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Pedagogy-driven Design of Digital Learning Ecosystems

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Abstract. In most cases, the traditional Web-based learning management systems (e.g. Moodle, Blackboard) have been designed without any built-in support for a preferred pedagogical model or approach. The proponents of such systems have claimed that this kind of inherent "pedagogical neutrality" is a desirable characteristic for a LMS, as it allows teachers to implement various pedagogical approaches. This study is based on an opposite approach, arguing for designing next-generation online learning platforms – so called digital learning ecosystems – with built-in affordances, which promote and enforce desirable pedagogical beliefs, strategies and learning activity patterns while suppressing others. We propose a conceptual and process model for pedagogy-driven design of online learning environments and illustrate it with a case study on development and implementation process of a digital learning ecosystem based on Dippler platform. We also describe the pedagogical foundation of Dippler that was guided by a combination of four contemporary pedagogical approaches: self-directed learning, competence-based learning, collaborative knowledge building and task-centered instructional design.

Keywords: digital learning ecosystems, pedagogy-driven design.

1. Introduction

This study was initially motivated by emerging opposition to the imperative of pedagogical neutrality of tools and platforms built for Technology-Enhanced Learning [1]. Among others, Koper [2] has argued that e-learning systems should not be biased towards any specific pedagogical approach, in order to allow every teacher to implement the teaching methods of his/her own choice. Some authors have argued that it is almost impossible to build technological tools that are completely pedagogically neutral or theory-agnostic. This is why we follow alternative path, proposed by Norm Friesen [3] who advocated the development of ‘pedagogically “engaged” or “committed” conceptions of content and systems that serve specifiable educational purposes, situations and methods’.

The main research problem for our study is: how to design next-generation Technology-Enhanced Learning (TEL) systems with built-in pedagogical affordances, which enhance innovative teaching and learning practices and reflect modern learning theories?

This paper is seeking the answers to the following research questions:

- What constitutes the model for pedagogy-driven design?
- Which pedagogical approaches could/should be promoted by the pedagogy-driven design of the next-generation online learning platforms?

- How to implement the pedagogy-driven model in the process of developing a new type of online learning platform: a digital learning ecosystem?

Methodologically, the study follows the tradition of design-based research, where theorizing is combined with participatory design sessions involving potential users and followed by design experiments where prototypes are validated in real-life situations.

2. Related Works

There have been few attempts to define explicitly and operationalize the driving role for pedagogy in designing and developing learning environments. For instance, Radcliffe et al [4] have proposed heuristic Pedagogy-Space-Technology (PST) framework for designing physical learning spaces in a pedagogy-driven manner. Instead of prescribing some rigid design principles, the PST framework builds on a set of guiding questions, e.g. "What type(s) of learning and teaching are we trying to foster and why? Why is this likely to make a difference to learning? What is the theory & evidence? What plans will be made to modify programs or courses to take advantage of the new facilities?" [4].

Quite often the characteristic of being "pedagogy-driven" is stressing the binary opposition with negatively connoted "technology-driven" approach. For instance, Adams & Morgan [5] contrast "second generation e-learning" from the previous generation, by claiming that the latter is technology-driven, while former is pedagogy-driven, learner-controlled, involving self-assessment and reflective practice, integrating theory with practice and work. Most of pedagogy-driven approaches are inspired by learner-centered or constructivist pedagogical paradigm [6].

Although critique towards technology-driven approach to e-learning has been widespread for more than a decade, there are only few attempts to formalise pedagogy-driven design of new online learning tools. For instance, Rubens et al [7] describe implementation of pedagogical principles based on knowledge building theory [8] in designing two online learning environments: Synergeia and FLE3 [7]. Another study by Kong & So [9] focuses on designing a learning environment in line with inquiry-based learning approach. So, Seah and Toh-Heng [10] have studied and confirmed the impact of pedagogy-driven design of Knowledge Forum on students' learning outcomes. As a result of an 8-years study carried out in the University of Antwerp, Colpaert [11] has explored the boundaries of pedagogy-driven research in the context of online language learning. His pedagogy-driven approach involves "a detailed specification of what is needed for language-teaching and -learning purposes in a specific context, defines the most appropriate method, and finally attempts to describe the technological requirements to make it work" [11]. As such, it is contrasted by Colpaert with three alternative approaches to development of online learning environment: technology-driven, attributes-based and affordance-based. Colpaert's pedagogy-driven design model takes eventually a form quite similar to generic design process model ADDIE: an acronym describing the traditional phases of generic 5-step design model (Analysis, Design, Development, Implementation, Evaluation).

Moodle is the most popular open-source LMS around the world with more than 65000 installations and 58 million users in 215 countries (according to the official statistics from Moodle's home page). Moodle was built in 2000-2002 by Martin Dougiamas with his PhD research, this initiative was fueled by his frustration about dominant commercial LMS of that time: WebCT [12]. Although Dougiamas claims that Moodle is based on social constructivist learning approach (ibid.), it is in fact not so much different from its proposed antipode WebCT with regard to its architecture, affordances and vocabulary used in user interface.

There are also some new initiatives in TEL researchers' camp, trying to define formalized domain ontologies for TEL, in order to be able to describe different pedagogical concepts and activities in interoperable manner. For instance, Arapi et al [13] have proposed a pedagogy-driven personalisation framework to support adaptive learning experiences in line with tradition of adaptive hypermedia and intelligent tutoring systems. Unfortunately, their understanding of pedagogy is limited with IMS Learning Design (LD) specification, which seems to be mainstream approach to operationalizing pedagogical ideas within the community of Technology-Enhanced Learning research. IMS LD is a notation and standard for describing pedagogical scenarios and it is built as "pedagogically neutral" in order to support variety of pedagogies [14]. To enforce pedagogical neutrality, IMS LD excludes from its base vocabulary familiar concepts related with learning and teaching, which might be associated with some pedagogical paradigm or approach. Instead, IMS LD uses metaphors borrowed from the theatrical realm: "play", "act", "role-part". Course (as well as section of the course or lesson) is called Unit of Learning in IMS LD. Unit of Learning consists of Learning Objects, Services, Tools, Activity-structures, Activities and Items [14].

As Rorty [15] has put it: our vocabulary creates the world, not vice versa. If we allow structuring of our pedagogical practice by vocabulary provided by pedagogically irrelevant LD, it is likely to hinder pedagogical creativity of teachers. Rorty refers to final vocabulary as the set of words a person uses to justify her/his beliefs, actions, and tell her/his life story. Rorty's ideal is liberal ironist who questions her final vocabulary, acknowledges that her current vocabulary is not the best one and tries to find alternative metaphors to re-describe the world. For an ironist, it would be a failure "to accept somebody else's description of oneself". We could bring this line of thinking to the level of teaching profession as a community of practice, which owns a set of vocabularies for describing its professional practice and identities, success stories and problems. Evolving and creative professional community should seek for new metaphors to re-describe their practice using new vocabularies. LD has built on metaphysical (in Rorty's sense) assumption that all potential pedagogical vocabularies can be translated into "neutral" set of LD concepts, implying the supremacy of LD as the ultimate final vocabulary.

Apart from rigid and pedagogically irrelevant vocabulary, LD has also other issues related with its technological implementation. Units of Learning (UoL) are usually sequenced in a linear manner, enforcing hierarchical top-down pre-structuring of learning experiences. The same linearity is common (because it is easiest to create) also as internal structure of an UoL. Such approach enforces the idea of learning as passive acquisition, as it is very difficult to describe active and discovery learning, collaborative knowledge building and inquiry-based learning with LD logic. On the level of architecture, IMS LD Units of Learning are expected to be handled by "players", which are available only for a few LMS. Majority of cases in literature are based on using separate LD software (e.g. Re-load, Re-course, Prolix OpenGLM, MOT+, LAMS), which are complex and hardly usable by an average teacher. LAMS is one of the few teacher-friendly LD tools, but is too much tool-driven and difficult to integrate with LMS, and it is not even compatible with IMS LD. Although several lab studies [16] have demonstrated general acceptance of LD tools by users, the use of LD has not scaled up within the last 8 years, which means it is becoming increasingly unlikely it ever will.

To conclude this brief literature review on the topic of pedagogy-driven design, we have to acknowledge that despite of the general attractiveness of pedagogy-driven design as an approach opposing to technology-driven design, there is no clear definition of this concept, neither well-established theoretical framework, nor practical design methodologies for implementing it in software engineering. This paper aims at filling in these gaps and validating our pedagogy-driven design model through a case study on developing a next-generation online learning environment Dippler.

3. Digital Learning Ecosystems

Laanpere, Põldoja & Normak [17] have described undergoing generation shift in Technology-Enhanced Learning (TEL) systems, arguing that closed and static Learning Management Systems belonging to the second-generation are going to be replaced by third generation, open and evolving Digital Learning Ecosystems.

Table 1. Generations of TEL systems

Dimension	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	Content was integrated	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

Several proposals considering ecological principles in e-learning have appeared in last decade [18], [19], but their uptake into the system design has been quite passive until the recent massive usage of social software for e-learning. Adopting ecology in digital e-learning systems suggests using the “digital learning ecosystem” concept that has been proposed by several researchers [20], [21], [22], but this concept has various modifications, particularly in how the biotic/abiotic component is modeled in ecosystem.

Biological ecosystems are usually divided in two parts: biotic component contains living organisms (species) and abiotic part is environment (air, temperature, humidity, soil, lighting). We define 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, economical and cultural environment. While the second generation of TEL systems presented software systems as an environment where learners and teachers interacted with each other as well as with learning resources, we propose to turn the roles upside down for DLE. In DLE, the “species” or “organisms” are various interacting software tools and services together with their users, while larger technological landscape, social and cultural contexts play the role of the “environment”. This is a change of paradigm, which will help us better understand, analyse and design the future tools and services to enhance learning. We are not using ecological concepts as metaphors, we propose to extend the ecosystems theory towards the digital world. Let us examine, how the three main principles of ecology translate into digital ecosystems.

The first principle in ecology is that the flow of energy and the exchange of matter through open ecosystem is regulated by the interactions of species and the abiotic component (by the web of energy and matter). Reyna [9] conceptualized “teaching and learning” as this energy that empowers digital learning ecosystems to changing “information to knowledge”. The permeability of a digital learning ecosystem to the export and/or import of information and knowledge depend on the nature of the ‘architecture’ of the components of the system (e. g. connectivity, clustering), the characteristics of species, and their diversity and distribution, and interactions between them (such as commensalism).

The second important ecological principle is existence of the feedback loop to and from the environment that enables species to be adaptive to the environment and the environment to change as a result of species. A recent literature in evolutionary theory elaborates the notion of niche construction [23] as an ecological factor that enables organisms to contribute for and benefit from environmental information. If organisms evolve in response to selection pressures modified by themselves and their ancestors, there is feedback in the system. In our approach to digital learning ecosystems, the “service-species” are activated by users with different roles (learner, facilitator) and their learning intentions. Ecological psychology [24] suggests that learner’s/teachers’ direct perception of the learning environment’s action potentialities (or so-called affordances) varies and this would give the variability to the actual use of services in the e-learning system. The niches for each service-species in the digital ecosystem may be collected from this user-behavior, for example by learning analytics (an emerging approach to tracing digital footprints of learners and groups, visualizing the learning-related patterns).

The third important principle that we extend from ecology to technology-enhanced learning domain is associated with the communicative interactions between species. The digital community is a naturally occurring group of “service-species” populations in e-learning ecosystem who inhabit the same habitat (but use different niches) and form temporary coalitions (communities). For example the mutualisms such as parasitism, symbiosis or commensalism may appear between service species are associated with sharing the resources and associate with our first principle (energy and matter exchanges in the network). Other type of interactions, based on communication, which assumes mutual awareness, signaling between agents (or using the accumulated signals left into the environment) may be distinguished as well.

As a result of applying these three ecological principles on designing the next-generation online learning platforms, an open, loosely coupled, self-organised and emergent digital learning ecosystem can evolve. Furthermore, above listed ecological principles of TEL systems design seem to be highly compliant with today's most influential pedagogical theories and innovative practices, as it will be demonstrated in the next chapter.

4. Conceptualizing the Pedagogy-driven Design

We have argued before that the first learning management systems (e.g. WebCT, Moodle) were designed by software engineers who took over existing solutions from other, non-pedagogical domains. For instance, to solve the problem of sharing the learning resources, designers provided file upload functionality in LMS. For synchronous communication, a chat module was provided, for asynchronous communication: forum. In contrast, designers of FLE3 [7] demonstrated, how asynchronous communication can be designed in the cognitive paradigm, in the pedagogy-driven manner. After outlining the characteristic phases of collaborative knowledge building (setting up the context, defining initial research problem, creating working theories etc.) they designed quite different discussion tool with strong pedagogical affordances.

Design is increasingly social activity, the traditions of user-centered and participatory design are drawing inputs to design process from potential users. Our pedagogy-driven design approach is combining the visions gathered from participatory design sessions involving users (learners, facilitators) with design concepts and decisions derived from the pedagogical foundation of Digital Learning Ecosystem.

Three main structural components for explicating our pedagogy-driven design framework are:

- **Software architecture:** software elements, relations among them and properties of both;
- **Affordances:** functionalities and process models designed into user interface, invoking certain activities of users;
- **Vocabulary:** metaphors and concepts implemented in user interface.

The initial pedagogy-driven design model was applied by us on designing the architecture and user interface of our first learning management system IVA back in 2003. The pedagogical foundation of IVA was Jonassen's 3C model [26]. IVA was a second-generation TEL system, which has been used by more than 25 educational institutions and 28000 users within the last decade. On 2010, we initiated pedagogy-driven design and development of a third-generation TEL system called Dippler (Digital Portfolio-Based Personal Learning Ecosystem), which is addressed in the next chapters.

4.1. Vocabulary

With regard to pedagogical vocabulary to be used as a building block of DLE, we identified four contemporary pedagogical frameworks or approaches to inform and direct the pedagogy-driven design of Dippler platform, taking into account four selection criteria. First, the approach should be compatible with contemporary mainstream pedagogy, which we define as the art and science of facilitating the students' learning. Secondly, it should be operationalisable to the level of affordances of user interface, as there are several attractive and well-known frameworks (e.g. Wenger's Communities of Practice or SECI model by Nonaka and Takeuchi), which are suitable only for qualitative/hermeneutic analysis of learning or for heuristic guidelines for teachers. Thirdly, it should be compliant with other components of the framework and with the concept of digital learning ecosystems (internal consistency). Fourthly, the selected set of frameworks should cover both learning process and its outcomes from learners and facilitator's perspective.

These four selection criteria helped us to identify four contemporary pedagogical frameworks (both theoretical and practice-based), which formed the core of the pedagogical foundation for Dippler:

- self-directed learning (SDL): introduced by Knowles (1975) [27], based on assumptions that learner's capacity and need to be self-directing grows and should be nurtured, that learner's experience is a valuable input to learning process, that learner's natural orientation is task/problem-centered, and internal incentives for learning are more important than external. Väljataga and Laanpere [28] extended the model of SDL to include learners' control over building and adapting their personal digital learning environment.
- competence-based learning (CBL): a new approach to disputed model of outcome-based education. Supports SDL, as it gives learners more control over their learning paths by fixing only generic performance-based learning outcomes in the form of competences [29], which are defined as personal characteristics (e.g. knowledge, skills, attitudes, social capital) of an individual, which are needed for performing an authentic task in a real-life context. Tammets et al [30] have demonstrated how e-portfolios can be used effectively for competence-based learning.
- collaborative knowledge building (CKB): a framework which distinguishes tacit and hardly observable process of learning from knowledge building that results with shareable (digital) artifacts - knowledge objects [31].
- task-centered instructional design models. Although traditional instructional design models were criticized for their incompatibility with dominant pedagogical paradigm (social constructivism), the new generation of instructional design models, e.g. 4C/ID [32] support SDL by reducing prescriptive components, situating learning in authentic context and suggesting problem-based approaches.

Figure 1 below illustrates how these four frameworks can be mapped to facilitator-learner and process-outcome dimensions to cover the most important aspects of pedagogical domain.

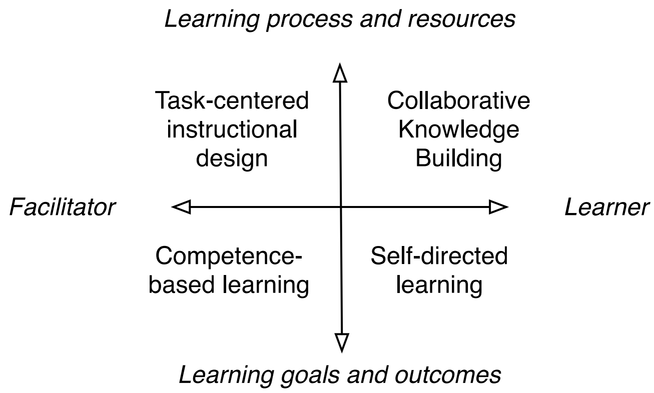

Fig. 1. Mapping of selected frameworks to pedagogical dimensions

The selected pedagogical frameworks were then analysed from the perspective of their potential contribution to the design decisions guiding the specification of software requirements for Dippler. Table 2 below provides a brief summary of these design decisions in relation to three structural components of our pedagogy-driven design model.

Table 2. An initial set of design decisions inferred from pedagogical foundation

	Architecture	Affordances	Vocabulary
Self-directed learning	Learner controls, adapts and expands her blog- based PLE	Self-directed goal setting, planning and documenting learning paths, scaffolds	Learning outcomes, learning path, scaffolding, goals, context
Competency management	Institutional repository of competency defini-tions, learning analytics module	Performance-based assessment, Binding artifacts with domain concepts, presenting evidences	Portfolio, competence, competence profile, evidence, competence record, level, badge
Collaborative knowledge building	Semantic layer, domain ontology evolution mechanism	Co-construction, Remixing, Social tagging, Recommendation, Peer-scaffolding	Knowledge object, artifact, share, annotate, thinking types, remix, project, product
Task-centered instructional design models		Binding tasks, resources with learning outcomes Embedded scaffolds	Course design, strategy, task types, learning activity stream, pattern

In order to research and evaluate the impact of alternative VLE design approaches on teaching and learning, we also needed to connect the vocabulary of VLE with a relevant theoretical framework. The main challenge in founding a sound framework for analysing pedagogical aspects of VLE is defining the units of analysis. Learning activities have always been among popular units of analysis in the educational research community, which has proposed various typologies of learning activities used in an online course should help us to identify and differentiate pedagogical approach of the teacher. Traditional classifications of learning activities are based on classical frameworks like Bloom's taxonomy of educational objectives [33] and Gagne's nine instructional events [34], but these are not suitable for our goal which is classifying online learning activities based on the data stored in VLE logs, as they provide only limited view on differences in pedagogical patterns applied in different VLEs. With the advent of e-learning, several technical specifications (IEEE LOM, IMS LD) have attempted to formalize the pedagogical models along with learning activities. Unfortunately, these classification schemes are too narrow, technical and pedagogically irrelevant to help us in our analysis. For instance, IMS LD specification defines only two types of activities: learning and support activities, while suggesting no typology for learning activities.

Conole [35] has proposed a typology of learning activities that contains six types of tasks:

- **assimilative** tasks, e.g. reading, viewing or listening;
- **information handling**, e.g. gathering and classifying resources from the Web or manipulating data;
- **adaptive**, e.g. engaging learners in using modelling or simulation software;
- **communicative**, e.g. engaging learners in debate or group discussions;
- **productive**, e.g. actively constructing an artefact such as a written essay, production of a new piece of software or creation of a video clip;
- **experiential**, e.g. practicing skills in a particular real-life context, engaging in live role-play or undertaking an investigation offline.

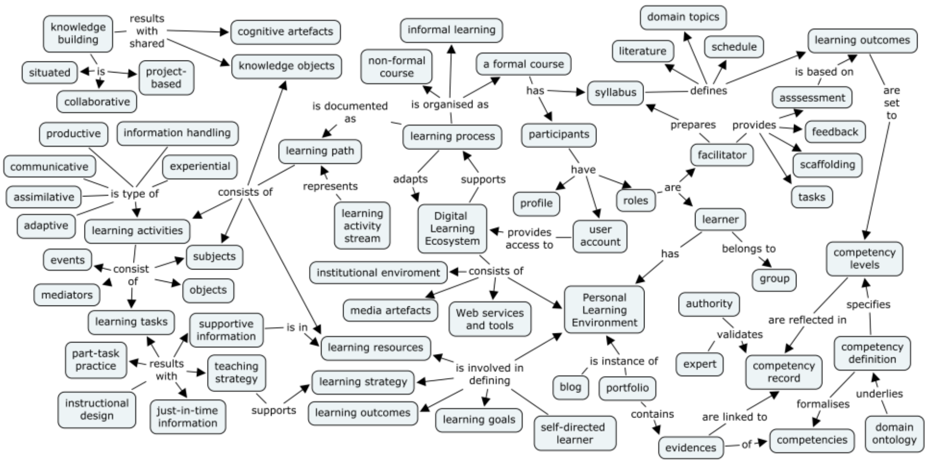

Fig. 2. Pedagogical vocabulary for Dippler represented as a concept map

The main advantage of Conole's taxonomy of learning activities is that it could be easily mapped to distinctive types of digital artefacts stored in VLE. For instance, the amount of forum posts clearly indicates the level of communicative activities, while online texts provided by teacher are related with assimilative activities.

While Conole's typology can be definitely used as the coding scheme for digital footprints of learners and teachers in the VLE database, a researcher cannot be sure whether the meaning he gives to an activity through coding is matching the pedagogical idea of this activity from the teacher's perspective. If we could connect the activity pattern analysis with analysis of affordances of VLE, it might lead us closer towards solving this problem.

Figure 2 above summarizes in the form of a concept map the surface level of pedagogical vocabulary drawn on the basis of literature review in this chapter and used in the pedagogy-driven design of Dippler.

4.2. Affordances

In order to understand and realise the potential impact of pedagogy on Virtual Learning Environments, a common ground should be established between pedagogical and technological realms on the conceptual level. The first place to start searching for such common ground is, indeed, the domain of Human-Computer Interaction (HCI) and user interface design, where integrating psychological, cognitive and computing perspectives has been widely acknowledged already for decades. The most promising direction here appeared to be related with the concept of affordances, which is used by HCI community in the context of designing user interfaces for digital tools. Originally, the concept of affordances has been introduced by Gibson as a crucial component of his theory of ecological psychology [36]. Unsatisfied with traditional theories of information and communication, Gibson defined affordances as possibilities for action in given environment, "*a specific combination of the properties of its substance and its surfaces with reference to an animal*". Affordances are not objective properties of environment, nor are they subjective representations of the things in head of perceiver [36] – they have nothing to do with representational information processing, thinking or cognitive schemas. Instead, Gibson explained affordances as "*emergent properties of the physical relationship between environment and the direct perceptual acts of embodied beings*" [37].

Norman (an ex-student of Gibson) introduced the concept of affordance in the context of Human-Computer Interaction [38], abandoning the key contribution of original Gibsonian approach: bridging the gap between the object and the subject [37]. Namely, Norman separates objective, "real" affordances from subjective (perceived) ones. The positive side of moving back towards traditional cognitive-representational approach was that it allowed Norman to explain better the role of knowledge in understanding the world around the perceiver [37].

Controversy and confusion over the concept of affordances has been continued by consecutive "turns" in [39], [40], [41]. Kaptelinin and Nardi [42] have criticized the variety of existing approaches to affordances in HCI domain: while some researchers try to hold on to the Gibsonian notion of affordances, the others are seeking to expand it in order to address mediated perception and socio-cultural context of human agents. As the concept of affordances seem to be important for the HCI community, but its interpretation in the framework of the original theory of Gibson is clearly in conflict with the problems HCI community is facing today, Kaptelinin and Nardi have an interesting proposal: the concept of affordances should be theoretically re-grounded, increasingly influential activity theory [42] should be used as theoretical foundation instead of Gibson's ecological psychology, which was focusing mainly on the non-mediated perception of an animal in the natural environment. Kaptelinin and Nardi [42] label their new perspective as "*mediated social action approach to technology affordances*", comprising of two complementing facets:

1. **handling** affordances, defined as possibilities for interacting with the technology (person-tool interaction),
2. **effecter** affordances, defined as possibilities for employing the technology to make an effect on an object (tool-object interaction).

Such approach connects the notion of affordances on one hand with contemporary context of increasingly social and ubiquitous computing, and on another hand with the most influential theories of learning today, based on the socio-cultural approach [43].

Among few others, Kirschner et al [44] have made use of affordances while conceptualising the design of online collaborative learning environments. They distinguished between three types of affordances in this specific context:

- **technological:** associated with usability of the software;
- **social:** properties of a CSCL environment "that act as social-contextual facilitators relevant for the learner's social interaction" [45];
- **educational:** properties of a CSCL environment that suggest "if and how a particular learning behavior could possibly be enacted within a given context" [46].

Although [44] demonstrated how these three types of affordances are defined as a part of their 6-stage interaction design model for CSCL environments, it appears that affordances are actually quite difficult to design, as they are not objective characteristics of a user interface of a software application. Even if affordance exist for a software developer, it does not mean it is perceived as such by the users who often have very different background, experience and skills from that of the developer. In a study carried out within a joint European research project iCamp, a theoretical framework based on soft ontology was created along with a software tool iCampFolio [47], which was then used for exploring the affordances of various distributed online learning tools [48]. This tool helped to visualise the relative "closeness" of affordance perspectives within a group of users or between the groups.

In the context of current study, we follow the definition of affordance from [49]: "affordance is 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". It means that affordances cannot be directly designed as properties of an environment, they could be only hinted or promoted by the designed features of the user interface. We designed a separate Web environment for facilitators who create and conduct online courses with Dippler. The user interface of this environment differs significantly from the learner's one, as we aimed to stress the hints for pedagogical patterns related with pedagogical foundation defined in the previous chapter. For instance, learning outcomes and tasks are promoted in the main menu. There is no way to upload and lock learning resources into Dippler, instead these could be embedded or linked and connected to the learning outcomes through domain ontology mapping.

4.3. Software Architecture

As it was demonstrated in the second chapter, in most of the cases documented in previous research publications, applying the "pedagogy first" principle in designing digital learning tools happens mainly through providing loosely structured design guidelines, which introduce some elements of pedagogic vocabulary in the user interface of the system. There exist approaches to specifying the software architecture, which give greater significance to domain concepts when designing domain-specific software. Digital Learning Ecosystems are constantly evolving, being subject to "invasion" of new services and middleware platforms, which have to be interoperable, interchangeable and integrated into larger habitats. In 2000, Object Management Group released a white paper on Model-Driven Architecture (MDA), addressing the challenges created by increasingly heterogeneous middleware ecosystems [50]. MDA proposed language-, vendor- and middleware-neutral approach to modeling the software architecture by providing three viewpoints to a software system on different levels of abstraction [50]:

- Computing-independent model (CIM): domain model that does not show the details of the system's structure;
- Platform-independent model (PIM): technology-neutral model that is computation dependent, but it is not aware of specific computer platform details;
- Platform-specific model (PSM): specification of a complete system.

MDA helps to define the functionality of a new software system using an appropriate domain-specific language, which can be formalised as domain ontology [50]. The key concepts from the given domain are elicited from domain experts using interviews, observations, concept mapping and other knowledge elicitation techniques. This domain knowledge is then formalised using UML or other modelling framework and only after that the Platform-Specific Model is created using a selected software engineering tool. MDA approach opens the door for native, domain-specific vocabulary into the database schemas, business process models, workflows etc.

Pedagogy-driven design targets mainly CIM and PIM by enforcing certain pedagogical concepts from the vocabulary (Fig.2) into domain model.

5. Methodological Framework

There exist a range of relatively young approaches to e-learning research, which are based on researchers intervention to the process under study, involvement of teachers and learners in designing this intervention, multivocal combination of various data collection and analysis methods. As the main focus of our research is iterative design and large-scale implementation of Virtual Learning Environments on a longer time scale, the most suitable methodological framework for current study appeared to be Design-Based Research (DBR), which is defined in [51] as "*a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories*". Just as design experiments and action research, DBR improves chances for creating synergies between research, pedagogical design and engineering of new software tools. DBR was born within the community of educational researchers, on the other hand the approach is similar to one used in other design-oriented sciences, e.g. human-computer interaction.

In particular, our research has been guided by Leinonen's [52] adaptation of DBR, labelled as research-based design, where software development is brought to the foreground and participatory design-based research activities provide input to design decisions. Leinonen's model consists of four phases:

- Contextual inquiry – studying trends, benchmarking, ethnographic studies, which result with defining the context and preliminary design challenges;
- Participatory design – engaging users in designing scenarios, conceptual models, which result with defining the key concepts and their relations;
- Product design – creating user stories, use cases, throwaway prototypes, which define basic interactions;
- Production of software as hypothesis – from developing and pilot-testing early prototypes towards feature-rich and fully functional software.

Our research group has dedicated more than ten years to iterative research-based design process, which eventually led us to development of Dippler platform – a distributed set of core services for a next-generation digital learning ecosystem. Figure 3 illustrates the three iterations of this process, each iteration contains both pedagogy-driven and user-centered design phases, as well as the analysis phase. The first iteration started with pedagogy-driven design of IVA learning management system, where the main design decisions were derived from social constructivist learning theory and Jonassen's 3C model [26]. The system was developed in a user-centered manner (phase 1.2) and 5 years after its wide-scale adoption, the design was evaluated (phase 1.3) through analysis of pedagogical activity patterns [53].

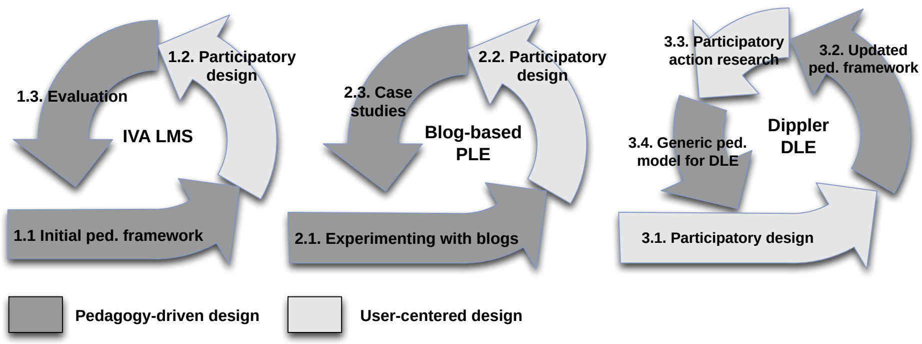

Fig. 3. Three iterations of research-based design of pedagogy-driven design model

Pedagogy-driven design decisions can be informed both by pedagogical theories and experiences from educational practice. In 2008, when IVA LMS reached its maturity and social media started to have influence on e-learning, we initiated a number of pedagogical experiments using blogs, wikis and others social media tools in formal higher education courses (phase 2.1). In these courses learners were encouraged to build their personal learning environments. We have studied how students perceive these distributed learning environments and their affordances [54]. These experiments have also indicated several issues that make it time-consuming to follow and to coordinate learning activities in blog-based courses. To address these limitations we developed two alternative software prototypes (phase 2.2): LePress and EduFeedr. LePress is a WordPress plugin that connects teacher's blog with those of students and creates a course coordination space for efficient management of course enrolments, assignments and assessments [55]. EduFeedr is an educational feed aggregator for blog-based courses and it doesn't require any plugins to be installed for teacher's and learners' blogs [56]. User-centered and participatory design approaches were used in both of these projects.

Experiences gained from development of IVA LMS and also from experiments with blog-based courses led us to the third iteration: design of Dippler. The design process of Dippler started with a participatory design phase (3.1) where we developed five personas and four narrative scenarios that described typical use cases of Dippler: (1) facilitator designs a course, (2) learner sets up a weblog and enrolls to the course, (3) submitting assignments and giving feedback, and (4) learner graduates and re-affiliates her Dippler blog with another university. The scenarios were validated in a series of a participatory design sessions involving lecturers and students representing different persona's. This paper focuses mostly on the phase 3.2: pedagogy-driven design of Dippler. Above we have described the pedagogical framework and related design decisions that guided the development of Dippler. Currently we are in the end of phase 3.3 (Fig.3), which involved conducting eight pilot courses with 164 MA students in Tallinn University, using Dippler ecosystem. The methodology of this ongoing action research is based on indicators based on the pedagogical vocabulary and affordances that were defined in our pedagogy-driven design model in chapters 3 & 4 above. For instance, we use the classification scheme based on Merrill's task-centered instructional design model and Conole's taxonomy of learning activities to analyse the emergent patterns in course design elements and their impact on learning interactions during the course. This theoretical framework would allow us to compare different Virtual Learning Environments with regard to the influence of their designs (incl. vocabulary, affordances and architecture) on the pedagogical approaches applied by teachers and actual learning process.

6. Implementation of Pedagogy-driven Design Model on Dippler

We applied pedagogy-driven design in the process of developing the next-generation TEL system Dippler. The design artefacts, documentation and source code (released under open-source license Apache 2.0) are available at TracWiki of Tallinn University. Figure 4 below illustrates the architecture of Dippler, consisting of a single centralised middleware application BOS (Java EE application running on Glassfish server), which is accessed by three types of client applications: teachers use institutional client (an original PHP application) to design and manage courses, learners use either their personal WordPress (enhanced with Dippler plugin which communicates with BOS via SOAP web services) or mobile clients (available both for IOS and Android platforms). There is supposed to be only one active instance of BOS per country – at least in a small country such as Estonia, covering the needs of all different educational institutions and maintained by NREN (National Research and Education Network organization). Several external services can be integrated into ecosystem, as we have demonstrated by connecting a IMS QTI compliant quiz tool Questr [57], which is used for delivering test and self-test tasks to learners' blogs. Dippler architecture enables sharing resources between services that is the basis for the symbiosis or commensalism between service species and promotes multiple emergent connections to appear between Dippler services, which increases the synergy at the ecosystem level. As an open learning ecosystem, Dippler opens those information flow channels that current users activate and require and is able to adapt to the dynamic changes in learning settings. Such architecture follows the first ecological principle and serves for increasing the permeability of Dippler learning ecosystem to the export and/or import of information and knowledge dynamically. Communicative interactions between Dippler services, which assumes mutual awareness and signaling between agents (or using the accumulated signals left into the Dippler environment) have been considered in Dippler architecture, as the third ecological principle requires.

In accordance with the second ecological principle, learner's interaction with Dippler ecosystem happens through personalized interface, in which the "service-species" are activated by user's different roles and learning intentions representing learner's affordance preferences.

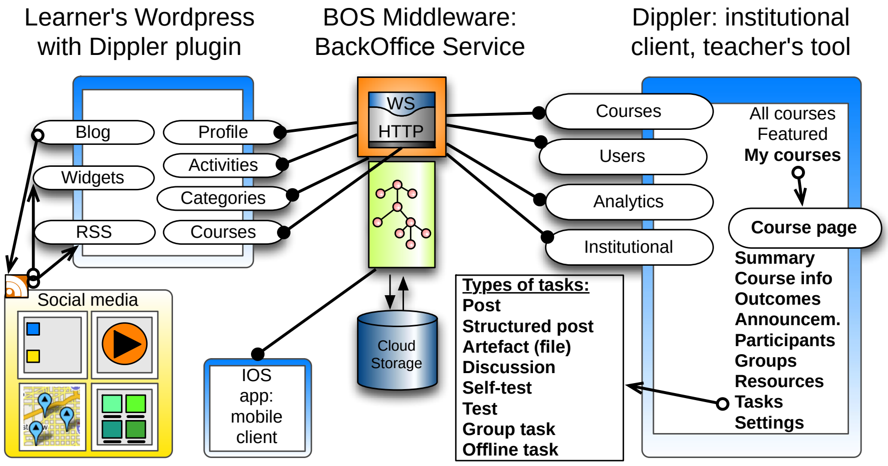

Fig. 4. The main components of Dippler platform

Such architecture allows a learner to host her personal learning environment wherever she prefers, independently of course provider. When the learner graduates from the university or changes her affiliation to another educational institution, she keeps in her portfolio all learning resources, submissions, reflections and communications which are usually lost by users of traditional institutional LMS after their user accounts expire.

A self-directed learner is able to enhance her Personal Learning Environment by adding plugins or sidebar widgets to her WordPress blog and change the "look and feel" of her PLE by modifying the WordPress theme. Learner does not have to visit the institutional Dippler environment after initial registration, as all course related content – e.g. course announcements, assignments, teacher’s feedback, grades - is displayed in learner’s blog, which could be installed in any server outside of the university network. Learner’s responses to assignments are submitted as blog posts, which are automatically annotated with a specific category (domain concept from teacher-created course taxonomy), linking the submission with a given learning outcome. Figure 5 below shows the list of learning outcomes and their mapping to domain ontology concepts in the Dippler‘s institutional client. Teachers can use these categories also for annotating the learning resources and announcements, which are related to a specific learning outcome or assignment. Learners can annotate any blog post with the relevant domain ontology concept, which allows them to advance their competence in self-directed manner, in addition to assignments given by the teacher. All submissions from learners’ blogs, which are annotated with concepts from domain taxonomy, are copied to the BOS database. Even if the learner removes or updates her blog posts later, the original versions of submissions are kept within institutions.

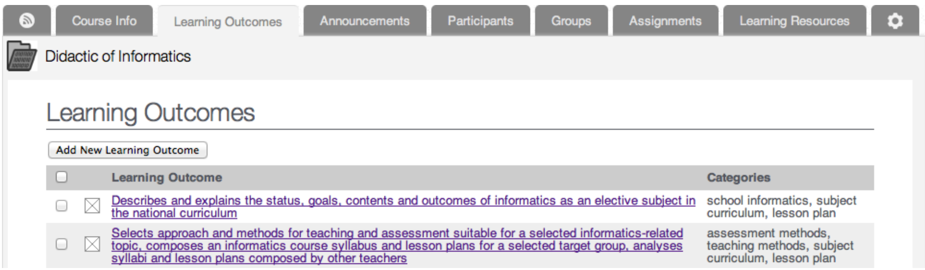

Fig. 5. Dippler‘s institutional client: mapping learning outcomes with domain ontology

By restricting uploading of learning resources (these can only be linked or embedded into Dippler course) and by establishing explicit connection between learning outcomes, learning resources and various types of learning tasks, Dippler enforces teachers to implement good practices of task-centered instructional design. Dippler also promotes self-directed and competence-based learning, as the learners have more control over their learning environment, yet they are guided by learning outcomes and tasks. Learners can easily create a competence-driven presentation portfolio by selecting a set of their blog posts and other self-created knowledge objects related to a given set of learning outcomes. Detailed activity stream (based on Activity Base Schema enhanced with educational action and object verbs) displays all recent activities on the course in both, the teacher’s client and in the learner’s blog, helping all participants to have a quick overview of the course in Facebook style. And, finally, the category annotations and activity streams of Dippler allow conducting a different kind of learning analytics, which is not supported by traditional LMS: analyzing distribution of activities and resources in relation to domain topics, addressed by the course. The biggest challenge for a blog-based PLE is supporting collaborative knowledge building, but Dippler addresses this through providing collaborative tasks, where the learners either share one copy of a blog post or embed to their joint blog post some external collaboration tool, e.g. typewith.me for collaborative writing or wiki for project work. Eventually, all four pedagogical frameworks selected to guide our pedagogy-driven design model have been implemented on three levels in developing the Dippler: in its software architecture, affordances and the vocabulary of the user interface.

7. Discussion: Towards Generalized Pedagogy-driven Design Model

In the beginning of this paper, the following three research questions were stated to guide our study and to focus our line of argumentation:

- What constitutes the model for pedagogy-driven design?
- Which pedagogical approaches could/should be promoted by the pedagogy-driven design of the next-generation online learning platforms?
- How to implement the pedagogy-driven model in the process of developing a new type of online learning platform: a digital learning ecosystem?

In this chapter, we revisit each of these three questions by generalizing the theoretical argumentation presented in chapters 3 & 4 as well as the case study on designing Dippler in chapter 6. As for the constitution of pedagogy-driven design model, we propose three different perspectives or representations that would complement each other: a conceptual model, implementation model and design process model. The first representation of the conceptual model for PDD is drawn as a concept map (see Figure 6 below). Concept mapping technique has been used both in pedagogical and knowledge management domains to visualize the key concepts aof a domain and relations between them. Each two connected nodes in the concept map should form a semantic triple or proposition, while the labeling of relations is not restricted by a limited set of relation types (unlike in E-R diagrams).

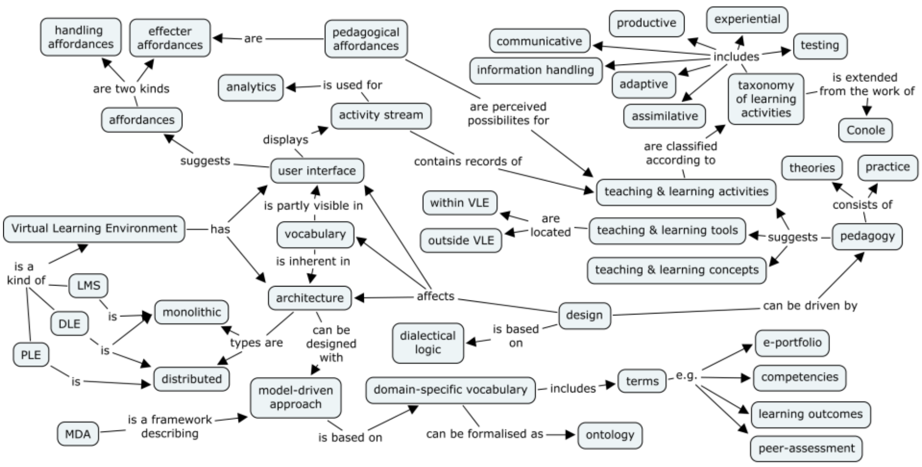

Fig. 6. Conceptual model of PDD in the form of a concept map

The concept map on Figure 6 has been created as a result of various knowledge elicitation procedures (interviews, prototyping and design sessions with users, content analysis of research literature) and it illustrates the key concepts of Pedagogy-Driven Design of Virtual Learning Environments along with their relations.

The second representation of the conceptual model for Pedagogy-Driven Design (PDD) is drawn as a Venn diagram in the Figure 7 below. Three targets of PDD (vocabulary, user interface and software architecture) are not separate and hierarchically arranged levels, rather they should be understood as overlapping sub-domains addressed by design methodology. Pedagogy-driven vocabulary is implemented in the VLE design not just as menu labels and messages visually displayed in the user interface, it cuts across also to the deeper levels of software architecture, not visible to the user. As the pedagogy-driven vocabulary presents not only the list of separate words, but a system of interrelated concepts, it affects also certain software engineering requirements on the architectural level.

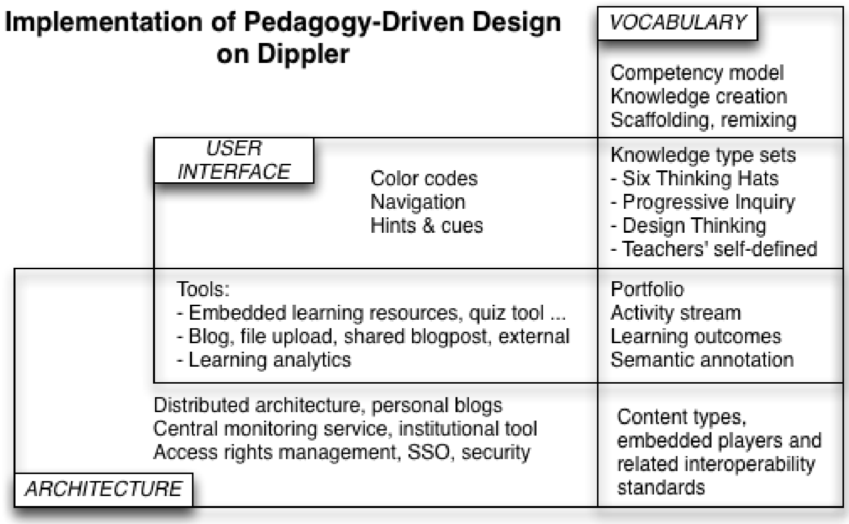

Fig. 7. Venn diagram illustrating PDD implementation on Dippler

Figure 8 illustrates the implementation of PDD on Dippler, stressing the influence of pedagogical ideas, theories and practice in the overlap areas of VLE's vocabulary, user interface and software architecture. While the core of the pedagogical vocabulary of IVA was derived from Jonassen's 3C model and its underlying learning theories, this terminology was not used in the user interface of IVA. Instead, the key terms (Context, Construction, Collaboration) were replaced by carefully selected metaphors and used as a pedagogical guideline for balanced structuring of the user interface into three parts: WebTop, Bookshelf and Workshops. Pedagogy-driven Thinking Type Sets used in the Knowledge Building forum of IVA contained several exchangeable sets, but also an opportunity for a teacher to create her own set. Some components of initial Pedagogy-Driven Design from IVA were carried along to the design of Dippler, but majority of components were revised as a result of our research-based design.

As it was mentioned above, PDD can also be understood and implemented as a process model. For instance, it could be seen as extension of Leinonen's (2010) 4-stage model of research-based design, where the 5th phase is added to address the user-driven co-evolution of DLE and pedagogy-driven inputs are taken into account in all previous phases (Figure 8).

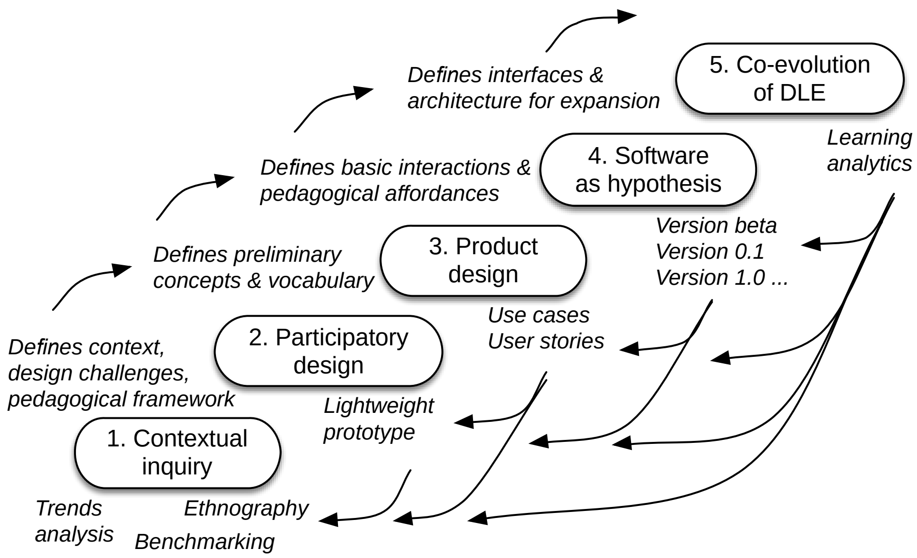

Fig. 8. Process model of Pedagogy-Driven Design (adapted from Leinonen, 2010)

This extended process model of pedagogy-driven and research-based design of VLE recommends the definition of the pedagogical framework as a result of the first phase of design (contextual inquiry). In the second phase, the core part of pedagogical vocabulary should be specified and matched with relevant metaphors for user interface. In the third phase (product design), the main pedagogical affordances of VLE should be defined, along with more generic interactions. As a result of the fourth phase (developing the software as hypothesis), the interfaces, protocols and other architectural requirements should be defined in order to facilitate self-regulated and user-driven co-evolution of Digital Learning Ecosystem. During the fifth phase, the activities of teachers and learners in the distributed digital ecosystem should be monitored automatically with the means of learning analytics, in order to inform the designers about the activity patterns and trends, new niches, deficiencies in affordances etc.

8. Conclusions

This paper proposed a three-component model for pedagogy-driven design of next-generation technology-enhanced learning systems: digital learning ecosystems (DLE). We extended the concept of ecosystem from biological world to the digital one and more specifically, to the domain of technology-enhanced learning, going beyond using DLE as a metaphor. Further on, we demonstrated how our pedagogy-driven design model was implemented in the development of a DLE called Dippler: a distributed and adaptable portfolio-based learning platform, which combines the strengths of institutional Learning Management Systems with those of blog-based Personal Learning Environments. We admit that our pedagogy-driven design model and its implementation in the Dippler ecosystem have some limitations and external validity issues. For instance, in many countries (e.g. Canada, US) the legislation sets rigid restrictions to openness of study- and learner-related information, which is an important prerequisite in our model. We also acknowledge that collecting meaningful data about learner interactions from all possible Web and mobile tools is still impossible today. Finally, the scalability of Dippler remains to be untested and might raise some doubts.

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