The A would run on and use various systems:* hardware (PC, laptop, notebook PC, personal digital assistance, smart phone, etc.) and other devices; operating systems (Windows Mobile, Palm OS, Symbian OS, iPhone OS, BlackBerry OS Android, etc.); browsers (Internet Explorer Mobile, FireFox Mobile, Opera Mini, Safari, PlayStation Portable, Nokia Browser, Blazer, etc.) and other applications software; multimedia format (AIFF, WAV, XMF, MP3, QuickTime, FITS, TIFF, 3GP, ASF, DivX, MPEG, GIF, WMV, AVI, MOV, Real Media, etc.); networks (RFID, IrDA, Bluetooth, WiFi, WiMax, UMTS, UWB, 4G, satellite, etc.), bandwidth requirements, quality of service (QoS), etc.
Type (*would be adaptable*)	*The A would be one or more of the following types:* summary, introduction; example, case study; review, critique, comparison, evaluation; hands-on experience, practice, application; theory, concept, model; dialogue, conversation, discussion; debate, negotiation; exploration, discovery; simulation; experiment; presentation; cooperation, collaboration; game; assignment, assessment, exercise, test, exam, etc.
Participants and teams (*would be adaptable*)	People (e.g., peers, teachers and tutors) and/or avatars participating, their roles and relationships; teams created, activities per team, relationships among teams, members per team, members' roles and relationships, connection to the state of each member, etc.

Table 2 Dimensions of the educational activity's state (continued)

Dimensions of educational activity's state	*Variables of each dimension*
Purpose	Diagnosis and identification of prior knowledge, activation of prior knowledge, monitoring learner's progress, revision of prior knowledge, enrichment of prior knowledge, acquiring and comprehending new knowledge, evaluating learner, classifying and ranking learner, motivating learner, abilities (cognitive, social, affective, conational and physical) enhancement, etc.
Expected educational outcomes	*The expected educational outcomes of the A would be one or more of the following:* cognitive domain: knowledge, comprehension, application, analysis, synthesis, evaluation; affective domain: receiving, responding, valuing, explaining, organising, characterising; psychomotor domain: imitation, manipulation, precision, articulation, naturalisation; conational domain; social domain; physical domain
Learning theory	*The A would be based on one or more of the following learning theories:* behaviourism – cognitivism – constructivism: active learning, project-based learning, experimental learning, discovery learning, authentic learning, situated learning, cooperative/collaborative learning, social learning, game-based learning, etc.
Instructional design	*The A would be based on one of the following instructional design models:* analyse, design, develop, implement, evaluate (ADDIE); introduction, connect, apply, reflect, extend (ICARE); lecture, application, discussion, reflection (LADR)
Management (*would be adaptable*)	*The A would be managed by:* learner (self-learning) – teacher/tutor (guiding) – coach (mentoring) – peer (cooperating and collaborating) – computer (automatic); time management (duration, scheduling, deadlines, etc.), time per module, events scheduling, etc.
Content (*would be adaptable*)	*The content of the A would vary with respect to:* quantity (details), depth and difficulty; educational subject's theories (e.g., opposing scientific, art, social, political and philosophical ideas and views); language, etc.
Presentation and media (*would be adaptable*)	*The presentation of the A would vary with respect to:* format (font size, page layout, colours, etc.); media (text-based, audio-based, graphical-based, video-based, immersion-based, etc.); media quality (resolution, colours, refresh rate, sound fidelity, video frame rate, etc.); special needs persons consideration (zooming, text-to-speech, etc.)
Sequencing, organisation and navigation (*would be adaptable*)	*There would be alternative mechanisms of the content modules' sequencing, organisation and navigation:* alternative menu levels; sequential (serial and inductive) path – all-at-once (global) view; short path – regular path – extended path; shortcuts; next module depends on learner's results from previous module; etc.

Table 2 Dimensions of the educational activity's state (continued)

Dimensions of educational activity's state	*Variables of each dimension*
Feedback (*would be adaptable*)	*The feedback of the A would vary with respect to:* given by real person or avatar, quantity (amount), activation reason and time, frequency, duration, goals, etc.;
	There would be alternative feedback types: informational: advise on content, help on assessment, support on collaboration, etc.; alert: reminder on deadlines, warning on danger, etc.; affective/emotional: sympathy, acceptance, positive surprise, etc.; motivational: attracting learner's attention, challenging, provoking, building self-confidence, assuring, encouraging, praising, etc.
Communication and collaboration (*would be adaptable*)	*The communication and collaboration of the A would vary with respect to:* synchronous (face-to-face, phone, chat, videoconference, etc.) – asynchronous (e-mail, SMS, MMS, IM, podcast, forum, discussion board, blog, Wiki, etc.); sharing and downloading; one-to-one – one-to-many – many-to-many; learner-to-learner – teacher-to-learner – learner-to-avatar; formal – informal; visual – oral; quantity and frequency of communication; collaboration – competition; etc.
Assessment (*would be adaptable*)	*There would be alternative assessment types:* self-assessment, peer-assessment, collaborative assessment, formal exam; questions, report, project, application, construction, experiment, simulation, presentation, performance, discover, etc.
Resources and connection to them (*would be adaptable*)	References, bibliography, alternative views and opinions, complementary educational activities, less/more advanced educational activities, less/more detailed same educational activities, relevant educational activities, extensions, FAQ, glossary, dictionary, etc.
Pricing and costs (*would be adaptable*)	*There would be alternative pricing and cost modes with respect to:* content, media used, resources used, tutor-support, etc.
Current status	Time elapsed and time remaining; content covered and content to be covered; resources used/reserved and available resources; feedback given; results achieved and results expected; current participants status; current presentation and media mode; current communication and collaboration mode; cost charged and remaining; etc.

The adaptations would be performed at the beginning of the A or 'on the fly' during its operation. Of course, it is easier to perform a single adaptation for all adaptable dimensions and variables just before the beginning of the A. However, it is more challenging, but complicated to perform adaptations during the operation of the A. For example, every time the learner answers correctly (wrongly) a question, a harder (easier, correspondingly) question would appear during assessment (Triantafillou, 2008a, 2008b). Similarly, feedback would support the learner during various steps of the A (Economides 2005a, 2006b). In order to decrease the complexity of the adaptive decision space, one would consider adaptations across only a few dimensions and variables.

The dimensions of expected educational outcomes, learning theory and instructional design are interrelated and various models have been proposed to describe them. Regarding the expected educational outcomes, we choose to adopt and extend Bloom's

(1956) taxonomy. Regarding the instructional design, we choose to adopt ADDIE and ICARE (Dick and Carey, 1978) models. Regarding the feedback dimension, we adopt the feedback attributes and the personalised cognitive, emotional and conational feedback types proposed by Economides (2005a, 2006a, 2006b). Regarding the communication and collaboration dimension, we adopt parameters proposed by Economides (2008c).

The A is connected to other A's via the dimensions of subject, keywords, resources and current status. It is connected to learners via the dimensions of participants and teams and current status. It is connected to infrastructure and environment via the resources' dimension.

At the end of the A's operation, the learner's final results that were recorded in his current status and the A's current status are transferred to his results and achievements dimension.

5.3 Infrastructure's state

We define the infrastructure's state to consist of the following: 'devices, networks, other hardware and software resources, and other adaptable activities in the vicinity of the learner' (Table 3). We describe each device's state to consist of the following dimensions: 'identification, type, location, schedule, availability and current status, aesthetics, input and output, user interface, software and multimedia, energy consumption, performance, connectivity to other resources, network connectivity, security, pricing and costs'. We describe each network's state to consist of the following dimensions: 'ID, availability and current status, protocols, location and topology, connectivity to other networks, bandwidth and QoS, security, pricing and costs'. Each one of these dimensions is described by many variables. For example, various pricing methods could be available (Sismanidis and Economides, 2007). We adopt various devices parameters from Economides and Nikolaou (2008) where handheld devices were evaluated with regards to mobile learning.

Table 3 Dimensions of the infrastructure's state

Dimensions of infrastructure's state	*Variables of each dimension*
For each device	
Identification	ID, owner, users (people and avatars), access rights, restrictions, etc.
Type	Server, PC, laptop, notebook PC, personal digital assistance, smart phone, sensor, etc.
Location	Position, mobility (e.g., device on car), etc.
Schedule	Reservations by users, avatars, etc.; scheduled activities
Availability and current status	Current users; current position; available (remaining) processing power, memory, energy (battery life), etc.; connectivity to other devices and networks, etc.; activities' history, software running; results achieved and expected; cost charged and remaining; available bandwidth, etc.
Aesthetics (*would be adaptable*)	*There would be alternatives with respect to:* design; size; colours, etc.

Table 3 Dimensions of the infrastructure's state (continued)

Dimensions of infrastructure's state	*Variables of each dimension*
For each device	
Input and output (*would be adaptable*)	*There would be various alternatives:* antenna, touchpad, keyboard, light pen, pointing stick, trackball, joystick, touch screen, interactive whiteboard, scanner, data probes, OCR, smart card reader, odometer, altimeter, barometer, compass, global navigation satellite system (GNSS), sensors (light, temperature, humidity, motion, acceleration, etc.), screen (size, resolution, etc.), photo and video camera, microphone, speakers, special needs persons facilities, etc.
User interface (*would be adaptable*)	*There would be various alternatives:* windows, buttons, lists, menus, icons, tree, 3D immersion, etc.
Software and multimedia (*would be adaptable*)	*There would be various alternatives:* operating systems (Windows Mobile, Palm OS, Symbian OS, iPhone OS, BlackBerry OS, Android, etc.); browsers (Internet Explorer Mobile, FireFox Mobile, Opera Mini, Safari, PlayStation Portable, Nokia Browser, Blazer, etc.); database management systems; search tools; geographical information systems (GIS); drawing and computer-aided design tools; communication tools; presentation tools; dictionaries; translators; calculator; calendar; planner; organiser; other applications software; multimedia format (AIFF, WAV, XMF, MP3, QuickTime, FITS, TIFF, 3GP, ASF, DivX, MPEG, GIF, WMV, AVI, MOV, Real Media, etc.); languages; communication protocols; special needs person tools, etc.
Energy consumption (*would be adaptable*)	*There would be alternative power modes:* power save, economy, regular, etc.
Performance (*would be adaptable*)	*There would be alternative modes for the following:* processing speed, memory, antenna ranges and transmission rates
Connectivity to other resources	Connected to databases, portals, devices, sensors, etc.
SW interoperability	SW interoperability and compatibility, portability to other devices
Network connectivity (*would be adaptable*)	Connected to networks (using RFID, IrDA, Bluetooth, WiFi, WiMax, UMTS, UWB, 4G, satellite, etc.)
Security (*would be adaptable*)	*There would be alternative levels of* security
Pricing and costs (*would be adaptable*)	*There would be alternative levels of pricing and costs with respect to:* usage (duration, processing, memory, energy, etc.), area, time/date, resources (databases, software, applications, etc.)

Table 3 Dimensions of the infrastructure's state (continued)

Dimensions of infrastructure's state	*Variables of each dimension*
For each network	
Identification	ID, owner (carrier, provider and operator), users (people and avatars), access rights and restrictions
Availability and current status	Current coverage; current users (devices); available bandwidth; current QoS; current connectivity to other networks; etc.
Protocols (*would be adaptable*)	*There would be alternative protocols at all layers for interoperability*, e.g., WIMAX, GSM, GPRS, HSCSD, CDMA2000, UMTS, HSDA, 3GPP, UMB
Location and topology	Nodes' locations and interconnections (links)
Connectivity to other networks	Interconnection to other networks (WiFi, WiMax, UMTS, UWB, 4G, satellite, etc.)
Bandwidth and QoS (*would be adaptable*)	*There would be alternative levels of* bandwidth, average delay, jitter, loss ration, reliability, etc.
Security (*would be adaptable*)	*There would be alternative levels of* security
Pricing and costs (*would be adaptable*)	*There would be alternative levels of pricing and cost with respect to:* usage (duration, time/date, area, participants, etc.), offered QoS, etc.
Other hardware and software resources	*Description of each resource*

5.4 Environment's state

Finally, we define the environment's state to consist of the following dimensions: 'terrain, weather and environment's conditions, sensors, neighbours (not participating in the educational activity) and other external activities' (Table 4). Each one of these dimensions consists of variables.

Table 4 Dimensions of the environment's state

Dimensions of environment's state	*Variables of each dimension*
Terrain	Morphology, mapping, altitude, indoors: rooms, corridors, furniture, seats, desks, doors, etc.; urban: buildings, streets, cross-sections, parks, bridges, etc.; rural: houses, alleys, grasslands, trees, fencings, etc.; wilderness: paths, forests, mountains, rivers, lakes, sea, etc.
Weather and environmental conditions	Sun, rain, snow, temperature, humidity, wind speed, etc.; light, sounds (noise), air quality (pollution)
Sensors	Sound, photo, video, motion, position, temperature, etc.; real-time locating systems (RTLS), RFID, GNSS (GPS, Galileo, etc.)
Neighbours	People and devices not participating in the educational activity
Other external activities	*Description of each activity*

6 Conclusions and future research

The paper presents a general framework for adaptive context-aware pervasive and ubiquitous learning. The mobile learner learns and performs an educational activity using various devices, networks and resources as he moves in an environment. He is supported by an adaptation engine that adapts the educational activity and/or the infrastructure. The goal is to help the mobile learner, to increase his satisfaction and learning, to decrease his limitations and restrictions in order to be unconcernedly engaged in learning.

The presented framework may help designers and developers of pervasive and ubiquitous learning systems at their decisions. It may help them to identify requirements, open problems, challenges and opportunities, to share ideas and methods, to take a holistic approach in developing systems and thoroughly evaluate them. This paper formulates the adaptive context-aware pervasive and ubiquitous learning system as a system of an adaptation engine with input and output. The adaptation engine may employ deterministic or probabilistic adaptation decisions. The input to the adaptation engine is the learner's state, the educational activity's state, the infrastructure's state and the environment's state. The output is the adapted educational activity and/or infrastructure. For example, the adaptation engine may present to the mobile learner adapted content and media according to his current position and available networks. In addition, it would locate other learners in his vicinity to form a team and perform a collaborative activity.

Hopefully, this study would stimulate future research and development efforts. The ultimate goal would be the implementation of adaptation engines that use the full context and produce the full adapted educational activity and infrastructure, as presented in the context model section.

By describing each state (learner, educational activity, infrastructure and environment) by many dimensions and variables, not only the accuracy of the context is increased, but also its complexity and the requirements to collect data. A harmonious integration of all these input data is an open research problem. There should be a balance between the number of dimensions and variables, model complexity and the accuracy of the model. Furthermore, identifying the relative importance of the dimensions of each state (learner, educational activity, infrastructure and environment) is an open research problem. Similarly, identifying the relative importance of the variables of each dimension is an open research problem.

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