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Ubiquitous Learning Architecture to Enable Learning Path Design across the Cumulative Learning Continuum

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Abstract: The past twelve years have seen ubiquitous learning (u-learning) emerging as a new learning paradigm based on ubiquitous technology. By integrating a high level of mobility into the learning environment, u-learning enables learning not only through formal but also through informal and social learning modalities. This makes it suitable for lifelong learners that want to explore, identify and seize such learning opportunities, and to fully build upon these experiences. This paper presents a theoretical framework for designing personalized learning paths for lifelong learners, which supports contemporary pedagogical approaches that can promote the idea of a cumulative learning continuum from pedagogy through andragogy to heutagogy where lifelong learners progress in maturity and autonomy. The framework design builds on existing conceptual and process models for pedagogy-driven design of learning ecosystems. Based on this framework, we propose a system architecture that aims to provide personalized learning pathways using selected pedagogical strategies, and to integrate formal, informal and social training offerings using two well-known learning and development reference models; the 70:20:10 framework and the 3–33 model.

Keywords: ubiquitous learning; pervasive learning; personalized learning; lifelong learning; learning path design; Experience Application Programming Interface (xAPI)

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1. Introduction

Over the past decade, there has been a significant increase in the use of computing and communication technologies, the key technologies of ubiquitous computing. A large number of small, portable electronic devices (e.g., mobile phones, Personal Digital Assistants (PDAs), wearable computers, sensors and actuators, Radio-Frequency IDentification (RFID) cards and tags) created new opportunities for individual learning activities to be embedded to our everyday life, and thus the term u-learning was coined to describe this new type of learning based on the use of ubiquitous technology.

Rapid changes of learning environments made it difficult for researchers to precisely define u-learning [1]. This resulted in various definitions that can be broadly classified into three categories, depending on the aspect they regard u-learning, i.e., the adopted technologies, the educational objects and the learning process. In a definition influenced by the classification of learning environments, u-learning was described as a combination of the e-learning and m-learning paradigms [2]. However, such a description does not consider five important characteristics of u-learning, i.e., permanency, accessibility, immediacy, interactivity and context-awareness. Therefore, this paper will refer to u-learning as "a learning paradigm which takes place in a ubiquitous computing environment that enables learning the right thing at the right place and time in the right way" [3].

Context-awareness distinguishes u-learning from other types of learning and is therefore considered a major characteristic by researchers, whereas permanency, accessibility, immediacy and interactivity are named common characteristics in the literature. The application of this major characteristic in technology-enhanced learning (TEL) systems was enabled by the use of mobile, wireless communication and sensing technologies, and it has led to the development of new learning environments that can remove the learning space limitations of the classroom, can provide personalized learning guidance (e.g., by using active learning support) [4], and can support learning in real-world contexts [5]. This new u-learning approach has been called "context-aware ubiquitous learning" or "contextual mobile learning" [1,6,7].

A research in the literature indicates the success of the context-aware u-learning approach in improving learning motivation, achievement and attitudes [6,8], and its effectiveness in conducting specific in-field learning activities supported by Mindtools [9]. However, this success entails new challenges for learners that are accustomed to traditional learning spaces and educational settings. Apart from the acquaintance with the latest u-learning technologies, learners are required to be highly adaptive as knowledge construction is now translated into forming connections among learning activities in various real-world contexts, and into recognizing knowledge patterns that appear to be hidden in these contexts.

Guiding learners to learn the right thing at the right place and time in the right way has proven to be a difficult task [10,11]. It involves arranging the learning activities in a way that takes the features of learning contents and the parameters of real-world environments into account. Without an effective guidance plan based on appropriate strategies and supporting tools, learners' performance could be significantly affected [12–14], especially when contexts combine both real-world and digital-world resources at the same time [15,16]. Therefore, developing an effective and efficient u-learning framework for designing personalized learning paths for lifelong learners is not only challenging, but also of great importance.

Although the terms ubiquitous computing and pervasive computing are synonymous and can be used interchangeably, this is not the case with pervasive learning and u-learning. Pervasive learning is highly localized and limited, whereas u-learning integrates a high level of mobility into the learning environment [3], and can thus be regarded as the successor of pervasive learning. U-learning enables learning through formal, informal and social learning modalities and this makes it suitable for lifelong learners that want to explore, identify and seize learning opportunities, throughout their life, and to fully build upon these experiences.

Preparing people for lifelong learning is considered nowadays a critical educational goal, which can be achieved by developing learners' capacity for self-direction [17]. However, even self-directed learners cannot cope with the increasing amount of available information regarding new learning opportunities. Although they strive to stay current in their field in a constantly changing society, they are still "confronted with the problem of how to find a way into and through a body of knowledge that is unknown at the outset. Without the benefit of any explicit guidance, a self-directed learner is obliged to map out a course of inquiry that seems appropriate, but that may involve a certain amount of difficulty and disappointment that could have been averted" [18]. There appears to be, therefore, a potentially important role for systems that can help learners plan their learning path at each key stage [19], and personalized learning has also the potential to be important for lifelong learning [20].

This article presents a theoretical framework for designing personalized learning paths for lifelong learners, which supports contemporary pedagogical approaches for learning across the learning continuum from Pedagogy through Andragogy to Heutagogy (PAH continuum) where lifelong learners progress in maturity and autonomy [21–24]. Although some researchers claim that e-learning systems should not be favourable to any specific pedagogical approach [25], this study follows a path that questions this pedagogical neutrality [26], and opts for "pedagogically 'engaged' or 'committed' conceptions of systems that serve specifiable educational purposes, situations and methods" [27]. The aim is to develop a theoretical framework that builds on Digital Learning Ecosystems (DLEs), the next-generation Technology-Enhanced Learning (TEL) systems with built-in pedagogical affordances [28]. Based on this framework, we propose a system architecture that integrates formal, informal and social training offerings using two well-known learning and development reference models, the 70:20:10 framework [29], and the 3–33 model [30].

The rest of the paper is organized as follows. Section 2 presents the theoretical framework while defining the key terms DLE, affordance and PAH continuum. In Section 3, we explain the technological aspect of the framework and its architecture. Section 4 discusses the integration of formal, informal and social learning, and Section 5 summarizes useful conclusions.

2. Theoretical Framework

The move to u-learning was mainly underpinned by new digital media and their transformative effects on learning environments. Therefore, a contemporary and future-proof theoretical framework for creating pedagogy-driven personalized learning pathways should be based on e-learning systems that use the latest ubiquitous computing technologies combined with appropriate learning theories. The last few years, a generation shift from closed and static to open and evolving systems seems to be happening in TEL [31]. Table 1 underlines the differences of the three generations of TEL systems in four dimensions, i.e., software architecture, pedagogical foundation, content management and dominant affordances.

Table 1. The three generations of TEL systems [28].

Dimensions	1st generation	2nd generation	3rd generation
Software architecture	Desktop software	Single server monolithic system	Cloud architecture, mobile clients
Pedagogical foundation	Operant conditioning	Pedagogical neutrality	Social constructivism, connectivism
Content management	Integrated content	Separated from software, reusable	Open, web-based, embeddable, placed outside, rich metadata
Dominant affordances	Presentation, drill, test	Presentation, assignments	Reflection, sharing, remixing, tagging, mashups, recommenders

The following subsection describes the third generation of TEL systems using ecological principles.

2.1. Digital Learning Ecosystems

A research in the literature reveals a recent trend towards describing TEL systems using the ecosystem metaphor. Uden et al. [32] use the term e-learning ecosystem to describe all the components required to implement an e-learning solution, i.e., content providers, consultants and infrastructure. A pervasive digital environment populated by digital components that evolve and adapt to local conditions comprises the digital infrastructure of the ecosystem. Ficheman and de Deus Lopes [33] consider a DLE as an aid for learning tool design, and describe it as the set of all relationships between biotic factors (actors and content) and between biotic and abiotic factors (environment). Another definition considers the same types of interactions, but models biotic components as Teaching Niche (lecturer, tutor and e-learning officer) and Learning Niche (student), and abiotic components as physical devices, internet connection, e-learning interface or portal and content. Teaching and learning are regarded as a source of energy and a transformative process where information generates knowledge [34].

The previous definitions model tools, services and content as the abiotic part of the ecosystem. While this is sufficient for describing second generation TEL systems, it cannot represent the third generation of open, loosely coupled, self-organised and evolving TEL systems. In order to describe such systems, we need to consider three important ecological principles: the flow of energy and exchange of matter, the feedback loop to and from the environment, and the interactions between species. We can then define a DLE as "an adaptive socio-technical system consisting of mutually interacting digital species (tools, services, content used in learning process) and communities of users (learners, facilitators, experts) together with their social, economic and cultural environment" [28].

Figure 1, adapted from [31], shows the landscape of TEL systems. Offline learning systems (e.g., textbooks on CDs and other teaching and learning software) are regarded as the first generation TEL systems, whereas Virtual Learning Environments (VLEs) are the second generation that appeared with the emergence of World Wide Web. The latter is a broad category that includes Personal Learning Environments (PLEs), Learning Object Repositories (LORs) and Learning Management Systems (LMSs).

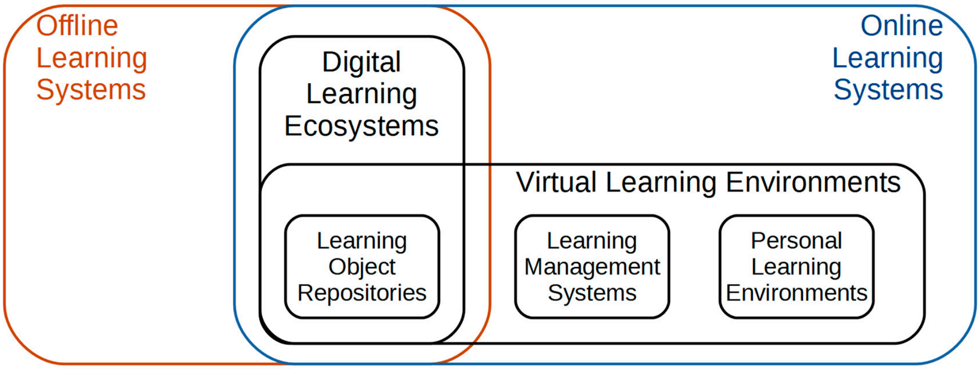

Figure 1. DLEs and their relationship to other key concepts of TEL systems.

The next parts of this study examine whether the above definition of DLE, which is based on ecological principles, is compliant with contemporary pedagogical theories and practices. The aim is to define a five-step approach that can be used for designing a pedagogy-driven u-learning framework. For this purpose, the concept of affordances is introduced, and the possibility of mapping affordances of learning theories on to affordances of technologies and standards is investigated.

2.2. Designing with Affordances

In consonance with the previous section that used the ecosystem metaphor to describe TEL systems, this section will use the affordances concept to describe the theoretical framework. The term affordance has its roots in ecological psychology and it was coined by Gibson in 1979 to describe the affordances of the environment as "what it *offers* the animal, what it *provides* or *furnishes*, either for good or ill" [35]. Not only has this concept of affordances evolved over the years, but it has also been adapted across different disciplines (cognitive science, design, education, Human–Computer Interface (HCI) studies and psychology) gaining new interpretations and uses (e.g., physical affordance, perceived affordance, social affordance etc.) [36].

In the HCI domain the term was introduced by Norman as "a relationship between the properties of an object and the capabilities of the agent that determine just how the object could possibly be used" [37]. Norman considered his definition of *perceived* affordance (usability) to be more important than the original definition of *real* affordance (utility) given by Gibson [38]. Kaptelinin and Nardi adopt a mediated action perspective on the term, considering both the possibilities for interacting directly with a technology (handling affordances), and the possibilities for employing a technology to make an effect on an object (effecter affordances) [39].

In the field of learning design, Kirschner et al. [40] provided an affordance framework for computer-supported collaborative learning (CSCL) environments based on three types of affordances, i.e., technological, social and educational. Technological affordances were associated with software usability, social affordances were defined as the "properties of a CSCL environment that act as social-contextual facilitators relevant for the learner's social interaction" [41], while educational affordances as "those characteristics of an artifact that determine if and how a particular learning behavior could possibly be enacted within a given context" [42]. Although this approach focuses on the development of a specific kind of learning environments, the use of affordances makes the learning design model ecological. However, the framework proposed by Kirschner et al. does not promote learners' self-monitoring and self-evaluating activities because the instructional designers are responsible for monitoring for affordances instead of the learners. The particular model does not fully support self-directed learning principles and it is, therefore, not appropriate for lifelong learners.

A more recent definition tried to address this issue by suggesting that learners should notice and negotiate the affordances of their individual and joint learning space, in order to allow self-planned, self-monitored and self-evaluated activities to be included in the learning design model [43,44]. Pata [45,46] identified the basic differences between traditional and ecological learning designs and proposed an ecological learning design framework for supporting self-directed learning in new social web.

While a variety of definitions have been discussed so far, this study will refer to the term affordance as "a perceived action-promoting property or relation between particular aspects of the situation and the subject who plans or undertakes actions in a certain environment" [47]. Based on the affordances of u-learning technologies, the following subsections describe a five-step approach for designing a pedagogy-driven u-learning framework. As shown in Figure 2, the process starts with selecting the learning theories that match the educational approaches of the PAH continuum.

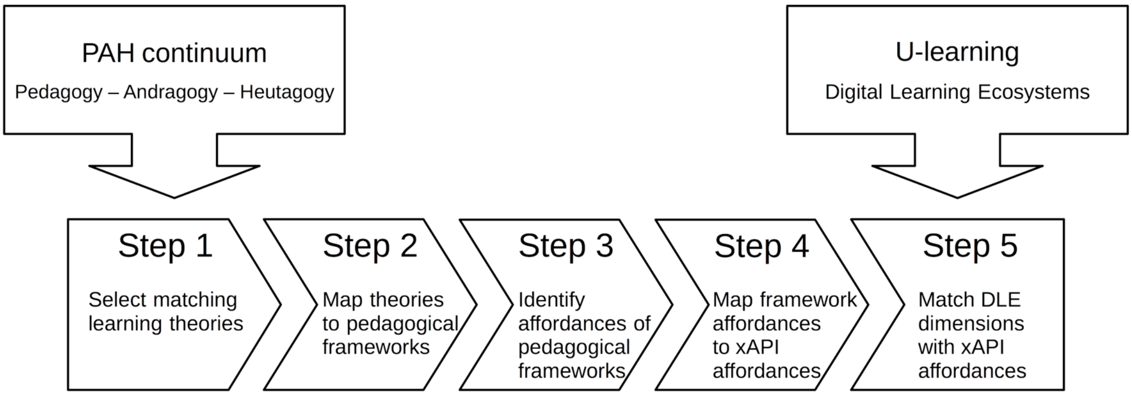

Figure 2. Five-step approach for designing a pedagogy-driven u-learning framework.

These theories are then mapped on to pedagogical frameworks. In the third step, the affordances of the frameworks are identified and mapped on to affordances of an e-learning software specification, which enables educational content and learning systems to communicate, record and track learning experiences—to this end the xAPI, [48–51], is adopted in this paper. The final step of this approach is to match the dimensions that define the potential/capacity of DLEs (which support the latest u-learning technologies) with the affordances of the xAPI. In this way, the proposed theoretical framework may promote pedagogy-driven learning path designs.

2.3. The PAH Continuum

Three different educational approaches form the pedagogical background of this framework. Luckin et al. [21] were among the first to interrelate these approaches and talk about a learning continuum from pedagogy through andragogy to heutagogy. The purpose of this study is to follow and facilitate learners' evolution and adapt to their arising learning needs, not only in the context of formal education, but over the span of a lifetime that also contains non-formal and informal learning experiences. We believe that this change in learners' needs as they develop their maturity and autonomy should be reflected in a change of applied educational approaches in DLEs, followed by a corresponding change of the facilitator's role as indicated by Canning [22].

Learners' maturation can be evaluated in terms of the three fundamental lifelong learning characteristics of self-direction, meta-cognitive awareness and disposition towards lifelong learning. Self-direction implies that the learning process is internally and psychologically controlled by the learner. This translates in learners diagnosing their needs and formulating their learning goals, choosing the learning resources, designing appropriate learning strategies and evaluating learning outcomes. Moreover, learners can take advantage of the collaboration with peers and colleagues, teams, informal social networks and communities of practice [52]. Metacognitive awareness is the learners' awareness of their own cognitive processes. Such skills are required in order for the learners to select learning behaviors and strategies, and to monitor and evaluate their effectiveness through self- assessment and reflection. Disposition towards lifelong learning can be translated in regarding learning as an ongoing process that requires learners to be intrinsic motivated, persistent, willing to take risks and learn from their mistakes, and having the intellectual curiosity and desire to build on existing knowledge.

Learners' progression in the PAH continuum can be scaffolded by appropriate learning design tools and support mechanisms controlled by tutors or experts and partially by the learners. Shift of tool control from tutors/experts to learners could indicate an increase in learners' maturity, and thus their readiness to undertake control of their own learning. Tutors'/experts' role with respect to learning design tools would then change from that of knowledge facilitators to learning strategy validators. It can be claimed, therefore, that heutagogy enables learners to determine their learning path when supported by an online technological framework, and social media can support important elements of the heutagogical approach like group collaboration and reflective practice through double-loop learning [23].

2.4. Learning Path Design across the Learning Continuum

Table 2 below depicts the first two steps of the proposed method (see Figure 2) for learning path design across the learning continuum. Each of the educational approaches is matched to one or more learning theories, based on previous research [53]. Then approaches are mapped to contemporary pedagogical frameworks in the third column of the table. For definitions of the learning theories shown in the table, interested readers can refer to [54].

Table 2. Mapping the PAH continuum on to learning theories and selected pedagogical frameworks.

Educational Approach	Learning Theory	Pedagogical Framework
Pedagogy	Essentialism, behaviourism, instructivism	Competence-based learning
Andragogy	Constructivism	Self-directed learning
Heutagogy	Connectivism	Self-determined learning

The selection of pedagogical frameworks was based on the following criteria:

- Importance in contemporary mainstream pedagogy;
- Compliance with the concept of affordances;
- Compliance with DLEs concept and other components of the framework;
- Frameworks should cover learning processes and their outcomes from both the learners' and the facilitator's perspectives.

For each of the selected pedagogical frameworks, a set of affordances is identified, shown in Table 3, following the affordances for competence-based and self-directed learning defined in [28]. This corresponds to the third step of the proposed learning path design approach.

All pedagogical framework affordances identified in the previous step are mapped to corresponding xAPI affordances as shown in Table 4. For information about the Tin Can API | Experience API (xAPI) readers can refer to [48–51].

Table 3. Affordances for selected pedagogical frameworks.

Pedagogical Framework	Affordances
Competence-based learning	Performance-based assessment, binding artefacts with domain concepts, presenting evidences
Self-directed learning	Self-directed goal setting, planning and documenting learning paths, scaffolds
Self-determined learning	Collaborative learning (team-based approaches) [1], development of capacity rather than competency (being able to learn in new and unfamiliar contexts), self-assessment and reflection, double-loop learning

[1] Communities of practice/interest, knowledge sharing in the form of sharing resources and information.

Table 4. Mapping pedagogical framework on to Tin Can API | Experience API (xAPI) affordances.

Pedagogical Framework	Framework Affordances	Tin Can API | Experience API (xAPI) Affordances
Competence-based learning	Performance-based assessment, binding artefacts with domain concepts, presenting evidences	Capture of (big) data on performance, learning analytics tool
Self-directed learning	Self-directed goal setting, planning and documenting learning paths, scaffolds	Aggregation of activity streams, learning paths that lead to successful learning outcomes can be identified and used for scaffolding
Self-determined learning	Collaborative learning, development of capacity rather than competency, self-assessment and reflection, double-loop learning	Allows for system-to-system communication, sharing statements, capture of instructional content and performance context information, and of (big) data on performance

In the final step depicted in Table 5, the xAPI affordances described above are mapped to DLE characteristics in four dimensions, those used to classify the three generations of TEL systems in Table 1. Readers can find more information about online and offline learning systems in Figure 1.

Table 5. DLE dimensions and corresponding Tin Can API | Experience API (xAPI) affordances.

Dimensions	DLE	Tin Can API | Experience API (xAPI) Affordances
Software architecture	Cloud architecture, mobile clients	RESTful web services (carry JSON payload) that allow activity providers store learning experiences in Learning Record Stores (LRSs), Tappestry mobile application
Pedagogical foundation	Social constructivism, connectivism	Supports recording and tracking of online and offline learning (formal, informal or operational) experiences, and therefore all types of pedagogies
Content management	Open, web-based, embeddable, placed outside, rich metadata	Allows for system-to-system communication, stand-alone system or embedded to an LMS, content can be linked to on the cloud, allows reporting and content analytics tools to extract data from any LRS
Dominant affordances	Reflection, sharing, remixing, tagging, mashups, recommenders	Capture of (big) data on performance, instructional content and performance context information (sub-APIs), sharing statements, aggregation of activity streams enables identification of learning paths that lead to successful learning outcomes

Having described the methodology for selecting pedagogical frameworks and the appropriate e-learning technology/standard, the following parts focus on the analysis of the proposed framework for pedagogy-driven u-learning and the corresponding system architecture.

3. Proposed Framework for Pedagogy-Driven Ubiquitous Learning

In this section, we discuss the overall framework and its constituent parts. Then we examine the architecture of the system.

3.1. Learning Path Design Framework

As depicted in Figure 3, key components of the framework include xAPI-compliant learning environments, a Personal Data Locker (PDL), one or more learning record stores (stand-alone and/or embedded), the learning path design tool, other applications and additional third party applications.

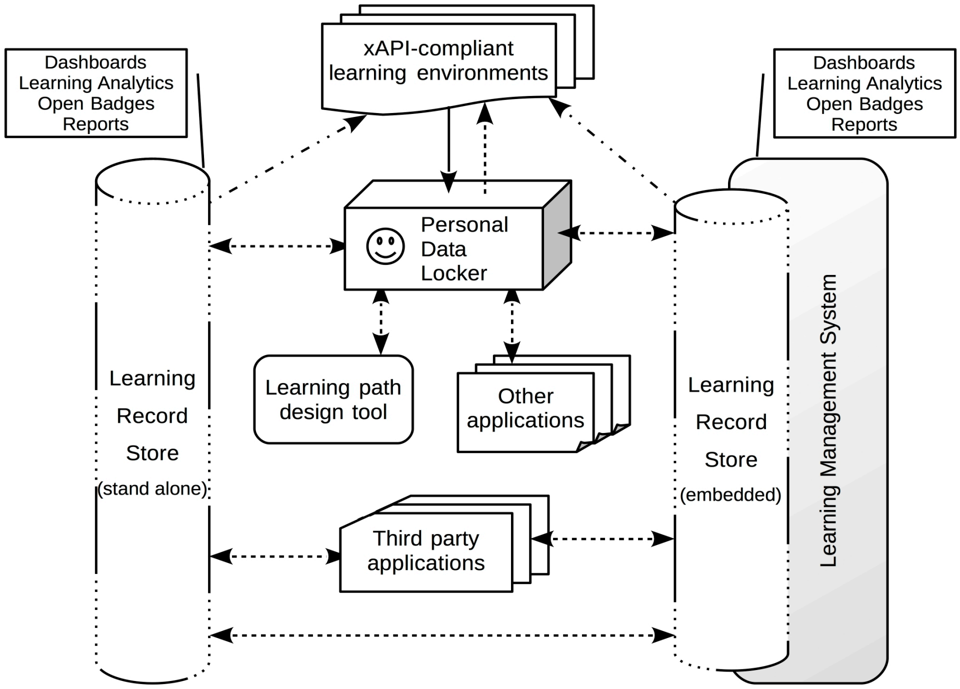

Figure 3. Proposed framework for pedagogy-driven ubiquitous learning.

In the remaining of this section, each of the framework parts as well as the way they communicate and exchange information will be reviewed starting with the xAPI-compliant learning environments. It is worth noting that Figure 3 shows a setup from the point of view of a single learner and therefore only one PDL is depicted. PDLs of different learners can communicate with each other and exchange information using the enhanced version of xAPI, which will be referred to in the remaining of this study as xAPI extended [55].

xAPI-compliant learning environments. All types of learning environments that can act as Activity Providers (APs), i.e., generate xAPI statements based on actions that occur within the environment and communicate those statements to one or more PDLs, are said to be xAPI-compliant. These learning environments are the primary source of information for PDLs along with the other types of APs (e.g., email programs, simulators, medical devices, mobile applications, etc.).

Personal data locker. The place where each learner can store his/her learning data and activities and which also gives learners complete control of this personal information is called a PDL. It is designed to hold xAPI statements and allow the owner to select the part of the data that should be made available to other PDLs, LRSs, and to any required form of learning (e.g., school, university or company training). The proposed framework adopts the xAPI extended version that puts emphasis on learners' personal rights and sovereignty over their learning data that xAPI-enabled applications record.

Learning path design tool. The most important element of the framework is the learning path design tool, which is used to help learners choose their learning paths. Its functionality is closely related to that of a PDL in the sense that it needs a PDL to store the user and domain models. As with the rest of the learning data, the owner of the PDL can decide if and which of the parts of these two models should be shared with other learners and applications. The tool has access to the learner's PDL and thus does not need to communicate with other PDLs and LRSs directly. When other learners' data is needed, the learning path design tool requests this information from the PDL, which in turn communicates and requests the information from other PDLs and/or LRSs. This capability of the PDL to connect to other PDLs and LRSs and collect data is really useful for exchanging learning path designs and learner models.

Other applications—third party applications. We use these categories to distinguish between applications that have been granted access to a PDL and can connect to it directly, and applications that can only access a PDL indirectly through an LRS. The former category results from the fact that users can take their learning records with them and transfer them from their school to their college/university and later to their employers or maybe to public authorities. Applications provided by such sources are considered to be trusted and they normally fall in the first category.

Learning record store. Statements from xAPI-compliant learning environments and other APs can also be saved in LRSs, the central store of xAPI. Learners have full control over the flow of data to LRSs because statements contain information about their learning experiences. There are two different types of LRSs, the stand alone and the embedded ones. Both types can connect to and exchange information with other LRSs and PDLs, but only the former type can provide some additional functionality with the stored data like dashboards, reports, learning analytics and even award Open Badges.

Learning management system. A LRS may be embedded to and thus be part of a LMS. In that case, the additional functionality described above can be offered by the LMS. However, the LRS will still have the capability to connect to other LRSs, APs and PDLs and exchange data. When extra information about a learner is needed, the LMS can send a request to the embedded LRS, which will then communicate with other LRSs to retrieve the requested data. The LMS can also act as an AP and report the learner's activity to the LRS.

In the next subsection, the architecture of the learning path design tool will be described. The PDL will also be depicted as part of the tool since it plays a significant role in the functionality of the overall system handling the communication and information exchange.

3.2. Learning Path Design System Architecture

The proposed architecture enables to combine technological, pedagogical and social aspects of learning path design, and to link different types of learning resources, integrating formal, non-formal and informal learning experiences. It was inspired by the generalized architecture of Adaptive Educational Hypermedia Systems (AEHS) [56], and the Informal Learning Support Framework (ILSF) [57]. Unlike AEHS, which store educational resources and their description model in the Media Space (MS), and ILSF, which holds informal learning objects and informal learning activities in a Learning Record Store (LRS), the proposed architecture does not provide storage for learning resources. However, it uses a PDL to store the user and domain models, and to exchange information with LRSs in order to search for and sequence all types of learning activities.

The social aspect of our architecture comes from the fact that it supports the exchange of lifelong learning paths between the users as a form of collaboration. This in turn requires comparability and exchangeability of courses, programmes and other types of learning actions, which can be achieved by adopting the learning path model [58]. In addition to learning paths, learners can also exchange their profile information. The lifelong learners' attributes that are stored in the user model can be found in [59].

The pedagogical aspect of the model architecture is based on the pedagogy-driven design of the framework that was discussed in the previous section. Learning path designs provided in early learning stages offer less autonomy to the learner, and this gradually changes in future learning path designs. It is important to note that the proposed framework of Figure 4 supports collaboration as a common approach for both its social and pedagogical learning design aspects.

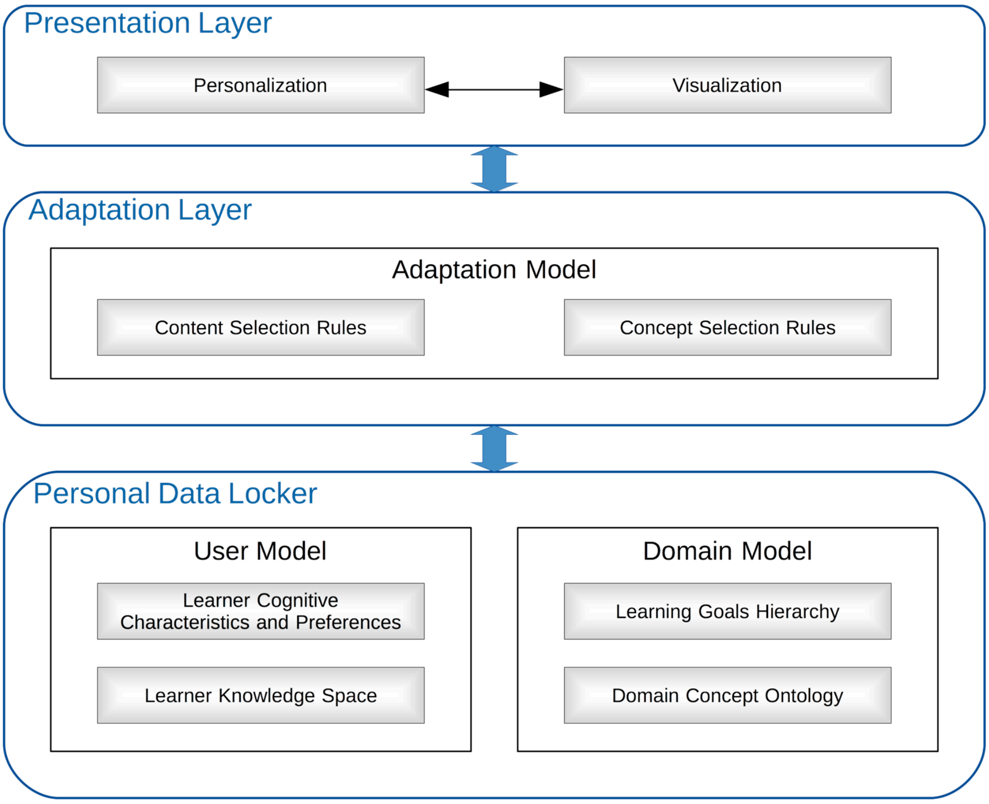

Figure 4. System architecture for pedagogy-driven learning path design.

Presentation layer. The task of the presentation layer is to present the contents of the PDL in a meaningful and easy to understand way, in order to support the design and decision making processes. It consists of the Personalization and the Visualization modules. The former is responsible for interpreting the adaptation rules specified in the Adaptation Model and for aligning them with the learning goals and the domain concept ontology, in order to generate personalized learning paths. In addition to the two main learning design roles Domain Expert and Instructional Designer [56], there are three additional roles (User, Parent and Tutor/Teacher) that can take part in the design process mainly by making decisions on the proposed learning paths by the system and on sharing of the user model and learning path information. The personalization module provides explicit and implicit user configuration as well as collaborative filtering [60]. The Visualization module helps users better understand the available information by making subject-based browsing and navigation easier [61]. There are several methods to implement the visualization of learning paths, e.g., timelines [62].

Adaptation layer. The adaptation model contains the rules for selecting both the concept and the content for the learning path. Selected concepts are retrieved from the domain model, while content is selected from external resources. It is envisaged that the proposed system can integrate formal, informal and social training offerings using two u-learning and development reference models; the 70:20:10 framework and the 3–33 model. This integration can be realized by translating these models into concept and content selection rules and by storing them in the adaptation model. A more detailed analysis of the use of these two reference models is presented in the following section.

Personal data locker. The PDL is used to store information in the user and domain models. Typical contents of the user model are the cognitive characteristics, preferences and the knowledge space. For the design of the latter, the overlay modelling approach can be used [63]. The domain model stores the domain concept ontology and the learning goals hierarchy, where each learning goal is associated with a set of concepts in the domain ontology. The PDL is designed to support group collaboration and knowledge sharing and provides all the functionality for sharing user models, learning paths and domain models.

4. Discussion

In the previous sections, the proposed framework was examined from a theoretical and a technological point of view. However, we have not discussed so far how the framework may use the 70:20:10 framework and the 3–33 model to integrate formal, informal and social training offerings. Since the selected e-learning software specification (xAPI) supports the 70:20:10 learning theory [64], we will explain the integration of training offerings through a usage scenario.

Jane is a secretary and she is interested in learning programming because she believes this knowledge will help develop within the organization she is working. Although she uses a computer at work every day, her background is not related to computer science and thus she does not know how to acquire the programming knowledge she needs. She decides to use the learning path design tool to achieve her learning goal.

Jane logs in the tool and gives it the permission to access her learning data by providing her unique PDL id. She has taken her learning records with her and transferred them from the college to her current employer so all her previous knowledge is recorded in the PDL. When the learning path design tool starts, it first searches the PDL for stored user and domain models. Jane has not used the tool before, which means that the tool will create her initial user model based on the statements recorded in the PDL. Then the user model will be stored in the PDL so that it will not have to be created again the next time the tool starts. Jane records her goal to learn programming, and also defines some search criteria (e.g., how long she can learn each day, the weekdays she is not available, etc.). The tool starts searching for existing learning paths that have the same learning goal by connecting to other PDLs and LRSs. During the search, it transpires that many of Jane's colleagues (PDL ids from the same company) have recorded programming knowledge.

When the search is finished, the tool ranks the resulted learning paths according to Jane's search criteria. In addition, the tool suggests that Jane should use the 70:20:10 framework to benefit from her colleagues' programming knowledge. Jane has not heard about that framework before, but after reading the short description, she decides to follow the suggested learning method.

Once the learning method is selected, the tool displays a new screen with instructions that explain what Jane should do next. Since the chosen framework suggests that approximately 70% of the learning time should be through workplace challenges and experiences, the tool suggests that Jane should spend 70% of her learning time to write a small software application (e.g., an appointment organizer software) to solve every day work problems. Then, 20% of her learning should be through contact with other people (social learning) so the learning path design tool shows the PDL ids of people that are available and willing to teach programming. Finally, for the remaining 10% of the learning time, the tool has selected an appropriate short course that Jane can attend when she is available. In this way, the learning path design tool has helped user Jane to successfully integrate formal, informal and social learning experiences.

A similar usage scenario could be presented to describe the integration of learning experiences using the 3–33 model. The only difference in that case would be that 33% of the learning should be acquired through formal, 33% through informal and 33% through social learning activities. The adaptation model would then apply the content selection rules that correspond to the 3–33 learning model to achieve the integration of these three types of learning experiences.

5. Conclusions

This paper described a framework for pedagogy-driven learning path design, as part of a u-learning environment where DLEs communicate and exchange information through the experience API. The framework is underpinned by the PAH cumulative continuum and aims to promote the u-learning definition of learning the right thing at the right place and time in the right way. Its value lies in the fact that the supported learning path designs take the features of learning contents and the parameters of real-world environments into account, and can link formal, informal and social training offerings using the 70:20:10 framework and the 3–33 model.

In the proposed layered system architecture for pedagogy-driven learning path design, there is a clear separation of the functionality of each layer, and a correspondence between layers and supported learning design features. Hence, the presentation layer implements the system's personalization features. The adaptation layer applies the content and concept selection rules to promote the PAH continuum and link formal, informal and social learning experiences. The PDL stores the user and domain models and enables collaboration (user model, learning path and domain model sharing).

The system's cloud architecture implements the experience API, which enables the recording and tracking of both online and offline learning. Thus, its efficiency can be easily proven. Future work will concentrate on examining possible ways to implement and evaluate the proposed framework.

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References

1. Hwang, G.-J.; Tsai, C.-C.; Yang, S.J.H. Criteria, Strategies and Research Issues of Context-Aware Ubiquitous Learning. *J. Educ. Technol. Soc.* **2008**, *11*, 81–91.
2. Casey, D. u-Learning = e-Learning + m-Learning. In *E-Learn 2005–World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education*; Richards, G., Ed.; Association for the Advancement of Computing in Education (AACE): Vancouver, BC, Canada, 2005; pp. 2864–2871.
3. Yahya, S.; Ahmad, E.A.; Jalil, K.A. The definition and characteristics of ubiquitous learning: A discussion. *Int. J. Educ. Dev. Using Inf. Commun. Technol.* **2010**, *6*, 117–127.
4. Hsu, T.Y.; Chiou, C.K.; Tseng, J.C.R.; Hwang, G.J. Development and Evaluation of an Active Learning Support System for Context-Aware Ubiquitous Learning. *IEEE Trans. Learn. Technol.* **2016**, *9*, 37–45. [CrossRef]
5. Yin, P.-Y.; Chuang, K.-H.; Hwang, G.-J. Developing a context-aware ubiquitous learning system based on a hyper-heuristic approach by taking real-world constraints into account. *Univers. Access Inf. Soc.* **2016**, *15*, 315–328. [CrossRef]
6. Chen, C.-C.; Huang, T.-C. Learning in a u-museum: Developing a context-aware ubiquitous learning environment. *Comput. Educ.* **2012**, *59*, 873–883. [CrossRef]
7. Din, F.S. The Functions of Class Size Perceived by Chinese Rural School Teachers. *Natl. Forum Appl. Educ. Res. J.* **1999**, *12*, 1–6.
8. Akkerman, S.; Admiraal, W.; Huizenga, J. Storification in history education: A mobile game in and about medieval Amsterdam. *Comput. Educ.* **2009**, *52*, 449–459. [CrossRef]
9. Hwang, G.-J.; Hung, P.-H.; Chen, N.-S.; Liu, G.-Z. Mindtool-Assisted In-Field Learning (MAIL): An Advanced Ubiquitous Learning Project in Taiwan. *J. Educ. Technol. Soc.* **2014**, *17*, 4–16.
10. Chiou, C.-K.; Tseng, J.C. R.; Hwang, G.-J.; Heller, S. An adaptive navigation support system for conducting context-aware ubiquitous learning in museums. *Comput. Educ.* **2010**, *55*, 834–845. [CrossRef]
11. Hwang, G.-J.; Kuo, F.-R.; Yin, P.-Y.; Chuang, K.-H. A Heuristic Algorithm for planning personalized learning paths for context-aware ubiquitous learning. *Comput. Educ.* **2010**, *54*, 404–415. [CrossRef]
12. Chu, H.-C.; Hwang, G.-J.; Tsai, C.-C. A knowledge engineering approach to developing mindtools for context-aware ubiquitous learning. *Comput. Educ.* **2010**, *54*, 289–297. [CrossRef]
13. Chen, C.M.; Li, Y.L.; Chen, M.C. Personalized Context-Aware Ubiquitous Learning System for Supporting Effectively English Vocabulary Learning. In Proceedings of the IEEE International Conference on Advanced Learning Technologies, Niigata, Japan, 18–20 July 2007; pp. 628–630.
14. Liu, T.-C.; Peng, H.; Wu, W.-H.; Lin, M.-S. The Effects of Mobile Natural-Science Learning Based on the 5E Learning Cycle: A Case Study. *J. Educ. Technol. Soc.* **2009**, *12*, 344–358.
15. Shih, J.; Hwang, G.; Chu, Y.; Chuang, C. An investigation-based learning model for using digital libraries to support mobile learning activities. *Electron. Libr.* **2011**, *29*, 488–505. [CrossRef]

16. Hwang, G.J.; Wu, P.H.; Zhuang, Y.Y.; Huang, Y.M. Effects of the inquiry-based mobile learning model on the cognitive load and learning achievement of students. *Interact. Learn. Environ.* **2013**, *21*, 338–354. [CrossRef]
17. Dunlap, J.C.; Grabinger, S. Preparing Students for Lifelong Learning: A Review of Instructional Features and Teaching Methodologies. *Perform. Improv. Q.* **2003**, *16*, 6–25. [CrossRef]
18. Candy, P.C. *Self-Direction for Lifelong Learning: A Comprehensive Guide to Theory and Practice*; Higher and Adult Education Series; John Wiley & Sons: Hoboken, NJ, USA, 1991.
19. Tattersall, C.; Manderveld, J.; van den Berg, B.; van Es, R.; Janssen, J.; Koper, R. Self organising wayfinding support for lifelong learners. *Educ. Inf. Technol.* **2005**, *10*, 109–121. [CrossRef]
20. Knapper, C.K.; Cropley, A.J. *Lifelong Learning in Higher Education*, 3rd ed.; Kogan Page Limited: London, UK, 2000.
21. Luckin, R.; Clark, W.; Garnett, F.; Whitworth, A.; Akass, J.; Cook, J.; Day, P.; Ecclesfield, N.; Hamilton, T.; Robertson, J. Learner-generated contexts: A framework to support the effective use of technology for learning. In *Web 2.0-Based E-Learning: Applying Social Informatics for Tertiary Teaching*; IGI Global: Hershey, PA, USA, 2010; pp. 70–84.
22. Canning, N. Playing with heutagogy: Exploring strategies to empower mature learners in higher education. *J. Furth. High. Educ.* **2010**, *34*, 59–71. [CrossRef]
23. Blaschke, L. Heutagogy and lifelong learning: A review of heutagogical practice and self-determined learning. *Int. Rev. Res. Open Distrib. Learn.* **2012**, *13*, 56–71.
24. Garnett, F.; O'Beirne, R. Putting heutagogy into learning. In *Self-Determined Learning: Heutagogy in Action*; Hase, S., Kenyon, C., Eds.; Bloomsbury Academic: London, UK, 2013; pp. 131–143.
25. Koper, R. *Modelling Units of Study from a Pedagogical Perspective: The Pedagogical Meta-Model behind EML*; OTEC working paper; Open University of the Netherlands: Heerlen, The Netherland, 2001; p. 40.
26. Laanpere, M.; Põldoja, H.; Kikkas, K. The second thoughts about pedagogical neutrality of LMS. In Proceedings of IEEE International Conference on Advanced Learning Technologies, Joensuu, Finland, 30 August–1 September 2004; pp. 807–809.
27. Friesen, N. Learning objects and standards: Pedagogical neutrality and engagement. In Proceedings of the IEEE International Conference on Advanced Learning Technologies, Joensuu, Finland, 30 August–1 September 2004; pp. 1070–1071.
28. Laanpere, M.; Pata, K.; Normak, P.; Põldoja, H. Pedagogy-Driven Design of Digital Learning Ecosystems. *Comput. Sci. Inf. Syst.* **2014**, *11*, 419–442. [CrossRef]
29. Lombardo, M.M.; Eichinger, R.W. *The Career Architect Development Planner*, 1st ed.; Lominger Limited: Minneapolis, MN, USA, 1996.
30. Pontefract, D. *Flat Army: Creating a Connected and Engaged Organization*; Jossey-Bass: San Francisco CA, USA, 2013.
31. Laanpere, M.; Põldoja, H.; Normak, P. Designing dippler—A next-generation TEL system. In *Open and Social Technologies for Networked Learning: IFIP WG 3.4 International Conference, OST 2012, Tallinn, Estonia, July 30–August 3, 2012, Revised Selected Papers*; Ley, T., Ruohonen, M., Laanpere, M., Tatnall, A., Eds.; Springer: Berlin/Heidelberg, Germany, 2013; pp. 91–100.
32. Uden, L.; Wangsa, I.T.; Damiani, E. The future of E-learning: E-learning ecosystem. In Proceedings of the 2007 Inaugural IEEE-IES Digital EcoSystems and Technologies Conference, Cairns, Australia, 21–23 February 2007; pp. 113–117.
33. Ficheman, I.K.; de Deus Lopes, R. Digital learning ecosystems: Authoring, collaboration, immersion and mobility. In *Proceedings of the 7th International Conference on Interaction Design and Children, IDC '08*; ACM: New York, NY, USA, 2008; pp. 9–12.
34. Reyna, J. Digital Teaching and Learning Ecosystem (DTLE): A Theoretical Approach for Online Learning Environments. In *Proceedings of ASCILITE—Australian Society for Computers in Learning in Tertiary Education Annual Conference 2011*; Australasian Society for Computers in Learning in Tertiary Education: Hobart, Tasmania, Australia, 2011; pp. 1083–1088.
35. Gibson, J.J. *The Ecological Approach to Visual Perception*; Psychology Press: New York, NY, USA, 2015.
36. Overhill, H.J.J. Gibson and Marshall McLuhan: A survey of terminology and a proposed extension of the theory of affordances. *Proc. Am. Soc. Inf. Sci. Technol.* **2012**, *49*, 1–4. [CrossRef]
37. Norman, D. *The Design of Everyday Things*; Doubleday: New York, NY, USA, 1988.

38. Bower, M. Affordance analysis—Matching learning tasks with learning technologies. *Educ. Media Int.* **2008**, *45*, 3–15. [CrossRef]
39. Kaptelinin, V.; Nardi, B. Affordances in HCI: Toward a Mediated Action Perspective. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI'12, Austin, TX, USA, 5–10 May 2012; pp. 967–976.
40. Kirschner, P.; Strijbos, J.-W.; Kreijns, K.; Beers, P.J. Designing electronic collaborative learning environments. *Educ. Technol. Res. Dev.* **2004**, *52*, 47–66. [CrossRef]
41. Kreijns, K.; Kirschner, P.A.; Jochems, W. The Sociability of Computer-Supported Collaborative Learning Environment. *J. Educ. Technol. Soc.* **2002**, *5*, 8–22.
42. Kirschner, P.A. Can we support CSCL? Educational, social and technological affordances for learning. In *Three Worlds of CSCL: Can We Support CSCL*; Kirschner, P.A., Ed.; Open Universiteit Netherlands: Heerlen, The Netherlands, 2002; pp. 7–47.
43. Fiedler, S.; Pata, K. Distributed Learning Environments and Social Software: In Search for a Framework of Design. In *Handbook of Research on Social Software and Developing Community Ontologies*; Hatzipanagos, S., Warburton, S., Eds.; IGI Global: Hershey, PA, USA, 2009; pp. 145–158.
44. Pata, K.; Väljataga, T. Collaborating across national and institutional boundaries in higher education—The decentralized iCamp approach. In *Proceedings of EdMedia: World Conference on Educational Media and Technology 2007*; Montgomerie, C., Seale, J., Eds.; Association for the Advancement of Computing in Education (AACE): Vancouver, BC, Canada, 2007; pp. 353–362.
45. Pata, K. Modeling spaces for self-directed learning at university courses. *J. Educ. Technol. Soc.* **2009**, *12*, 23–43.
46. Pata, K. Revising the Framework of Knowledge Ecologies: How Activity Patterns Define Learning Spaces. In *Educational Social Software for Context-Aware Learning: Collaborative Methods and Human Interaction*; Lambropoulos, N., Romero, M., Eds.; IGI Global: Hershey, PA, USA, 2010; pp. 241–267.
47. Normak, P.; Pata, K.; Kaipainen, M. An Ecological Approach to Learning Dynamics. *J. Educ. Technol. Soc.* **2012**, *15*, 262–274.
48. Tin Can API. Available online: http://tincanapi.com (accessed on 14 July 2016).
49. Experience API (xAPI). Available online: http://experienceapi.com (accessed on 14 July 2016).
50. Layers of the Tin Can Onion. Available online: http://tincanapi.com/wp-content/assets/Onion/Layers-of-the-Tin-Can-Onion.pdf (accessed on 14 July 2016).
51. Human Performance (Big) Data Specification. Available online: https://adlnet.gov/adl-assets/uploads/2016/01/xAPI_OnePager_FINAL.pdf (accessed on 14 July 2016).
52. Kerka, S. *Self-Directed Learning. Myths and Realities*; ERIC Clearinghouse on Adult, Career, and Vocational Education: Columbus, OH, USA, 1999.
53. Gerstein, J. Moving from Education 1.0 through Education 2.0 towards Education 3.0. In *Experiences in Self-Determined Learning*; Blaschke, L.M., Kenyon, C., Hase, S., Eds.; Create Space Independent Publishing Platform: Milton Keynes, UK, 2014; pp. 83–98.
54. Essentialism. Available online: http://www.siue.edu/~ptheodo/foundations/essentialism.html (accessed on 30 July 2016).
55. Schaffarzyk, H. The Enhanced Version of xAPI (xAPI extended). Available online: https://personal-data-locker.org/en/ (accessed on 2 August 2016).
56. Karampiperis, P.; Sampson, D. Adaptive Learning Resources Sequencing in Educational Hypermedia Systems. *Educ. Technol. Soc.* **2005**, *8*, 128–147.
57. Galanis, N.; Mayol, E.; Alier, M.; Garcia-Peñalvo, F.J. Designing an Informal Learning Support Framework. In Proceedings of the 3rd International Conference on Technological Ecosystems for Enhancing Multiculturality, Porto, Portugal, 7–9 October 2015; pp. 461–466.
58. Janssen, J.; Berlanga, A.; Vogten, H.; Koper, R. Towards a learning path specification. *Int. J. Contin. Eng. Educ. Lifelong Learn.* **2008**, *18*, 77–97. [CrossRef]
59. Baajour, H.; Magoulas, G.D.; Poulovassilis, A. Modelling the lifelong learner in a services-based environment. In Proceedings of the ITA 2007—2nd International Conference on Internet Technologies and Applications, Wrexham, North East Wales, UK, 4–7 September 2007; pp. 181–190.
60. Instone, K. *Information Architecture and Personalization: An Information Architecture-Based Framework for Personalization Systems*; Argus Center: Melbourne, Australia, 2000.
61. Marwick, A.D. Knowledge management technology. *IBM Syst. J.* **2001**, *40*, 814–830. [CrossRef]

62. De Freitas, S.; Magoulas, G.; Oliver, M.; Papamarkos, G.; Poulovassilis, A.; Harrison, I.; Mee, A. L4all-a web-service based system for lifelong learners. In *The Learning Grid Handbook: Concepts, Technologies and Applications: The Future of Learning*; IOS Press: Amsterdam, The Netherlands, 2008; pp. 143–155.
63. Brusilovsky, P.; Millán, E. User models for adaptive hypermedia and adaptive educational systems. In *The Adaptive Web*; Brusilovsky, P., Kobsa, A., Nejdl, W., Eds.; Springer: Berlin, Heidelberg, Germany, 2007; pp. 3–53.
64. 70:20:10. Available online: https://tincanapi.com/70-20-10/ (accessed on 5 August 2016).