Journal of Universal Computer Science, vol. 18, no. 16 (2012), 2274-2300
submitted: 9/1/12, accepted: 26/8/12, appeared: 28/8/12 © J.UCS

Digital Learning Resources in Higher Education: Designing for Large-scale Use

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Abstract: In a series of faculty-based projects on design, realization, implementation, use and evaluation of digital learning resources for higher education, many design requirements emerged and were evaluated. This paper focuses on those requirements that are related with large-scale use. It is argued that sustainable quality of design and realization of digital learning resources will only be possible when these resources are used by many students and teachers. Design requirements of digital learning resources should therefore be consistent with one or more scenarios for large-scale use. This paper discusses eight large-scale use scenarios that can be useful reference scenarios for design of digital learning resources in higher education. It is argued that different large-scale use scenarios imply different sets of design requirements. Vice versa, certain design requirements are relevant in some reference scenarios and irrelevant in other reference scenarios.

Keywords: activating digital learning resources, learning objects, requirements engineering, design-oriented research, large-scale use
Categories: K.3.0, K.3.1

1 Introduction

Since 1997, a series of projects on design, realization, use, implementation and evaluation of activating web-based digital learning resources for a range of disciplines have been completed at Wageningen University (WU) [Aegerter-Wilmsen, et al., 2003, Aegerter-Wilmsen and Bisseling, 2005, Aegerter-Wilmsen, et al., 2005, Aegerter-Wilmsen, et al., 2005, Aegerter-Wilmsen, et al., 2006, Busstra, et al., 2005, Busstra, et al., 2007, Busstra, et al., 2007, Busstra, et al., 2008, Busstra, et al., 2008, Diederen, et al., 2002, Diederen, et al., 2003, Diederen, et al., 2005, 2005, 2006, Kolk, et al., 2008, Kolk, et al., 2011, Kolk, et al., 2012, Schaaf, et al., 2003, Schaaf, et al., 2006, Schaaf, et al., 2006, Sessink, et al., 2003, Sessink, et al., 2004, Sessink, et al., 2005, Sessink, et al., 2006, Sessink, et al., 2007, Sessink, et al., 2007]. In this paper, these projects will be referred to as WU projects, and the corresponding resources as WU resources.

Activating digital learning resources should be distinguished from presentational learning resources. The latter present information in the form of texts, diagrams, slides, recorded lectures, screen-recordings or animations et cetera. The focus of this article is on activating digital learning resources. These require the student to take conscious actions (they interact with the system) in order to progress through the resource. Examples of activating digital learning resources are virtual experiment environments, which enable the student to prepare virtual experiments and/or to carry out virtual experiments [Hartog, et al., 2010, Sessink, et al., 2006]. Here, a virtual experiment is an experiment that is based on a computer model of some object system. Activating digital learning resources often support the student in processing, analysing and interpreting experimental results. These resources can be client-side applets or resources based on web-server technology [Hartog, et al., 2008].

The projects listed above, were faculty-based projects in the sense that faculty or chair holders within university departments were the primary problem-owners and stakeholders. These projects required deep subject matter knowledge. The projects were aimed to produce an innovative design, applying typical concepts of design methodology and to contribute to a knowledge base, not only in terms of artefacts but also in terms of publications in peer-reviewed scientific journals. In such projects the challenge is to define goals that make sense in the real life context of university education, to articulate goals in terms of observables or measurable quantities, to realize digital learning resources with the intention to achieve these goals and to describe how goals are achieved. Such research fits the label of Design-Oriented Research (DOR) [Hartog, et al., 2010, Österle, et al., 2011]. A DOR approach enables synthesis of research and teaching tasks of faculty and fits the necessity to stay in touch with developments of information and communication technology (ICT) in academic environments. Here, design is viewed as a process that involves exploration, generation and satisfaction of constraints [Chandrasekaran, 1990, Gross, 1985, Jonassen, 2008, Lawson, 2006] where design requirements are also constraints.

Examples of other publications that fit a label of faculty-based design-oriented research are [Anderson and DiCarlo, 2000, Aziz, et al., 2007, Barak and Dori, 2005, Barak, et al., 2007, Breakey, et al., 2008, Coffey and Koonce, 2008, Corsi, et al., 2006, Costelloe, et al., 2009, Deek and McHugh, 2003, Gerosa, et al., 2003, Gütl and Pivec, 2003, Jeschke, et al., 2007, Miller and Upton, 2008, Navarro and Hoek, 2005, Reyes-Palomares, et al., 2009, Rodríguez-Caso, et al., 2002, Shanklin, et al., 2003, Shin, et al., 2002, Toumoto, et al., 2006, Westbrook and Braithwaite, 2001, Yokaichiya, et al., 2004].

From the viewpoint of faculty, activating digital learning resources are sometimes considered 'expensive', because the effort invested by faculty in comparison to other faculty obligations is considerable. However, it makes also sense to relate the invested efforts to the number of users of the digital learning resources, thus looking at impact and cost per user. Probably the best example that illustrates this viewpoint is the PhET initiative where computer simulations for education have been developed that have been downloaded by millions [Wieman and Perkins, 2006]. The example illustrates that more users justify more investments in the quality of learning resources. At the same time, more users imply more impact of corresponding design and development efforts.

With only a few users it will be difficult, and in most situations impossible, to sustain design, realization and evaluation of high quality learning resources. In short, sustainable quality requires large-scale use. However, in practice such large-scale use is often not achieved in faculty-based projects [Ehrmann, et al., 2007].

In this article, we argue that in faculty-based DOR projects aiming to deliver digital learning resources, 'large-scale use' should be translated into design requirements. Moreover, we will argue that ‘large-scale use’ design requirements should be matched with a ‘large-scale use scenario’. A scenario is a configuration of roles, tasks, events, goal (including target population) and a context. A ‘large-scale use scenario’ is a scenario in which many teachers and/or students use the digital learning resources. Some relevant roles related to large-scale use are for instance ‘teacher’, ‘student’, ‘evaluator/reviewer’, ‘publisher’, ‘stakeholder’, ‘designer’, ‘provider’, ‘sponsor’, ‘broker’. In this article we do not go into the details of subtasks and events and we only touch upon roles insofar they are relevant for design requirements related to large-scale use. In succeeding sections we will discuss these design requirements in more depth. In particular, we will show that different large-scale use scenarios for digital learning resources can involve different sets of design requirements. In the following section, potential large-scale use scenarios for activating digital learning resources in higher education are listed. Only those characteristics that imply design requirements related to large-scale use are shortly discussed. In analogy to reference information models [Verdouw, et al., 2010], we may regard the large-scale use scenarios below as ‘reference use scenarios’. A reference use scenario is (to be) used as a ‘frame of reference’ for a university-specific use scenario. For each of these scenarios, design requirements for digital learning resources in higher education are articulated. An important question to be answered in a faculty-based DOR project is to find or define a reference scenario that guarantees large-scale use and to articulate corresponding design requirements. For reasons of readability we will mostly use the term ‘large-scale use scenario’ to denote a reference scenario for large scale use.

2 Eight reference scenarios for large-scale use

This subsection provides a short description and abstraction of a number of well-known scenarios for large-scale use of digital learning resources. In practice, many hybrid forms of these scenarios are being tried out as well.

2.1 Collective Development and Sharing of Learning Resources by Faculty of Different Universities

In this first large-scale use scenario, faculty of the same discipline share learning resources across different institutes of higher education. Faculty within a certain university develop some learning resources but the learning resources are used by faculty across many institutes of higher education. Large-scale use is achieved because the scenario thrives on contacts within the discipline and because faculty who contribute learning resources also experience the benefits of easy access to high quality learning resources that are contributed by their peers.

This scenario is quite old and has been successful in the past [Maurer and Makedon, 1986, Maurer, 1987]. For sustainability, this scenario tends to rely on stable personal contacts and not primarily on links between positions in the university. When a professor moves to another position within the university or to another job, use of the resource should be transferred to the person who takes over his courses. When this person is not already active in the collaborating network, this person might decide not to adopt the resources. At the same time, the initial user may have moved on to a position where use of the specific resources does not fit his teaching tasks. This is what occurred several times with WU resources. Use of WU learning resources at universities other than WU was mostly based on personal contacts. Indeed several times it has occurred that use was discontinued when faculty using the resource moved on to another position. As will be explained below, this discontinuation may also be due to the fact that adoption of the activating or interactive digital learning resources requires in general much more effort by faculty than adoption of presentation type learning resources.

2.2 The Funded Cooperation Scenario

The second large-scale use scenario is what we will call a 'funded cooperation' scenario. In this scenario, cooperation within a disciplinary field is supported by a program that is funded by governmental or non-governmental organizations. Examples are the Nutrigenomics Organization [NuGO, 2006], B-Basic [B-Basic, 2007] and ALTB [SURF, 2008]. Often in such a disciplinary cooperation, one of the goals is to 'spread' or 'disseminate' knowledge. One way to do this is by the design, realization, implementation and use of learning resources in dedicated work-packages or subprojects. This scenario may enable large-scale use. However, without continued funding, sustainability is only possible by a transition to another scenario.

2.3 Large- scale Use Scenarios Based on Repositories/Referatories/Portals

A Learning Object Repository (LOR) is a searchable store of digital learning objects that can be accessed over the internet. With the term LOR scenario we will refer to a cluster of scenarios ranging from completely open to the world to relatively restricted access. Over the years there have been many such repositories or referatories (i.e. 'portals' or 'brokers' that connect to digital learning materials in other repositories). Some that are currently still accessible are ARIADNE [Ariadne-Foundation, 2007], the BEN portal [NSDL, 2008], DLESE [DLESE, 1999], MERLOT[MERLOT, 2007], the Open Educational Resource initiative [InternetArchive, 2008], SCORE [SREB, 2006], SMETE [SMETE-Open-Federation, 2003] , Wikimedia-Commons [WikimediaFoundation, 2008], Wikiversity [WikimediaFoundation, 2008] and WISC-ONLINE [Wisc-Online, 2008]. Most of these are or were partly supported by funding organizations such as the National Science Foundation or the European Commission or cooperatives of schools and/or universities.

Large-scale use of digital learning resources in a repository- or portal-based scenario is only likely when the following conditions are met. Firstly, a 'large' number of professors and students must know which concepts, topics and methods for which subjects are supposed to be covered by the repository or portal. Anyone who searches useful digital learning resources needs a short and clear description of what the repository or portal 'contains' and what not. This in turn requires coherence. The less coherent the total content of the repository or portal, the more extensive the description of this total content will have to be. In comparison with the first two scenarios, the content in most repositories is much less coherent. Secondly, the probability that a quick search based on these expectations fails, must be low. When a teacher has several times searched for learning resources in a certain repository or portal and failed, this teacher is not likely to come back. Thirdly, quick search must be enabled by standard search functionality. In practice, this also requires that a module of digital learning resources or learning object is described by data about this module. Such data are called metadata [Duval, 2001]. A standard for metadata is the IEEE Learning Resource Meta-data Specification [IMS, 2006]. Finally, the total effort of formulating search questions, filtering the results (for instance based on ratings by peers), downloading, installing and evaluating the learning resources must be small. Currently, repositories and portals give access to hundreds of thousands of modules of digital learning resources.

On the one hand, we cannot determine if a certain LOR and its contents satisfy the requirements in the previous paragraph as long as 'short', 'clear', 'coherent', 'large', 'quick' and 'low' are not operationally defined. On the other hand, for the concepts, topics and methods that were relevant in the WU projects, we performed many times a search of about an hour. None of these searches produced descriptions of available learning objects or resources that led to a decision to adopt these objects/resources in one of our projects. This holds even for more discipline-oriented portals such as the BEN portal. Given such a low density, a search within such an incomplete repository is often waste of time. Apart from this, learning resources that can be found in these repositories or portals are mostly presentational and not activating. Given this current state of affairs, faculty might decide to make learning resources available via repositories and portals, but this will currently require additional efforts and it is not clear to what extent these efforts contribute to large-scale use of the resource. Below, we will explain that this holds in particular for activating digital learning resources. With respect to presentational learning resources, it is important to be aware of the fact that over the last few years more and more of these resources are uploaded to commercial repositories with an orientation that is not restricted to the educational sector such as Slideshare [Slideshare_Inc., 2009], YouTube [LLC., 2009] and iTunes U [Inc., 2009]. To faculty for whom large-scale exposure is in itself sufficient benefit, these commercial repositories are apparently more attractive because the additional effort is much lower and additional exposure tends to be higher. In particular, these repositories are not only visited by faculty but also by students.

Finally, it should be mentioned that some of the repository organizations have set up a formal peer review model for digital learning resources (see in particular [Merlot, 2009]). We consider peer review of digital learning resources an essential contribution to design-oriented research on digital learning resources. Apart from realizing large-scale use, this can be an important reason for faculty to submit learning resources. However, this is outside the scope of this article.

2.4 The Institutional Open Courseware Scenario

In an open courseware (or open educational resources) large-scale use scenario, an organization or individual provides free web-based access to many or all resources that have been developed within the organization or by that individual. The examples that are probably best known are MITOPENCOURSEWARE [MIT, 2007], OnlineLearningInitiative [Carnegie Mellon, 2011] and OpenLearn [The Open University, 2008]. While most learning resources currently made available as open courseware are mainly presentational, recently, institutes that provide open courseware are offering more and more activating or interactive learning resources such as applets. In the institutional open courseware scenario, benefits for the university are in the first place corporate image benefits. Depending on her primary source of funding, a university might also regard it as a moral obligation to provide free access to the learning resources of the university.

Over the last few years, the movement towards open access and open educational resources seems to gain impetus. More and more, universities invest in setting up attractive web-based repositories for open courseware. Faculty desiring to draw attention to their activating digital learning resources and to provide easy access can make use of the university's open courseware repository. This saves faculty the work of setting up such a repository themselves or submitting their applets on some of the repositories listed in the previous section. In general, it is likely that faculty efforts of submitting digital learning resources to the open courseware system of their own university will be relatively low.

More recent developments are the foundation of companies like Udacity [Udacity Inc., 2012] and Coursera [Coursera, 2012] that deliver university-level on-line courses. Coursera already delivers about 120 on-line courses from (currently) 16 top universities and has more than a million subscribers.

It is yet too early to establish the benefits of open courseware initiatives for faculty. However, it is clear that for many university-level open learning resources the demand by learners world wide is in the order of magnitude of thousands or tens of thousands.

2.5 Focusing on One Type of Interactive Learning Objects and Relying on Sponsors

In the PhET approach [University of Colorado, 2008], the interactive learning objects are computer simulations that provide primarily opportunities for inquiry-based learning. The learning objects are JAVA or FLASH applets. Much effort has been invested to lower any barrier that might impede teachers or students from anywhere to run the simulations or to download the simulations. Sustainability relies on what the authors call the 'Mother Teresa Model', i.e. on charitable support from public and private foundations [Wieman and Perkins, 2006]. In the case of PhET this has been very successful. In 2008 already millions of downloads were reported (see supplementary material to [Wieman, et al., 2008]). While the PhET project is one of the most inspiring projects for digital learning resources in higher education, bootstrapping an approach like PhET is likely to be beyond the possibilities of faculty in most universities.

2.6 Leveraging Teacher Capacity in On-campus Large-enrolment Courses

In many universities a number of the courses have enrolments of hundreds of students. For such a course it is attractive to design, develop, implement, use and evaluate digital learning resources. The first reason is that sufficiently high enrolment numbers enable acceptable costs-per-student. Of course, one should still quantify 'sufficiently high' and 'acceptable', but this is out of the scope of this article because actual costs and benefits will vary a lot across different institutes in different countries. The second reason is that in large-enrolment courses there is a strong need to leverage capacity of the teacher. Digital learning resources are tools that can provide such leverage. In on-campus large-enrolment courses, the main issue is not how to lower barriers for other faculty to adopt the learning resources. Moreover, in this scenario, more than in any other scenario, the benefits of investments in digital learning resources will be experienced by the primary problem owners i.e. by those faculty who are involved in design, realization, implementation, use and evaluation of the resources for their own course. In this scenario it will still be a challenge to shift the investments to an earlier point in time: instead of incurring costs during course activities in a number of years, the design and realization of digital learning resources incurs costs that have to be made in advance.

2.7 Distance Learning Large-enrolment Programs

Currently more and more web-based distance learning programs are initiated by universities (see e.g. [Arneberg, et al., 2007, Mayadas, et al., 2009]). The challenge for a university is to identify the worldwide demand for the knowledge that matches her core competence and to match this demand with suitable distance learning programs. The reasons to take up this challenge may range from a sense of public responsibility for the world to an expected return on investment. Not surprisingly, most distance learning programs rely rather heavily on design of educational activities and digital learning resources. For instance, Laurillard [2002] states that more than 40% of staff time in online distance learning is allocated to design efforts as opposed to about 5% in traditional learning. Thus, like in the on-campus large-enrolment course scenario, digital learning resources provide leverage and are interesting because of the reciprocal relation between costs per student and number of students. But in distance learning the need for digital learning resources is also based on the need for asynchronous communication. Clearly, the market for distance learning will also be a market for digital learning resources.

2.8 The Class of Publishers' Large-scale use Scenarios

A publisher will define and implement a business model. A business model is a coherent description of products, services, business processes, resources, supply chains, customers, value propositions, and a revenue model. In particular, such a business model will take marketing costs into account. A number of publishers currently develop digital learning resources in connection to textbooks. A professor who decides to prescribe the textbook for a course can often import a corresponding course cartridge in the learning management system (LMS) of the university [IMS Global Learning Consortium, 2008]. Then, the LMS makes the digital learning resources in the course cartridge available to the students who are enrolled in the course. More and more publishers currently offer cartridges for major LMS's. Alternatively, a publisher can host a publisher-based LMS and provide students the opportunity to buy access rights to digital versions of textbooks or chapters of textbooks. The costs of access to these learning resources are considerably lower than the costs of buying the corresponding hardcopy. Furthermore, the digital learning resources and the hardcopy of the textbook essentially can provide different value to the student. For instance, digital learning resources can include sound, video and interaction, while on the other hand a traditional hardcopy does require no technology in order to be read.

Some publishers offer teachers the possibility to configure their own common cartridge or textbook, using resources made available by the publisher. In addition, they offer support of an editor to the teacher. Many publishers provide web-based access to digital learning resources on a publisher-managed system (e.g. [Harvard, 2000, Pearson, 2008]) or web-based sales of interactive learning resources such as educational simulations (e.g. [Forio On-line Simulations, 2011]).

Currently, several publishers are experimenting with different business models along these lines. Thus the abstract description of this scenario actually represents a whole class of different ‘publisher-based’ scenarios.

3 Design Requirements Related to Large-scale Use

[Littlejohn et.al., 2008] identified 12 key characteristics of learning resources that are specifically designed to change eLearning practice: such learning resources must be easily sourced, be durable and maintained, be of recognized quality, have no legal restrictions, be in accessible formats, incorporate adequate representations, be easy to repurpose, be of a critical size, involve a context that is meaningful to the practitioner, engage the learner, be reusable in a range of educational models.

While these characteristics have not yet been fully operationalized, we do agree with the general picture of design requirements that they suggest. Moreover, it is likely that the less a learning resource conforms to these characteristics, the less it is likely to be used by many teachers and students in higher education. Thus, these characteristics can also be interpreted as drafts of qualitative design requirements. Taking these requirements as starting point we now discuss additional and partly overlapping requirements that must be satisfied in order to enable large-scale use of activating university-level digital learning resources. In comparison to requirements that are implied by Littlejohn’s key characteristics, these additional design requirements are more directly related to specific large-scale use scenarios. Most of these requirements are closely related to the *interface* of the learning resource. Here, the interface of a system describes a set of assumptions about the context in which the system will function and a definition of the function(s) of the system. *Implementation* is: fitting a realized design to its context. In this article, this mostly refers to what a teacher has to do in order to make use of the activating digital learning resources in his/her own course and own working context. This means that the teacher has to make changes or additions to the course, the working context, or provide additional resources whenever an assumption in the interface of the learning resource does not hold for his/her course and working context.

3.1 Design Requirements Related to Prior Knowledge of Students

When a module of learning resources is intended to be used worldwide, the assumptions in its interface de facto define the target population. This not only holds for assumptions with respect to available technology, but also with respect to assumptions about students who might use the learning resources.

Alternatively, for learning resources that will be used within a course in an existing program within a university the target population is already defined. For this resource, a design requirement is that the assumptions in the interface with respect to prior knowledge will hold for 'this' cohort of students being registered for 'this' curriculum in 'this' year. The importance of knowledge about the prior knowledge of students in the target population is well described in the literature [Ausubel, 1968, Laurillard, 2002]. In classroom teaching, one can try to avoid a mismatch between assumed prior knowledge and actual prior knowledge by means of interacting with the students in order to find out about their prior knowledge. This is not possible in the context of design and realization of learning resources that are intended to be useful for a range of years and aimed at student populations with which the designers have no contact. A mismatch between assumed prior knowledge and actual prior knowledge will require additional efforts of the teacher who adopts the learning resource.

3.1.1 Design requirements derived from descriptions of prior learning

Within one university, it is usual to derive assumptions about the prior knowledge of the student from a description of courses that the student already is supposed to have completed. Furthermore, it is often assumed that students in one group or one class have more or less the same background in terms of previously attended courses. Arriving at assumptions about prior knowledge in ways such as described in this paragraph is the cheapest approach that fits large-scale use scenarios such as the 'cross universities cooperating faculty' scenario, the 'funded cooperation scenario' and 'on-campus large-enrolment' courses. However, the assumptions can easily be wrong, in particular with respect to detailed knowledge of different individual students and at universities that attract students from many different countries.

3.1.2 Assumed prior knowledge should be within prerequisite knowledge

For a worldwide target population, the above approach of deriving assumptions about the target population is unlikely to work. One approach is to define prerequisite knowledge and clarify this definition by providing self-tests [Hartog, 2008]. Next, we would then require that the assumptions about prior knowledge that are in the interface of the learning resource do not transgress the prerequisite knowledge.

3.1.3 The 'self-contained' requirement

An alternative is to avoid unnecessary assumptions about the prior knowledge of members of the target group. This is also relevant for a publisher trying to define a target population. More in general, we can require that learning resources for students whose prior knowledge is little known should fit in one of three categories: self-contained learning resources, adaptive learning resources or learning resources that can be extended 'on the fly'.

A body of self-contained learning resources provides the student with all information and opportunities for learning that are needed to achieve a learning objective or a set of learning objectives. A learning resource is self-contained when it does not imply any assumption about relevant prior knowledge. Learning objects are intended to be self-contained but many textbooks or courses also aim to be self-contained. One problem with a self-contained resource is often that it imposes unnecessary cognitive load on students who do already master much of what is necessary to achieve the learning objectives. These students have to process a lot of information that contributes little or nothing to knowledge construction related to the learning objectives. Another problem is that designing and developing self-contained resources often implies a considerable investment.

The first problem of self-contained resources can be solved by matching the needs of each individual student to the presentation of resources. For instance, the Proteus system [Sessink, et al., 2007], dynamically measures the performance of the student with respect to learning objectives and makes at any moment a selection of a specific question to offer the student. Systems like Proteus adapt the selection of what they present to the individual students. Adaptivity and personalization can go much further than Proteus [Brusilovsky and Millan, 2007, De Bra, et al., 2010]. Many adaptive systems are de facto still self-contained but, contrary to a self-contained book, these systems avoid imposing unnecessary cognitive load for the individual student. They do this by filtering out interactions and presentations that require the student to pay attention to knowledge that (s)he already has in sufficient depth.

The second problem of aiming at self-contained learning resources is inherent in the fuzzy meaning of 'self-contained'. Not making use of any assumption with respect to relevant prior knowledge is just not realistic. Firstly, there will always be people for whom a body of learning resources is not self-contained. Secondly, we may want to use assumptions about prior knowledge and take it as an entry point to interaction with our students [Diederen, et al., 2003]. Thirdly, the approach of creating an adaptive system that aims to be self-contained often implies an investment of which a considerable part may never be used. Thus, it may happen that an adaptive system after a few years in use still has not presented some of its components to any user. In fact, self-contained resources and adaptive systems that are essentially based on self-contained content, imply an investment in a large stock of resources. In many industries and supply chains we would prefer just in time (JIT-) production, instead of production to stock.

In higher education we are used to approach the second problem by ad hoc answering questions of the student. This can be regarded as JIT production but at the same time these answers ‘evaporate’, i.e. they cannot easily be reused. An alternative is to design systems that enable automated capturing or 'logging' and anchoring of interactions between student and teacher to relevant locations in the learning resource. The anchored logs of such interactions thus enhance the learning resource. A more advanced approach is based on the concept of 'active documents' that enable adequate automated response to a question of a student concerning an element of this 'active document'. The automated response would be based on automatic retrieval of relevant questions previously asked by students and answers previously given by Subject

Matter Experts (SME's) [Heinrich and Maurer, 2000, Maurer, 2003]. Such an approach also implies collection of data about prior knowledge of students including all their ideas and conceptions. Notably, such an approach relies much less on making use of assumptions about prior knowledge of students in the target population. Instead, in such an approach the system captures how experienced teachers actually make their perception of the prior knowledge of the student an entry point for their response. Capturing such interactions between students and teachers is relatively easy when most communication is 'digital'. This condition is most naturally satisfied in a distance learning program.

3.2 Basic Technical Design Requirements Related to the Target Population

In faculty-based DOR projects certain technical design requirements will tend to make optimal use of the university's technological infrastructure, such as a local area network and a learning management system, and available hardware, such as desktop computers, laptop computers, projection facilities et cetera. When the intention is that the activating digital learning resources will be used at a larger scale worldwide, the designers should be aware that many other variables or parameters such as bandwidth, screen resolution and processing capacity are likely to be important. This tends to lead to requirements that go hand in hand with resources having an ‘accessible format’ as described in [Littlejohn, et al., 2008].

If one specifies a target population, one can derive requirements from the technical limitations of the infrastructure and hardware that is available to this target population.

If one does not specify the target population, the assumptions in the interface of the design will de facto restrict the target population. In practice, faculty in universities with advanced infrastructure and equipment will have difficulty in satisfying both their own target population as well as certain target populations elsewhere in the world. Technical requirements that are constraints of bandwidth, screen resolution and processing capacity can greatly increase the costs of actual realization of the learning resources or force the designers to relax other requirements. Such constraints are relevant for a university aiming at a large-enrolment distance learning scenario or a publisher aiming at a worldwide market. They are of little relevance for faculty aiming to support large-enrolment classes within their own university. Not being specific about a large-scale use scenario will confuse discussion about technical design requirements and may incur considerable waste of resources.

3.3 Design Requirements Related to Authentication, Authorization and Integrated Learning Experience

In most universities, an LMS is now a standard component of the facilities that support teaching and learning. The prevailing paradigm for handling digital learning resources is that the teacher configures a collection of resources for his course in the LMS. In particular, this may involve learning resources that have been uploaded by the teacher into the LMS. Alternatively, a learning resource might be a web-based application that lives outside the LMS that may be made available to the student from within pages generated by the LMS. In general, we want a configuration that provides an *integrated learning experience* within the LMS environment. A learning experience is called integrated if it does not involve any form of cognitive load due to switching between different tasks or due to switching between the use of different media and if any other effort needed for such switches is negligibly small.

Authentication and provision of authorized access is straight forward for resources that have been uploaded and are stored within the LMS. Providing authorized access to resources that live 'outside the LMS' requires a protocol for communication with the system that manages those learning resources. Establishing the implementation of such a protocol across universities in practice still tends to require interaction with administrators of LMS's of different universities [Hartog, et al., 2008] and in practice sometimes also involvement of the teachers of courses.

In order to provide the student an *integrated learning experience* and in order that the learning resource can delegate certain tasks to the LMS, it is a requirement that both conform to a common interface.

In relation to the upload paradigm, the most well-known specifications for such interfaces are SCORM2004 4th edition [ADL, 2006], IMS Content Packaging [IMS Global Learning Consortium, 2007], and Common Cartridge [IMS Global Learning Consortium, 2008]. These interfaces aim to be standards that will realize *interoperability*. In the context of this article, interoperability means that any learning object or package or course cartridge can be functional in any LMS as long as both conform to the same specification. Non-conformance to SCORM2004, IMS content packaging and IMS Common Cartridge specification can impose additional implementation efforts on teachers who use an LMS, thus contributing to a barrier for large-scale use.

A publisher aiming to sell copies of learning resources to universities that want to incorporate these learning resources within their own LMS's will probably define conformance requirements as to SCORM2004, IMS Content Packaging and IMS Common Cartridge. Conformance to these specifications might also be required by funding agencies in a funded cooperation scenario.

In relation to paradigms that provide web-based access to learning resources, applications or tools that live 'outside' the LMS, the Learning Tools Interoperability (LTI) specification is being developed [IMS Global Learning Consortium, 2010].

However, it is important to be aware that interoperability is not a strict requirement in several other scenarios. Scenarios that are not based on providing an integrated learning experience within a certain LMS environment could ignore the specifications mentioned above. For instance, the Open Courseware scenario is more aimed at students than at teachers. The intention is rather that students can directly access the learning resources and there is no role for an LMS. Thus, in an Open Courseware scenario it is less likely that conformance to learning technology standards is a design requirement. Moreover, the Open Courseware scenario is often primarily a scenario in which the institution provides free access to resources that are developed for students already enrolled in a course of the university.

In large-scale use scenarios that are not primarily based on cooperation, but, for instance, at realizing an attractive business model there can be two reasons to forsake conformance to standards. Firstly, specifications that are adopted as interoperability standards are likely to be compromises. Consequently, these specifications are likely to be inadequate for certain specific large-scale use scenarios. Secondly, when a large-scale use scenario is based on realizing a competitive edge, this competitive edge might be realized by defining interfaces that provide more possibilities than the standards. Alternatively it is likely that a competitive edge might be realized with approaches in which the standard interfaces do not make sense. For instance, a publisher aiming to sell a learning service and attract students to her own server might well decide to set her own standards.

The same may hold for a university aiming at a distance learning program. In a competition between a few universities with overlapping core competences each aiming a distance learning program at the same target population of students there is no reason to invest in interoperability. On the contrary, each university might primarily want to realize a competitive edge. However, when a consortium of universities decides to set up a common distance learning program, interoperability becomes very relevant.

The conclusion is that the importance of interoperability requirements depends on the large-scale use scenario at which one aims. Rather than focusing on interoperability per se, faculty should focus on a suitable large scale-use scenario.

3.4 Design Requirements Related to Barriers that Impede Adoption by Other Faculty

Long and Ehrmann [2008] see “serious barriers to wide spread adoption of any faculty-developed innovation in technology, including the fact that instructors are rarely prepared, supported or rewarded for finding innovations.” Rogers [2003] argues that " Innovations that are perceived by individuals as having greater relative advantage, compatibility, trialability, observability and less complexity, will be adopted more rapidly than other innovations." In case of innovative activating digital learning resources, the relative advantage and compatibility will depend very much on the large-scale use scenario that is selected. Moreover, as we will show in this section it can often be laborious to evaluate digital learning resources by trying them out. Also, even though the resources themselves can often be easily accessed, the results of actually working with such resources are seldom visible to others. Finally, activating digital learning resources in higher education are inherently complex. Thus, wide-spread adoption by faculty who is not involved in development of innovative activating digital learning resources cannot be expected soon.

Like Littlejohn’s key characteristics, Rogers’ characteristics are high-level characteristics that must be further operationalized for activating digital learning resources. In this subsection, we make a first step towards such operationalization. In particular, we identify barriers that are specific to adoption of activating digital learning resources by faculty who were not involved in its design and development and discuss design requirements that are intended to avoid these barriers.

3.4.1 Design requirements related to the evaluation effort by faculty

Generally speaking, evaluation of digital learning resources for use in a specific course at the university will require more effort than evaluation of a textbook. Firstly, an experienced reader can scan pages of text in a textbook very fast. Scanning multimedia learning resources often requires more time because of its sequential nature. Secondly, one may doubt if faculty reviewing a textbook will take the time to answer all the questions and make all assignments at the conclusion of a chapter.

Rather, it is likely that a university teacher evaluates a textbook mainly on the basis of the presentational parts of the textbooks. During the course the teacher can select ad hoc which questions and assignments are suitable. On the other hand, evaluation experience with activating digital learning resources in WU projects made clear that a university teacher who evaluates such resources wants to 'walk' through all the actions that the student has to take. A reason is often that the teacher needs to know if a student may get stuck when (s)he skips certain actions.

Thus, faculty, designing digital learning resources that are intended to be adopted by other faculty, will have to ensure that the resources impose little evaluation effort on anyone who wants to implement the resource in a course. Ideally, evaluation of digital activating or interactive learning resources should not require more efforts than evaluation of a text that covers the same subject matter. Comments of different SME's who evaluated parts of the WU activating digital learning resources suggest that this design requirement at least implies that an evaluator must be able to:

- directly see what learning objectives might be achieved with the resource,
- continue at any moment at a different computer,
- reset at any moment his 'state' within the learning resource (i.e. restart at the beginning),
- walk back and forth through any of the possible learning paths with 'previous' and 'next' buttons, without being forced to re-answer any question and without having to complete any assignment,
- scan content-related chains of inference without being forced to carry out each inference step,
- inspect any model that is incorporated in the resource.

In fact, the last two requirements are classical requirements for knowledge based systems and intelligent tutoring systems [Hartog, 1989, Wenger, 1987]. In these systems, subject matter knowledge is represented in a specific format that is readable by SME's and not 'integrated' in the source code. Generic inference rules constitute a separate inference engine. A slightly different form of separating subject matter knowledge from 'other' knowledge is defined in specifications for the representation of closed questions such as the QTI 2.0 specification [IMSglobal, 2005]. Such a specification defines a generic format for defining closed questions that allows faculty to read through the questions and proposed answer sets without having to go through the questions in the way a student is intended to do. A separate delivery environment presents closed questions on the screen for the student and handles the response processing.

Another way to enable faculty to quickly scan content related chains of inference and models would be to document the resources by means of a visual design language analogous to blueprint formalisms used in construction. The idea of using flow diagrams for this purpose is already old [Smith and Ragan, 1993]. Research in this area is quite recently receiving more attention [Botturi and Stubs, 2008].

Different large-scale use scenarios can lead to different requirements. The requirements in this subsection are primarily relevant in a large-scale use scenario that relies on adoption of the learning resources by faculty who have not been involved in the design of the resources. Requirements that are intended to enable efficient evaluation by SME's, might be relaxed in scenarios directly aimed at students, as in certain Open Courseware scenarios. They can also be relaxed in a large-enrolment scenario in which faculty who use the resource are directly involved in the design and realization of the resource.

3.4.2 Design requirements related to implementation efforts by faculty

Implementation of digital learning resources by a teacher in his/her own course will usually involve certain efforts. For faculty, who has not been involved in the development of these resources, implementation in a course is likely to involve more effort than for faculty involved in the actual design and realization of the resources.

Within settings that resemble to a certain extent the first large-scale use scenario of cross university cooperating faculty, the WU projects provided some experience with implementation efforts for WU digital learning resources at the NPUST university in Taiwan, the Technical University of Łódź, the Ecole Polytechnique Fédérale de Lausanne, Cornell University in the US, Asian Institute of Technology, Graz University of Technology and The Royal Veterinary and Agricultural University in Copenhagen.

Within 'funded cooperation scenarios', the WU projects provided some experience with implementation efforts within the NuGO organization [2006], (see also [Busstra, et al., 2007]) and a number of efforts in the B-Basic DiMoBio project [Hartog and Tramper, 2006].

These experiences suggest three categories of efforts that teachers have to invest in order to implement available resources in their own course as well as corresponding design requirements aimed to limit these implementation efforts:

- efforts related to ‘freeing space’ for new learning goals within a course,
- efforts related to realizing an adequate learning scenario,
- efforts related to providing authorized access to the learning resource.

3.4.3 Design requirements related to ‘freeing space’

Digital learning resources can bring new learning goals within reach. When a DOR project focuses on new learning goals, this implies that existing learning goals in the course or curriculum must be achieved in less time or must be removed. This will be referred to as ‘freeing space’. In the WU projects, the effort associated to ‘freeing space’ for new learning goals had already been invested within the context where the learning resource was designed and developed. However, in the WU projects it turned out that faculty of other universities who thought about implementing WU learning resources in one of their courses must invest time in the problem of ‘freeing space’. As faculty of the other university was not involved in the initial design, this should not be surprising.

The effort of ‘freeing space’ will be related to the students' study load that is imposed by the learning resource. A larger study load implies a need for freeing more space.

Faculty who were not involved in the development of the learning resources must be enabled to grasp quickly what students will learn from this resource and how much study effort this will cost. This implies design requirements. Ideally, this would imply that a package of digital learning resource includes the operational definitions of the learning objectives, i.e. a set of corresponding exam questions or assignments. The latter, together with a normative indication of the study effort that this will require, should clearly convey the weight of the new learning goal per unit of study effort.

Efforts to 'free space' for new learning goals, point to the role of discipline-specific education journals or to leading disciplinary journals in the field. These journals provide the most obvious forum for discussions about introducing new learning goals and dropping old learning goals within disciplinary higher education. Note that a discussion about dropping old learning goals becomes more relevant as soon as the possibility to achieve new learning goals has become more tangible due to evaluations and publications that report on the feasibility of achieving those new learning goals.

3.4.4 Design requirements related to learning scenarios

Most of the case studies in which the WU products were evaluated were based on the following learning scenario:

- Initially, students work more or less synchronously on the same cases in one computer room at the university.
- A staff or faculty member is present for technical problems, error corrections and for students who want to question and discuss issues that actually reach beyond the learning objectives.
- Students are stimulated to work together, for instance in pairs.
- Part of the time a number of students will use the resources in other settings, for instance at home.

At WU, this learning scenario was also believed to provide an appreciated alternation with other learning scenarios such as lectures and problem-based learning activities. In addition, at WU as well as at other universities, 'live' interaction of students with teachers and students with each other is often highly valued. This was a reason to schedule the work with the learning resources at specific times in a computer room. Being together in one and the same room with fellow students and an instructor may make it easy to discuss questions, assignments, approaches and answers with each other and with the teacher. Learning scenarios that imply a high level of such direct 'live' interaction are favored at many universities where such a scenario can be realized.

In many universities, the learning scenario described above requires the lecturer who is responsible for the course to invest time in organizational efforts. The lecturer has to make early computer room reservations and make sure that the right desktop/laptop configuration is active at the right moment. In many universities, this can be a time consuming and error prone activity given the local technical and organizational structure. In our experience, this has often required somewhere between four to sixteen hours of a teacher's or assistant's time.

Alternatively, the learning scenario wherein the lecturer uses the resource as the core of his lecture tends to require less organizational effort. Moreover, this learning scenario can be carried out in universities that do not have sufficient computer room capacity. Another learning scenario that requires less organizational efforts from faculty, is the scenario wherein the students use the resource outside the precincts of the university and wherein the students are responsible for their own desktop, laptop or tablet configuration. Experience with this scenario would also be important for use of learning resources in distance education.

If the intention is that faculty in many different universities will adopt the digital learning resources for use in their courses, these resources should support a range of learning scenarios and not just one learning scenario. This position is also taken in [Littlejohn, et al., 2008]. This range should at least include lecture-based learning scenarios and learning scenarios in which students do not necessarily have to work in one room. However, if the learning resource is to be used in a large-enrolment course in one university or a distance learning program of one university, the requirement that the resource should enable a range of learning scenarios can be relaxed.

3.4.5 Design requirements related to the size of what to deliver

In the last decades, the concept of *learning object* has received much attention. In the literature on digital learning resources, an ideal has been sketched of bodies of learning resource that can be configured on the basis of learning objects. This ideal matches well with the repository/referatory/portal scenario. However, in some large-scale use scenarios the primary demand is delivery of relatively large coherent modules. A module should have a ‘critical size’ (see e.g. [Littlejohn, et al., 2008]). The problem of critical size is related to discussions about granularity and levels of granularity and how to arrive at an operational definition of ‘size’ and ‘granularity’ (see e.g. [Allen and Mugisa, 2010, Balatsoukas, et al., 2008, Boyle, 2010]). The details of these discussions go far beyond the scope of this article. Rather, we choose to focus on the relative implementation effort.

A lecturer will not easily invest much time in implementing one small piece of learning resource in his course. It will be different if one and the same implementation effort is adequate for a large body of learning resources, many students and several years. Thus, most lecturers will implicitly look at the **relative** implementation effort $\mathbf{E}_{\mathtt{relative}}$.

- $\mathbf{E}_{\mathtt{relative}} = \mathbf{E}/(\mathbf{n}*\mathbf{e}*\mathbf{y})$

  where
- **E** is the absolute implementation effort
- **n** is the average number of students that use the resource in a specific year
- **e** is the average number of hours of study effort that the resource generates and
- **y** is the number of years for which the implementation effort is valid.

When **E** is more than a few hours, the barrier for the lecturer to actually make this effort will be lower for larger packages of learning resource i.e. for a package that covers a larger study effort and a larger part of the course.

Also, larger packages will make it easier to minimize the number and scope of prior knowledge assumptions because the necessary knowledge can be provided within the package. Different scenarios for large-scale use will require different design requirements with respect of the size of what to deliver, but this size will also depend on the required implementation effort. These considerations suggest that in scenarios such as a distance learning scenario or a scenario based on a publisher's business model, early focus on strict design requirements for digital learning resources aimed at the LO-LMS paradigm is counter-productive. Recently, more literature has been appearing that identifies design and realization areas where a supposed generic value of early focus on a high modularity is contested [Hölttä-Otto and De Weck, 2007, Hölttä, et al., 2005, Schilling, 2000]. Rather, decisions about the degree of modularity should be derived from the complete set of constraints that define the goal. Where some constraints, in particular business constraints, might require a high degree of modularity, other constraints such as technical constraints may make it difficult to realize a high degree of modularity.

4 Concluding Remarks

In a series of faculty-based DOR projects on digital learning materials many design requirements for such materials were discussed and evaluated. In this article, we focused on those requirements that are related to sustainable large-scale use. We discussed requirements that are related to large-scale use and linked to certain large-scale use scenarios. The list of requirements and scenarios is not claimed to be exhaustive.

We argued that stakeholders in faculty-based projects that involve design of digital learning resources should consciously aim at one or more specific large-scale use scenarios and define design requirements that are consistent with those scenarios. Stakeholders should be aware that different large-scale use scenarios imply different sets of design requirements and, vice versa, that certain design requirements are relevant in some scenarios and irrelevant in other scenarios.

Faculty teaching large-enrolment classes, on-campus or off-campus, to students who pay regular tuition fees, should initially choose for a large-enrolment scenario. In such a scenario, stakeholders should not blindly require interoperability and/or modularity. Holding on to interoperability and modularity constraints, such as those implied by the interfaces of many learning management systems and by interoperability standards, may impede or even exclude the realization of valuable goals. In a large-enrolment class scenario, the set of design requirements that are directly related to large-scale use is relatively small. In such a scenario, depending on the financial structure of the university and depending on the accounting model of costs and returns, it is likely to be possible that a viable business model and corresponding design requirements can be formulated. It should be noted though, that up till now, faculty-based DOR projects have provided little insight in financial variables and corresponding design requirements. At the same time, in practice, sustainability is almost always dependent on such design requirements. Data collection in faculty-based DOR projects is necessary to lay a foundation for such design requirements. In particular, it makes sense to register consumption of project resources in relation to subtasks or in relation to the realization of specific components [Hartog, et al., 2008].

When a business model for design, realization, implementation and use of activating digital learning materials in large-enrolment classes has been realized, it will still be a challenge to get peers from outside the university to review the materials and achieve large-scale use outside the university. In faculty-based DOR projects, reviews by peers of other universities are also an essential component of the research process. Our experience has taught us that designers should avoid imposing a workload on evaluators that is not really necessary for a valid evaluation. We have looked into details of evaluator efforts that can be avoided and formulated design requirements to avoid unnecessary evaluator workload. In relation to this, it is noteworthy that requirements related to avoiding these efforts match well with high level characteristics of those innovations that are widely adopted [Rogers, 2003].

In general, we will want that the learning resources are also adopted by faculty at other universities. This fits scenarios based on submitting the resources to repositories/referatories or one of the publishers' scenarios. In general, one can expect that in many universities non-conformance to interoperability standards will impose a barrier for adoption by faculty. Thus, in scenarios based on repositories/referatories and in a number of publisher's scenarios, interoperability requirements become important.

Wide spread adoption by faculty also tends to be related to availability of coherent packages of critical size. Delivering such packages requires much routine design and routine realization of digital learning resources as well. Doing this efficiently also requires generic tools and infrastructural facilities. This suggests that stakeholders in faculty-based DOR projects after a bootstrapping phase should try to incorporate their projects in larger design and realization contexts such as a publisher's program, a distance learning program or an open courseware program. Part of the success of Udacity and Coursera may be attributed to the fact that they offer complete courses instead of much smaller modules.

In a distance learning program, an open courseware program and in certain publisher's programs, non-interoperability may become a requirement. In such programs, stakeholders may want to realize a competitive advantage by setting their own standards. Doing so gives them freedom in design and makes it more difficult for competitors to enter the same market. In such scenarios, a wide heterogeneous target population comes into view and requirements related to prior knowledge of students are very important. In such scenarios it is possible to continuously monitor knowledge of individual students both by gathering their answers to questions as well as gathering their questions, and to use this information to extend or personalize the learning resources on the fly. Actually, this is one of the approaches in Coursera. This fits web paradigms that are beyond current interoperability standards.

Often, it is believed that sustainability requires a viable business model. However, in general, it is difficult in an academic context to come up with a good business model for highly interactive digital learning resources even in projects that are aimed at wider populations [Mayo, 2009, Wieman and Perkins, 2006]. On the other hand, publishers have since long been able to realize successful business models for large-scale use of textbooks. Since a few years, publishers are starting to offer several web-based services that are based on digital learning resources. Some of these approaches (e.g. [Forio On-line Simulations, 2011, Harvard, 2000, Pearson, 2008]) really have achieved large-scale use. Alternatively, one might expect that any web venture that attracts hundreds of thousands or even millions of registered and active users such as

Udacity and Coursera may eventually be linked to a business model. Such a business model may for instance be based on fees for proctored exams.

At least, both faculty as well as all stakeholders involved in design and realization of activating digital learning resources should regularly monitor successful large-scale use scenarios.

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