Adaptation of Learning Spaces: Supporting Ubiquitous Learning in Higher Distance Education

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Abstract. Ubiquitous learning is supported by ubiquitous computing and represents the next step in the field of e-learning. The goal is, that learning environments will be accessed increasingly in various contexts and situations. From this challenge, new questions arise concerning the adaptation of learning spaces to different contexts of use, so that they continue to enable and support learning processes. As a basic work in this direction, this paper introduces a first notion of a comprehensive definition of 'plasticity of digital learning spaces'. It exemplifies some of the facets affecting the plasticity and presents aspects of a first system prototype, which enables to select learning materials depending on a given situation.

1 Introduction

Ubiquitous learning is the next step in performing e-learning and by some groups it is expected to lead to an educational paradigm shift, or at least, 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, it enables seamless combination of virtual environments and physical spaces.

The focus of our research in the field of ubiquitous learning is affected by our experiences in teaching at a distance university for higher education. Starting from the vision of ubiquitous computing, we tackle the issue of supporting learning processes while the learner makes use of ubiquitous computing technology. By this we follow a slightly different research direction, since most other work deals with the fundamental question of how to utilize ubiquitous computing technology to enhance learning processes. In this contribution we present our steps towards the plasticity of digital learning spaces, the objective of which is the adaptation of learning resources to different contexts of use, so that they continue to enable and support learning processes.

The structure of the paper is as follows: In the rest of this chapter the terms ubiquitous computing and learning are presented. Since the web has become the predominant platform for realizing learning spaces, the focus within this paper is on web-based learning. After a brief overview of existing approaches to adaptation (chapter

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2), chapter 3 introduces the author's work towards the definition of plasticity of digital learning spaces. The paper discusses different facets to be considered in implementing plastic digital learning spaces, presents in chapter 4 a first prototype and concludes in chapter 5 with the current state of work.

1.1 Ubiquitous Computing

The term ubiquitous computing, as coined by Mark Weiser, refers to the process of seamlessly integrating computers into the physical world. As a researcher at Xerox PARC, he described in the late 80s and the early 90s his vision for the next generation of computing. He pointed out, that "the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it." (Mark Weiser, 1991) The desktop computer will be replaced by computing embedded in physical objects of everyday life, by which these are not detracted from their original functionality but enhanced by computing. Besides this kind of physical disappearance, ubiquitous computing also comprises mentally disappearance. In the latter case computers can still be there but the user perceives them as, for example, interactive walls or interactive tables (Streitz & Nixon 2005), or still as laptops, personal digital devices like the electronic whiteboard, palm pilot, digital cameras, mobile phones, PDAs, etc.

Many research and industry groups are engaged in ubiquitous computing, each focusing on special aspects. Over the years slightly different definitions of ubiquitous computing arise emphasizing selected aspects, e.g., technical infrastructure and/or context awareness. Notions like pervasive computing, proactive computing and ambient computing are introduced to stress the particular direction of a work and project, respectively, but are also used synonymously with 'ubiquitous computing'. Regardless of the term used, research focus is on the disappearing artefact, and the environment and situation within which people experience it. Like, for example, in the case of driving a car, where mentally and physically the engine disappears. People simply drive the vehicle to a destination, considering the way to reach it and the physical environment - but normally not thinking about the engine itself, how it works or is constructed. Similarly, people don't need computing at all - they need the information, functions and services to perform their tasks. This is not a totally new issue in computing, e.g., the desktop metaphor and the concept of direct manipulation (Shneiderman 1992) were introduced to excuse the user from paying too much attention to technical aspects – the desktop computer, however, remains in the foreground. With the disappearing computer, but ubiquity of computing, supporting the user with the right information and services at the right time and place in the right way is a new, far more challenging and complex issue than in the case of traditional applications.

1.2 Ubiquitous Learning

Ubiquitous computing leads to ubiquitous learning allowing to embed individual learning activities in everyday life. Hereby, a learning activity is "… not constrained by schedules and physical spaces; rather, it is pervasive and ongoing, prevalent in many interactions among students, faculty, parents, administration, staff, a wide variety of community stakeholders, etc." (Prometeus 2001). The main characteristics of ubiquitous learning are (Ogata, H.; Yin, C.; Yano, Y.: referencing Chen et al., 2002; Curtis et al., 2002):

- Permanency: Learners can never lose their work unless it is purposefully deleted. In addition, all the learning processes are recorded continuously everyday.
- Accessibility: Learners have access to their documents, data, or videos from anywhere. That information is provided based on their requests. Therefore, the learning involved is self-directed.
- Immediacy: Wherever learners are, they can get any information immediately. Therefore learners can solve problems quickly. Otherwise, the learner may record the questions and look for the answer later.
- Interactivity: Learners can interact with experts, teachers, or peers in the form of synchronous or asynchronous communication. Hence, the experts are more reachable and the knowledge is more available.
- Situating of instructional activities: The learning could be embedded in our daily life. The problems encountered as well as the knowledge required are all presented in their natural and authentic forms. It helps learners to notice the features of problem situations that make particular actions relevant.
- Adaptability: Learners can get the right information at the right place in the right way.

Currently, ubiquitous learning is performed in diverse educational settings and investigated in different directions, focusing, e.g., on pedagogical or technical issues, using it in classrooms or to support outdoor studies to overcome the restrictions of traditional environments. Early applications of ubiquitous learning were tourist and museum guides, by means of which a visitor gets information based on his current position, e.g., facts about a painting he is standing in front of. The Electronic Guidebook is an example of a system by which this concept is further elaborated. It combines a physical hands-on museum with a web-based system, which not only delivers text, images, digital audio and video, but in addition enables the visitor to construct a personal record of his visit by bookmarking exhibit content, taking digital pictures from a camera near the exhibit, and accessing this information later on (His 2002). Another "typical" application area of ubiquitous learning is computer supported language learning, where students are provided with the vocabulary they need in a current situation. In (Ogata, H.; Yin, C.; Yano, Y.), for example, a context-aware support system for learning polite Japanese expressions is presented. Aiming at support of outdoor activities the Ad Hoc Classroom system enables teacher and students to establish a virtual classroom dynamically irrespectively of location and time bounds (Chang and Shu 2002).

In most ubiquitous learning approaches the physical environment is directly (semantically) related to learning objectives and activities (e.g., the museum visitor gets information each time based on his current location). Information and services are "brought" to the environment and/or situation they "belong to". The fundamental question is how to utilize ubiquitous computing technology to enhance learning processes. In our own research the investigation follows a slightly different direction:

How to support learning processes while the learner makes use of ubiquitous computing technology? Which learning material, for instance, should be provided to a student while he is sitting in a noisy lounge in front of an interactive desk?

The motivation for our work arises not only from the challenging field of ubiquitous learning but also from our background of teaching at a university for distance education and the situation of our students. Most of them are already employed or bring up children, so that learning independently from time and location is of fundamental importance. Students frequently get into unplanned situations with spare time they could use for learning if only they had learning material at hand or had access to their learning group. People have to wait in a doctor's waiting room or public lounges; part-time students working as salesmen spend a lot of time driving from one customer to another either by train or by car. In many cases these situations are not predictable, but in most cases these persons carry a mobile device with them – and like to use it for their studies. In the future, following the developments in the field of ubiquitous computing, students will not only learn by means of desktop and mobile PCs but also by means of a set of diverse local and mobile devices based on ubiquitous technology. In such situations, learning material is not semantically (although it could be) related to the physical environment. Basic concepts of Databases, for example, are not related to a hotel lounge. Nevertheless, the environment will probably have an impact on the learning experience because of, e.g., noisy surroundings distracting a student from concentration.

2 Approaches to Adaptation

As Fischer pointed out, the challenge is not only to make information available to people at any time, at any place, and in any form, but specifically to say the right thing at the right time in the right way (Fischer, 2001). 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. Thus, adaptation according to context information is indispensable to all kinds of learning activities in ubiquitous learning environments.

A comprehensive and systematic approach to adaptation to a variety of different environmental conditions is needed. Our approach to this is the realization of 'plasticity of digital learning spaces'. Since the web has become the predominant platform for realizing such spaces, the focus within this work is on web-based learning. Before introducing the concept of plastic learning spaces, a brief overview of existing approaches to adaptation is given.

2.1 Ubiquitous Web Applications

The development of ubiquitous web applications involves adaptation not only to different kinds of devices, but also to, e.g., network, location and time. Kappel and her colleagues (Kappel et al. 2002), for instance, proposed a framework, within which the generic model for describing contexts is divided into a physical and a logical model. The physical context model specifies characteristics being outside of the control of ubiquitous web applications, i.e., characteristics which can not be affected by adaptation. This model comprises properties of location, time, device, browser, network, and the user. The logical context model is defined by enriching the semantics of the physical model for the purpose of customization. While, for example, locations within a physical context model may be described by cell IDs, they may be described in the logical context model by postal addresses.

The context model also describes information about an application itself as its states may influence adaptation. If the completion of a task, for example, is not successful this may constrain subsequent execution of further tasks. The part of the model related to the application dependent aspects is not elaborated in (Kappel et al. 2002), thus the proposed framework has to be expanded by the application relevant context descriptions. These supplementations can not be specified generally for all ubiquitious learning applications since the diverse kinds of learning systems impose different requirements on adaptation (see also Ahonen, Syvänen & Vainio 2005).

2.2 Adaptive and Intelligent Web-based Educational Systems

Adaptation in the field of e-learning has been investigated for decades. As pointed out by Brusilovsky and Peylo (Brusilovsky & Peylo 2003), adaptive and intelligent web-based educational systems "… attempt to be more adaptive by building a model of the goals, preferences and knowledge of each individual student and using this model throughout the interaction with the student in order to adapt to the needs of that student. They also attempt to be more intelligent by incorporating and performing some activities traditionally executed by a human teacher – such as coaching students or diagnosing their misconceptions." Hereby, adaptive educational systems, which deal with adaptive presentation and navigation, are integrated with intelligent educational systems, which focus on curriculum sequencing to guide the learner through the digital learning space (hyperspace), intelligent solution analysis dealing with the learners' solution of educational problems, and problem solving support interactively providing the learners with help on each step of problem solving. In those systems the digital learning space is adapted to the learners, i.e., each individual student is provided with his personal digital learning space, under the tacit assumption that all students access the space by means of a standard browser running on a PC. With the increasing spread of mobile and wireless devices adaptation has to overcome this limitation. Doing so, more characteristics of the environment than only the properties of the devices have to be considered.

2.3 Adaptation of User Interfaces

Adaptive learning systems have been dealing with adaptation of the content presented in each page and with changing the appearance of visible links according to the student model (Brusilovsky & Peylo 2003). Their main focus is on what can be adapted in terms of presentation and navigation, while in developing ubiquitous web application the emphasis is on describing the context. In addition, adaptation of the user interface has to be of special interest since this is the part by which a digital learning space is accessed. In general, usability is a key factor for acceptance of an interactive system, and thus for educational systems. The results of different studies document the importance of usability for a successful learning process (which is not astonishing from the view of usability engineering and related fields). With the spreading use of mobile devices, adaptation of the user interface to support multiple platforms is again challenging in UI development. In the CAMELEON project (Thevenin & Coutaz 1999), for example, a framework was developed for dynamic UI adaptation. It covers properties of the context, which are directly relevant for interface customization in general, and is not specialized for the purpose of web based systems, particularly, not for the purpose of educational systems. Furthermore, aspects of the underlying functionality and thus the aspects of utility and semantic relevance, respectively, are not regarded in the approach.

3 Plasticity of Digital Learning Spaces

The overview above shows the complexity of realizing digital learning spaces that meet up-to-date requirements. An integrated approach with stress on ubiquitous web-based education is needed, so that a digital learning space can be utilized in different contexts without losing its most important property, the property of supporting learning processes. This capacity is described by the term “plasticity”, which includes different facets of context and adaptation.

3.1 The Meaning of Plasticity

The term plasticity of digital learning spaces (Bomsdorf 2005) is motivated by that of plastic user interfaces (Thevenin & Coutaz 1999). Both definitions make use of the similarity of the desired properties of the learning space and user interface, respectively, with that of a shapeable material. Applied to e-learning, plasticity describes the ability of a digital learning space to retain suitability for learning in different, changing contexts (context of learning). This definition is beyond plasticity of user interfaces, which denotes the capacity of a user interface to withstand different contexts of use while preserving usability. In addition to UI adaptation, plasticity of digital learning spaces takes into account selection and/or adaptation of learning material (content), functionalities, services and tools. Furthermore, the notion of plastic digital learning spaces exceeds the measurement criteria by considering not only usability but also usefulness. Key terms of the definition ‘plasticity of digital learning spaces’ are ‘space’, ‘context of’ and ‘suitability for learning’:

3.1.1 Digital Learning Space

In the stricter sense, a digital learning space is a configuration (or repository) of concrete digital learning objects, i.e., of any piece of digital material for the purpose of learning. Web-based educational systems realize such a learning space by a net of interlinked web resources. In a broader sense, it is defined also by functions, services, and tools of a learning environment, comprising components related to communication and collaboration that focus on the process of social knowledge building and sharing. In this meaning a digital learning space integrates a digital repository with a computer supported cooperative learning (CSCL) environment.

3.1.2 Context of Learning

In general, a context describes circumstances under which something exists or occurs, as well as the interrelations of those circumstances. The model describing the context of learning includes all aspects characterising the situation within which a digital learning space is used to perform learning activities, and which are relevant to adaptation. Both the space and the learner take different parts in adaptation. The space, on the one hand, is adapted to different contexts, and on the other hand, it is part of the context, e.g., its state and configuration, respectively, may influence customization. The learner is in the role of a user using the learning system and accessing the space to reach learning goals and to perform related activities. Regarded from the "view" of the digital learning space and its adaptation, the learner is part of the context being described by a user model and a student model[1]. In adaptable and semi-adaptable systems the learner takes an active role in the adaptation process deciding about and directing adaptation. The learner plays an additional, important role in determining criteria of plasticity because these are based primarily on the learners' experiences in using the space for learning activities.

3.1.3 Suitability for Learning

Since a plastic learning space has to preserve its property of learning suitability, the question arises how an adaptation can guarantee this property. First of all, as argued above (see section 3), criteria of usability have to be applied. In addition, utility, i.e., suitability for learning, has to be considered. There are different definitions of learning; often it is described as an "internal" (cognitive or mental) process of a person, which cannot be observed itself but by the changes in the learner's behaviour caused by the learning process. This process occurs not in isolation but in a social context. Since the process differs for the students, similarly to usability, learning suitability can be considered as mainly a function of the learners interacting with and by means of a learning space. For a concrete context it relates to the impact a special (adapted) learning space has on an individual learner. Defining an appropriate set of criteria is an open issue. Investigations in this direction are undertaken in the field of mobile learning, reported, for example, in (Syvänen & Nokelainen 2004).

3.2 Context-Aware Adaptation

In different publications (for example in (Kappel et al. 2002) and (Brusilovsky & Peylo 2003)) classifications and overviews of aspects relevant for adaptation have

[1] While a user model describes more general properties of the learner, e.g., computer literacy, the learner model includes properties associated with his learning processes, e.g., current knowledge, misunderstandings, styles and strategies of learning.

been given. This is not reviewed here; instead, in the following, an overview is given of context information and adaptation techniques which are considered basically in our first steps towards plastic digital leaning spaces.

3.2.1 Context information

Information describing the context can be divided roughly into technical aspects, physical environment and facets of learning. Technical aspects are captured by profiles containing information about infrastructure such as networks, bandwidth and specifications of the end user device. Properties of the physical environment describe the surrounding of learning activities, such as objects, persons, events (Thevenin & Coutaz 1999), which are peripheral to the learning activities but affect the learner's behaviour or influence the learning process. Facets of learning are described by attributes defined within didactic analysis and planning such as learner's qualifications and requirements, taxonomy of instructional/learning goals, methodology of teaching, and communication/collaboration settings, learner's progress and learning history (Becking et al. 2004, Cui & Bull 2005).

The non-technical aspects strongly influence the process of learning in mobile scenarios and the selection of learning resources and services. For example, the attribute *Frequency of Interference* describes the frequency of interferences during a learning session, e.g., when sitting near the door in a cafeteria, while the attribute *Level of Concentration/Distraction* reflects the learner's self evaluated ability to keep concentration in spite of environmental interferences.

3.2.2 Adaptation techniques

Adaptation of a digital learning space requires realization of different techniques, examples of which are:

- Content filtering: Depending on the learning situation the learning content is selected and presented to the learner. For example, a student sitting in a café may want to perform some learning task using his smart phone to access the learning space. If the frequency of interference is high and the concentration level is low it makes no sense to provide him the content of a complicated mathematical proof – even if the content is "small" enough to be presented on a small display.
  In a similar way as the shape of real plastic material can not be retained under all conditions, the learning space is not fully adaptable to arbitrary learning contexts, as shown by the café example. Hence, content filtering may be used for selection of content as well as for the decision of "hiding" content if it is considered inappropriate for learning under the given conditions.
- Application filtering: Depending on a learning method the same content is to be provided by different applications. For example, the definitions of technical terms could be presented within the course material provided by the learning management system (*"first-time" learning*) or by means of digital index cards (*repetitive learning*) (Bomsdorf 2005).
- Polymorphic presentation: Learning content could be presented with different levels of detail, e.g., showing the entire content or a keyword-like presentation

(such as used on slides). The keyword version supports displaying content on small screens, showing an overview, or repetitive learning. (Stary & Auinger)
– Content Ranking: Based on content and application filtering a list of learning materials is provided, from which the learner can select those learning objects he decides to work on. This technique is implemented within the mentioned prototype. In a two-step process the learner first sends his current situation profile to the system, so that it can determine the material appropriate for that situation. Since the result can be a large set of material, only a list of it is presented at first. Based on the learner's choice the learning content is provided.

4 First System Support

A prototype was developed focusing in its first version on didactic profiles. The didactic profiling aim at providing students with those (and only those) learning resources which can reasonably be used under given conditions of mobile (ubiquitous) conditions taken into account the strong environmental impact (Becking et al. 2004). However, since the prototype implements a generic context and rule model, it can be enlarged with additional profiles. Currently, the framework comprises (see figure 1)

– a learner model for the specification of learner profiles and didactic profile, respectively,
– a resource model for characterizing learning objects and services (e.g., by means of meta-data),
– a rule model for the definition of filtering rules, and
– an ascertainment engine for determining learning materials based on the evaluation of filtering rules according to learner profiles and characterization of learning resources.

4.1 Basic Concepts

Based on a meta-model, which itself can be modified, different models for describing context information can be specified flexibly. The adaptation is divided conceptually into different levels: Similarly to the physical model described in (Kappel et al. 2002), the context model includes an external sub-model, which deals with those kinds of context information, which are outside the scope of the adaptation process. Within the next level all the information defined by adaptive educational systems is processed. Based on this, on the technical level the system context (such as network) is considered. Situation properties, as far as not processed within the levels just mentioned, are subject of matter at the situation level. Most of the attributes defined by the didactic profiling are treated at this level.

Because of the existing dependencies between different kinds of context information several rules of adaptation span two or more levels because of the existing dependencies of different kinds of context information. Even if a video sequence, for example, may be appropriate because of the learner's personal didactic profile, the video may be excluded in that specific situation because of an unacceptable quality of network services. The different levels are introduced to enable separation of concerns during design and authoring of a learning space. They do not impose a special order regarding the processing of adaptation rules at run time. Instead, for reasons of performance the ordering is influenced by the point in time at which a rule can be processed.

The rule model of the prototype is implemented generically, too, so that it can be expanded easily. The structure of the rules is given by the pattern

event, condition → *action.*

An event results from change(s) of context and triggers those rules, the conditions of which hold true. The condition part specifies a condition which has to be satisfied for the filtering, and the action part describes the filtering action, such as retrieving learning objects. According to the different adaptation levels, the rules are divided into single-model rules depending on a single model and multi-model rules describing interdependencies between two or more models. Further, they can be characterised according to the degree of impact by didactical aspects as independent (e.g., size of display), influenced (e.g., filtering out content with video streams in the case this is not supported by the device) or dependent (e.g., based on learning style).

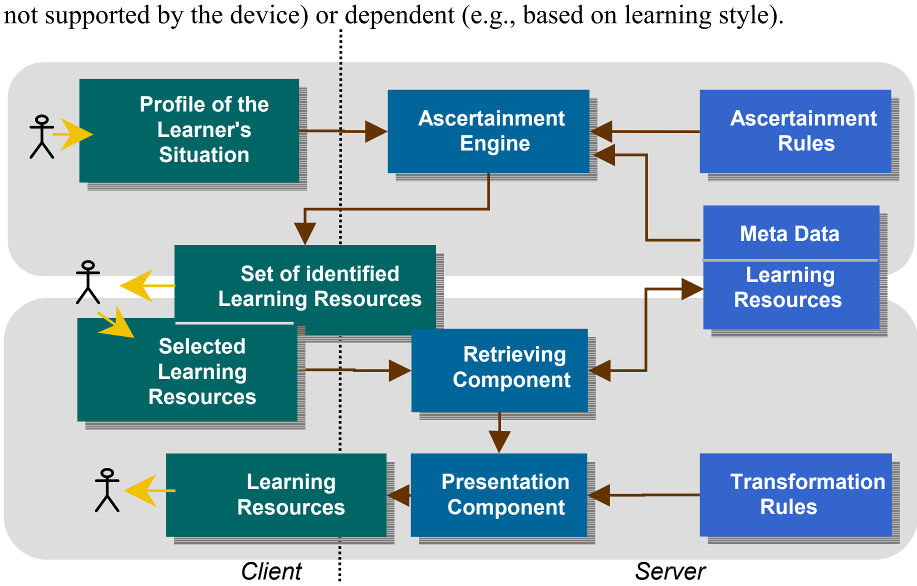


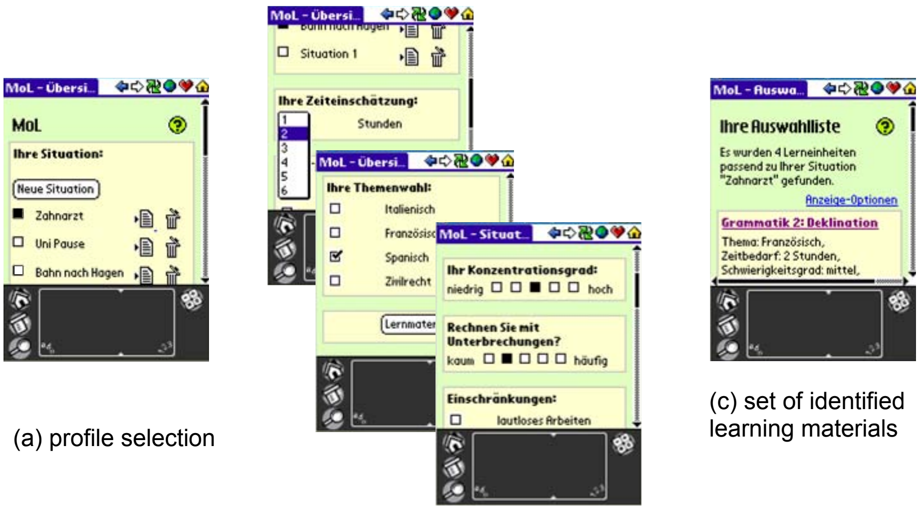
Fig. 1. System Overview

4.2 Example

Figure 1 depicts the components of the prototype, showing the order of invocation. First of all, the learner selects a profile. In the example shown in figure 2 (a) the profile ‘dentist’ is chosen as in this fictitious scenario the learner sits in the waiting room of his dentist. Alternatively, the learner could create a new profile. Afterwards, he can modify and fill in, respectively, parameters characterizing his current situation. In figure 2 (b) some examples are given: The learner estimates the time he can spend learning (here ‘2h’), chooses a subject (‘Spain’), estimates his level of concentration (‘medium’) and frequence of disruptions (‘seldom’).

By sending the profile to the university server the learner’s data are forwarded to the ascertainment engine. Based on the set of defined rules learning objects are identified, the meta-data of which “match” the profile parameters. As indicated by this example, the meta-data of learning resources comprise attributes as defined by our didactic profile as well as those specified by existing standards like SCORM (SCORM 2004). Other extensions of meta-data descriptions to adequately characterize circumstances in mobile learning settings can be found, e.g., in (Chan et al. 2003) and (Bull et al. 2004).

After evaluating all relevant rules for a given learner profile the engine provides a set of identified learning resources to the student. Since the set can comprise a great number of elements, only a list showing its entries by means of abbreviations is presented (for an example see figure 2 (c)). The leaner selects one or more objects, based on which the presentation component retrieves the material from the underlying database and file system, and delivers it to the student.



(a) profile selection

(b) setting attributes of a profile

(c) set of identified learning materials

Fig. 2. Part of a scenario using the prototype

5 State of Work

Currently, we redefine partially the set of attributes defined so far for didactic profiles. Since the prototype can easily be modified at the level of the meta-models, this causes no reimplementation. The prototype comprises models for the specification of attributes of the didactic profile and end devices as well as a resource model for characterizing learning objects and services by means of meta-data. Additional context information is under investigation and will be introduced in the next version. While in the first version the didactic profile is specified by a separate sub-model, its integration into a more general context model focusing on ubiquitous learning will be investigated according to the characterizations above. In addition, the rule model will be enhanced by the possibility to define rule priorities to solve conflicts during run time.

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