Deep Learning Design for Sustainable Innovation within Shifting Learning Landscapes

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Abstract. Changes in the underpinning technologies for TEL is occurring at a pace that we have never before experienced, and this is unlikely to slow down. This necessitates a broader and more profound understanding of design that needs to be more future-proof than relying on the latest or emerging technologies and yet embraces the collaborative, multimodal and ubiquitous nature of learning in 21C. In addressing this challenge this article develops, exemplifies and tests the approach of Deep Learning Design (DLD), which has led to relatively large-scale and sustainable innovations and also outlined clear directions for near-future developments. Specifically, in this article we: justify why DLD is necessary and describe its key principles; exemplify these principles through four TEL initiatives; and, draw some implications and conclusions from across these projects about DLD and future learning.

Keywords: learning design, sustainable innovation, contemporary pedagogy, case studies.

1. Introduction: Why we need deep learning design (DLD)?

A general perception in the TEL (hereafter TEL) community that has been made explicit by some researchers [e.g. 1], is that changes in the underpinning technologies for learning and teaching is occurring at a pace that we have never before experienced. This is combined with a similar pace in the emergence of new digital tools that offer original opportunities for learning and teaching. This shifting landscape for TEL necessitates a broader and more profound understanding of *design*, that is more future-proof than relying on the latest or emerging technologies and yet embraces the collaborative, multimodal and ubiquitous nature of learning in 21C. This implies that we need an approach to learning design that is in harmony with the digitally literate teacher and learner in the Web 2.0 age and beyond, and, also recognises attested notions of pedagogy that we need to re-configure [2]. Or, we argue that using technology to make education better is more important than using digital tools to do it differently.

In addressing this difficult but important challenge, in this article we will develop, exemplify and test the paradigm of Deep Learning Design (hereafter DLD) [1], through four distinctive TEL projects that are Case Studies of the approach. These focus on: supporting collaborative and critical thinking and learning on the web (Digital Dialogue Game Project); the production and use of pedagogy rich reusable learning objects on a large scale (Centre for Excellence in Teaching and Learning in Reusable Learning Objects); the use of mobile phones to realize learner-centred and highly contextualised learning experiences (CONTSENS project); and the exploitation of social and semantic technologies to promote increased informal learning in the workplace (MATURE Project).

Note that we will deliberately avoid a focus on 'Learning Design (LD)' based around the IMS-LD standard [3]. However we consider our approach to have some complementarity with learning design more generally [4]. A main difference however is that DLD is a research driven paradigm for designing contemporary learning that adopts a more humanistic and holistic stance, instead of focussing ostensibly on sharing teaching practice. Hence, it incorporates an emphasis on learners' and teachers' active processes and practices within contexts, or is more 'performative' and based on the meditational role of learning technologies [5]. The paradigm makes use of a combination of Design-based Research [6] and Action Research methodologies. But, unlike Design-based Research, that is quite wide-ranging in supporting educational research in general and is arguably quite diffuse, DLD has the particular focus of designing learning in the Web 2.0 landscape and beyond. It does this through allowing us to focus on: designs linked to theories/conceptual foundations, technologies and contexts of use; empirical evaluation; and, the prescriptive imperative that we want to change learning for the better.

2. Key principles of DLD

The following key principles of DLD that were originally proposed by [1] have been refined through being applied to the broader and more varied range of projects that are presented in this article, which also provides a generality test of this approach.

2.1 Theoretical and conceptual foundations

Why do we want to incorporate or advance theory or conceptual foundations in our TEL designs? Firstly, there is a strongly held view throughout the TEL community that applications should be informed by learning theory or pedagogical frameworks, and without these, they aren't TEL designs. Instead they are simply interaction designs. Or theory is the 'anchor' for good design. Secondly, and perhaps most obviously, good theories have powerful potential to guide design, and therefore instantiating them through technology will increase the likelihood of a TEL interaction leading to desired learning. Thirdly, which is related to the points below about opposing pure technological determinism, is that a theory, like a design, does not have to be technology dependant. So adopting a theoretical stance means that we can appropriately articulate technology to realise a more wide-ranging and often

proven approach to learning, rather than adopting one that is simply doable through current or emerging technology. Fourthly, as the saying goes, 'nothing is as practical as a good theory'. Theoretical foundations should inspire and imply designs as well as allowing us to decide what is important in evaluations.

2.2 Design as the key development concept

In accepting the rapid pace of change of learning technologies, we argue that 'design' is a suitably rich, flexible and yet formal enough concept to help us to engineer, or at least favour, better learning whilst also supporting better understanding of the processes at play. This stance is partly a reaction to research in the TEL field that has been overly predicated on technologies. It is interesting and important to note that, for most previous technological waves (e.g. Artificial Intelligence and Education, Hypertext, Computer Supported Collaborative Learning), often prestigious researchers and research centres have advocated these as being imbued with great transformative powers that will address the fundamental problems with learning. But as yet, none of these revolutions have occurred, and worse, our collective memory is so poor, that we tend to jump onto the next technological bandwagon without learning the lessons from the ones we were previously riding.

2.3 Development and interaction in context

DLD recognises that we need to perform development and devise interaction designs within social and culturally coordinated contexts to address clear problems or opportunities. And these designs should ideally incorporate an articulation of learning that links cognition, communication and context [7]. This means that we need to link notions of cognitive change, in terms of improved knowledge or reasoning, to communicative competencies, that in turn link to tangible practices in contexts. And where improvements that correspond to learning are measurable through evaluations. For example, as illustrated by two projects in Section 3, linking Vygotskyan notions of learning through participating in zones of proximal development (ZPD) to identifiable changes, such as improvements in understanding a topic or general improvements in critical thinking that are displayed through observable dialogue.

2.4 Evaluation linked to conceptual frameworks and authentic contexts

A final key element of DLD is the adoption of an evaluative framework linked to the theoretical and conceptual foundations and authentic learning activities or contexts. In contemporary learning situations, to cover both ecological validity and reproducible empirical rigour, the development of a suitable framework can be challenging and involve qualitative and/or quantitative methods, and may also follow Action Research or more conventional empirical approaches. But, the key point is that, whatever methods are adopted, they should be appropriate in addressing the key assumptions or claims made about the design (e.g. whether they do improve learning in some

measureable way) and not just superficial characteristics (e.g. numbers who have used a design and/or anecdotal opinions from selected users).

3. Four exemplar projects of DLD

This Section exemplifies DLD through the four different projects that were introduced above, that are Case Studies to demonstrate the generality of the approach, through mapping them to the principles of DLD. The first two of these have already led to sustainable innovations, and the latter two outline clear directions for near-future work that that we argue should to be taken into account to realize future innovations in their related areas.

3.1 A digital dialogue and social software perspective

Our first project and perspective is motivated by the increased prevalence of collaborative dialogue and discourse within our social software landscape. Within this context it is worth remembering that dialogue is arguably the primary mechanism which links communication, cognition and context within education, and therefore supports thinking and learning in collaborative situations [8, 7, 9]. Although the form and means of realisation of 'learning dialogue' is changing through the increased prevalence of the highly participative and discourse intensive social software, or web 2.0, technologies, some underpinning pragmatic level, or deep and social, discourse processes are arguably more stable and still at play. These points are exemplified by research and development into Digital Dialogue Games (DDGs) and InterLoc (see www.interloc.org).

3.1.1 Theoretical and conceptual foundations

Theoretically, the DDG approach is driven by Vygotskian [10] and Bahktinian [11] notions of conceptual development that have informed a contemporary articulation of *dialogic* and *dialectic* dimensions of learning dialogue [12]. This work also involves a re-configuration of Vygotsky's notion of the zone of proximal development (ZPD) to accommodate collaborative learning through technology mediated dialogue interaction [13]. These are realised within interaction designs that build upon the well-attested approach of 'dialogue games' [14, 15, 16] and also make use of Speech Act theory [17]. This has been reported extensively in previous articles (see [18] for a review). These notions are complemented and realised through applying original conceptual principles of 'ambient pedagogy' and 'experience design' [19].

3.1.2 The design level

The DDGs are by their nature a flexible design paradigm that has been implemented using various technologies over the past ten years, spanning Artificial Intelligence in Education (AIED), Computer Supported Collaborative Learning (CSCL) and now more recently social gaming and other social software technologies. This trajectory of related research and development is described in detail in [18] and [21]. Central to

this is a methodology, of 'investigation by design' (hereafter IBD) developed by [20] that is technology neutral, in that it formulates models that are formal enough to be implemented, yet without predicating a particular technology for implementation.

The DDG and InterLoc design enable a tutor, or learning manger, to set up a dialogue rich activity linking digital content (on the web) to a pre-defined dialogue game, and also providing a critical question that seeds it. The interface in Figure 1 illustrates a critical discussion and reasoning game (CDR-DG) that was produced by the IBD methodology and is implemented through the InterLoc tool.

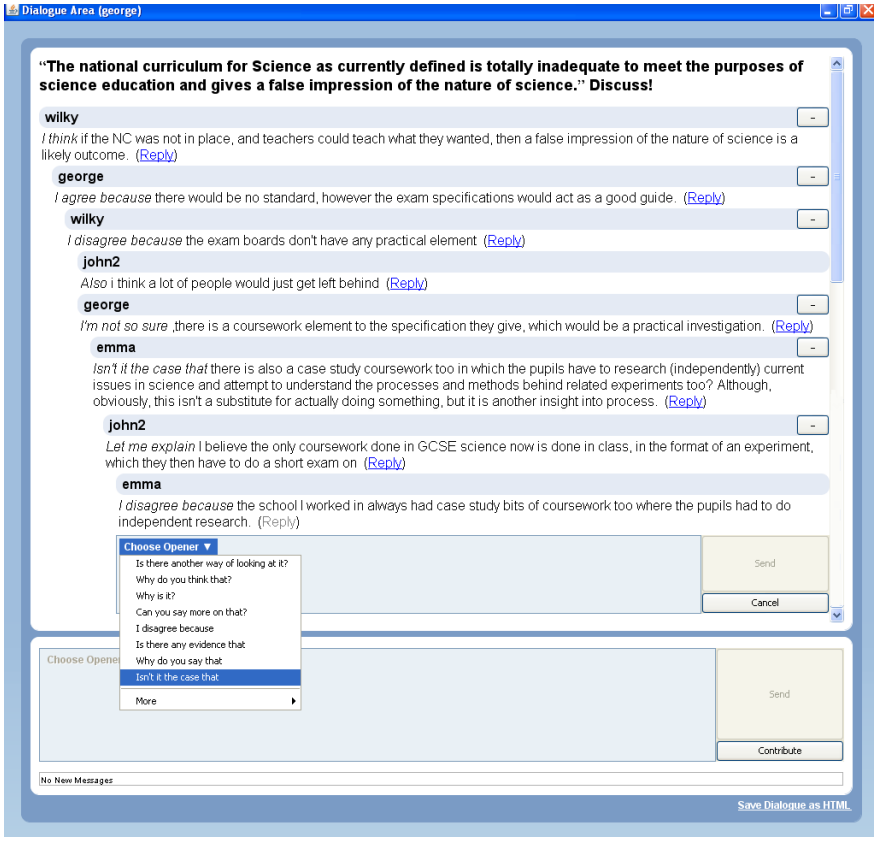

Figure 1: InterLoc(v5) Screenshot demonstrating the Critical Discussion and Reasoning (CDR) game

Through modeling natural (non digital) discussions, a fundamental distinction is made between "Contributing" to the developing dialogue (using the large reply bar at the bottom), typically responding to the latest 'state of the dialogue', or replying to a specific previous contribution (by selecting "Reply" next to each contribution). All contributions or replies are made using the pre-defined Move categories (*Inform, Question, Challenge etc.*) and the specific locution openers ("*I think…*", "*I disagree because…*", "*Let me elaborate…*" etc.) that have to be used to perform the dialogue. Similarly, rules about the legitimate and logical responding openers, based on the

specific Openers that are replied to, are offered selectively. So in this example (in Figure 1) the responding player (George) is presented with logically legitimate responses to *"I disagree because…"*, such as *"Is there another way of looking at it?"*, "*Why do you think that?" etc.*. Although they are not restricted to this preferred response set, and can instead select "More" to see the full range of Openers. So a structured and yet flexible form of scaffolding is provided that resides in a digital space that is familiar to students, where the surface realization of this design is similar to Skype or MSN.

3.1.3 Development and interaction in context

The example above demonstrates how the DDGs and InterLoc embody the need to reconcile learners developing digital literacies with the well-established requirements for reasoned and purposeful dialogue. Specifically, through incorporating the notions of 'ambient pedagogy' and 'experience design', the developers have provided a managed and yet attractive and inclusive learning context and experience through realising a structured, collaborative and engaging learning practice. The design was developed through evolutionary prototyping that incorporated a user-intensive and participatory Action Research approach. *This rendering of a validated dialogue framework (e.g [22]) and similarly validated learning design (e.g. [23]) into a tutoring practice and digital learning experience (see Figure 1) that is relevant and familiar to users, and which is subsequently evaluated (see below), is the essence of deep learning design.*

3.1.4 Evaluation approach and findings

The DDG approach has proven efficacy for a range of learning problems and contexts, as documented in a range of research projects over the past ten years that are summarised in [18]. The positive findings that emerged from all these studies are summarised in [23]. These led to considerable improvements in the design and implementation of the current DDGs and InterLoc that have recently been deployed and evaluated within an Action Research project across five HE Institutions in the UK, with over 350 students and 10 tutors [21].

3.2. A Learning objects and reusable learning design perspective

This second exemplar case of DLD adopts a different approach to interaction design that is more oriented to how learners interact with the digital world than other students. It is based on the development of pedagogy rich multimedia learning objects, that are conceived as 'micro contexts for learning' [25]. Whereas the traditional standards-based approach to learning objects has focused on packaging and describing content (e.g. IMS, IEEE & ADL SCORM standards), [25] has argued that we also need to tackle the central issue of *pedagogical design*. This initiative was started to address significant problems with learning computer programming, where the learning objects were conceived as micro-contexts that scaffolded learning, and their success in this respect was striking [24]. Since then, the approach has been

scaled-up considerably to provide methodologies and tools (such as the GLO-Maker authoring tool) for producing similarly conceived learning objects on a large scale.

3.2.1 Theoretical and conceptual foundations

The theoretical base for the learning objects is the constructivist ideas of Piaget and Bruner [26] and in particular Bruner's notion of 'ratiocinative amplifiers' [27, 26]. These have been resolved into a series of design principles for developing reusable learning objects [25]. These linked two types of design principles: pedagogical principles derived from a constructivist approach, and structural principles for ensuring reusability derived from software engineering.

A major evolution in these design ideas led to the concept of Generative Learning Objects (GLOs). GLOs rely on design patterns rather than content as the basis for reuse. This required a theoretical base for a 'generative' rather than a 'descriptive' approach to representing design. This theoretical base was supplied by generative linguistics, in particular, Systemic Grammar. Generative linguistics distinguishes between the deep structure and surface structure of language. In Systemic Grammar deep structure is represented as the *functions* which language serves. These functions are mapped onto the surface *forms* of language. This framework of the deep structure of (pedagogical) functions being mapped to surface structure of form provides the basis for the generative learning objects approach. This generative conceptual perspective distinguishes it from approaches to describing learning designs that are essentially descriptive in their approach (e.g. [29]).

3.2.2 Design as the key development concept

The concept of 'generative learning objects' thus focuses on *design as the basis for reuse*. This approach arose out of the work of the Centre for Excellence in Teaching and Learning in Reusable Learning Objects (http://www.rlo-cetl.ac.uk). This centre has developed and evaluated around 200 rich multimedia learning objects and these are all available from the website. The 'deep structure' design is captured as the decisions that the tutor makes about the *functions* that the learning object should serve. These are captured in the Planner section of the GLO Maker authoring tool (background object in Figure 2). These functions are then mapped onto surface forms – screen layouts, which realise these functions (foreground object in Figure 2). These screen layouts provide flexible templates for the insertion of media content such as text, pictures and videos. The process of developing a GLO thus involves making deep functional decisions, which are mapped to default 'surface structure' screen layouts, to which the individual media content is added. So the conceptual approach is, in essence, generative [29], and can be realised through relatively straightforward changes in existing teaching practice.

3.2.3 Development and interaction in context

The RLO-CETL has developed an Agile approach to the design and development of learning objects [29] that can be realised in most pedagogical contexts that require adaptation, use and reuse. This approach may be used to create one-off learning objects, or reusable designs that provide the basis for creating many learning objects. This Agile approach involves tutors, and usually students, working in groups to

collaboratively design solutions in their teaching-learning situations. Formative evaluation is thus built in at all stages in the design and development process, which moves from initial brainstorming and sketching of ideas, through to producing a multimedia learning object that is then deployed.

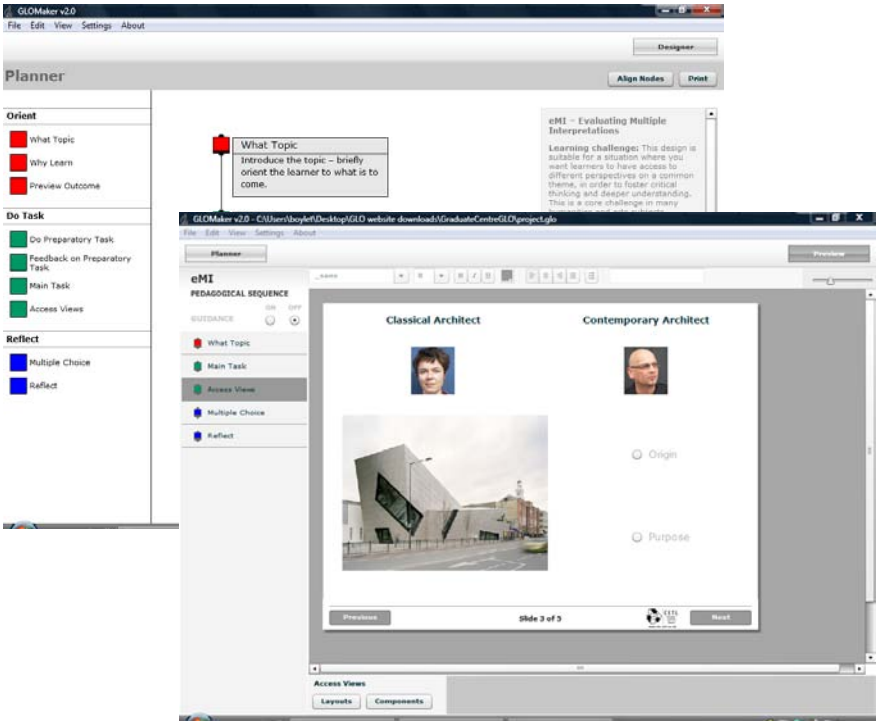

Figure 2: A pedagogical design in GLO Maker and the surface structure realization of the design

3.2.4 Evaluation approach and findings

The learning objects have been deployed in a wide range of teaching-learning contexts, where some have demonstrated particularly positive results when used in blended learning situations as diverse as learning computer programming [30] and Study Skills [31]. Similarly, the GLO Maker tool has evolved through a process influenced by continuous formative feedback from users. The most significant result of the latter was the major transition from version 1 of GLO Maker to version 2, released in August 2009. This incorporated a series of major changes requested by users. In particular, considerable work was put in to ensuring an improved interface and 'look and feel' so that it could be intuitively adopted by users.

3.3 A Mobile learning and augmented contexts perspective

The third exemplar project was initially a development from the initiative above that required a more particular focus and significantly different theoretical base, as it moved from Mobile Learning Objects (MLOs) to Augmented Contexts for Development (within the CONTSENS project). This was required to address the potential offered by emerging mobile phones and devices that can support new forms of highly contextualised activities that are digitally augmented and mostly learner-generated [32]. This now forms part of the movement in 'Mobile learning', which [33] suggest is part of the more general trend where society is currently witnessing a significant shift away from traditional forms of mass communication and editorial push towards user generated content and augmented communication contexts. Below, like the first (DDG) case, [32] extended Vygotsky's notion of the ZPD to conceptualise the approach of Augmented Contexts for Development, or ACD, [32]. A Case Study in designing a mobile phone based, location-aware field trip exemplifies the DLD principles. This places context as a core construct of the ZPD, enabling collaborative problem solving where learners generate their own 'context for development'.

3.3.1 Theoretical and conceptual foundations

As illustrated earlier, Vygotsky's notion of the ZPD and the changing notion of a 'more capable peer' have become increasingly attractive as foundations for designing and evaluating TEL (eg .[8, 12, 32]. However, one aspect that is particularly focussed on by [32] in his framing of ACD is Vygotsky's account of the temporal dimension to development that revolves around attention and perception. Here notions of time fields and the centre of gravity within related notions of causality are important and so any tools in an Augmented Context for Development could, for example, provide the visualisations that assist these underlying functions. Time fields in the Augmented Contexts for Development are created in context through tools, interactions and the internal reconstruction of these functions. A time field is a personal construct of an individual that is in particular based on the visual-spatial environment, speech, gestures and the current focus of attention (where the latter will be influenced by historical factors that include the task and personal interest as well as socio-cultural factors). When all of these elements of the time field construct come together, we get what Vygotsky calls the centre of gravity of a time field. The centre of gravity becomes the focus of attention and is directed by a learner in a dynamic way as problem solving progresses and development and understanding takes place. The centre of gravity has a temporal dimension that guides activity across contexts, allowing the learner to dynamically direct attention so as to take into account the past (history), present activities, desires and their goals that are planned in the future.

3.3.2 Design as the key development concept

In foregrounding the ACD approach, there is a particular emphasis on design-based research methods that identify and model technology mediated, social learning and behaviours in order to design tools that support and promote the practices under

investigation. In this case the design methodology followed a (design-based) evolutionary prototyping approach proposed by [35], which follows the typical cognitive science 'research triangle' incorporating theory, empirical studies and computational studies. So this considers repeated cycles of: empirical work, theory/model development and tool/artefact refinement. These particular aspects are typically conceived as overlapping activities and phases (rather than as sequenced 'steps'); it is thus an evolutionary design-based research approach to analyzing the role of theory/models, empirical work and technology in learning. For example, a qualitative analysis is used to foreground process, explanatory perspectives, and the inner features of the situation.

3.3.3 Development and interaction in context

In one example realising this approach the learning tasks were devised with an archaeology tutor from a UK University, who gave students a framework within which to operate during a field trip to a Cistercian Abbey in Yorkshire (UK). One task, which is triggered when the mobile phone is in the correct GPS location on the site (at the Abbey), stated: look at a movie of the reconstruction of the interior of the church including the nine Altars [Figure 3]; discuss the evolution of the structure of the abbey; and, make a video blog of your discussion using the Nokia phone. The collaborating pairs had two phones, one with the 3D/multimedia visualizations running the location-based software MediaScape and another mobile device for recording the video blog.

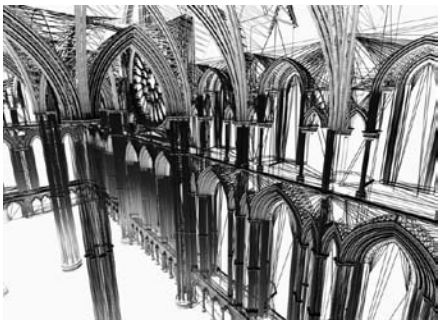

Figure 3: Screen shot of wire-frame movie reconstruction of Nine Alters

Figure 4: Students interacting at the Cistercian Abbey

The analysis of video data captured on site illustrated the emergence of a 'co-constructed area' linking the physical world (i.e. what is left of the Cistercian Abbey) and the virtual world that is visualised in 3D on the mobile devices (Figure 3); this 'area' is inhabited by a shared representation – or what Vygotsky calls a 'time field' (described above) – that is jointly developed and owned by the students.

3.3.4 Evaluation approach and findings

A Demonstrator of this approach was evaluated in a formative and Action Research manner to pilot test the ACD approach. The activity involved pairs of students who were videoed on the site by a researcher as they carried out the authentic learning task and collaborative problem solving activity. Reflective feedback after the session was gathered from the student population, of 10 MA Landscape Studies students. Within their emergent ACD the learners generated and embedded their own 'temporal context for development' as they evolved their understanding of the architectural form under investigation. The notions of attention, perception, temporality and causality seemed key processes in the augmented and temporal contexts for development. This Case Study also emphasises designs that foreground processes, explanatory perspectives, and the 'inner features' of a learning situation. These notions of temporality, learning rich contexts, and the development of knowledge and understanding over time are particularly relevant to our final example of DLD, which focuses on digitally mediated informal learning and knowledge maturing at work.

3.4 An Informal learning and knowledge maturing in the 'Web 2.0 workplace' perspective

The final example will show how the principles of DLD are being applied within a large-scale and ongoing European project called "MATURE: Continuous Social Learning in Knowledge Networks" (www.mature-ip.eu). This is an important project to consider because in shifting to informal learning in the workplace, and emphasising social and semantic technologies, we are applying DLD to another widespread context (of work) and also testing it's applicability to a forward looking and complex initiative with strong 'Web Science' [36] features. According to [37], within enterprises, new perspectives bring together traditionally separated disciplines like e-learning, knowledge management, and HR development. This requires a fundamental change of the culture of the respective enterprise towards an enterprise 2.0, which is characterised by enhanced collaboration and a culture of employee participation.

3.4.1 Theoretical and conceptual foundations

This rationale for MATURE means we have to rethink our understanding of learning and broaden our perspective particularly towards *informal learning* activities. This is built around a model of knowledge that is based on the idea of *knowledge maturing* [38] which is understood as "*the advancement of knowledge (i.e. learning) on a collective level and where it becomes less contextualized, more explicitly linked, and easier to communicate"*. The model organises this into a process of five phases: 1) *Expressing ideas*; 2) *Distributing in communities*; 3) *Formalizing*; 4) *Ad-hoc learning*; and, 5) *Standardization*.

Recently, this model has been supplemented by the application of Vygotskian [10] ideas, involving anothre re-working of the ZPD where the asymmetric less learned and more learned other are replaced by more symmetric peers (with common goals, or objectives) using mediating technologies in ways that allow them to co-learn to realise higher levels of understanding. This is achieved within what [13] have

called a ZPDpt (where "pt" indicates peers and technology), which is seen as an important way of engineering knowledge maturing across phases 1 – 3 above, and thereby, also actively supporting knowledge maturing in each of these phases also.

3.4.2. The design level: Emphasising Personas, Use Cases and Scenario linked design

In MATURE the design level systematically harmonises top-down and bottom-up design approaches. For example, Use Cases are linked to personas and particular knowledge maturing activities (see [38]). These personas have been distilled from comprehensive empirical investigations to provide a 'real human element' through the design process. The knowledge maturing activities cluster these Use Cases and cover processes such as 'Becoming aware of developments and changes' and 'Learning by finding and communicating with people'. So the methodology emphasises: the reality of, and variation in, 'real people' using the tools; the interaction of users (i.e. actors) with the software system; and, the linking of interactions to predominantly social knowledge maturing processes and activities. Also, this specialised Use Case technique is not dependant on technical details, and is primarily synthetic, in that it is a 'language of design' that all stakeholders can understand and contribute to. Eight initial Design Studies were performed which investigated how candidate technologies could support the key conceptual dimensions of the project. The successful evaluation of this initial design work [39] led to the development of four 'Demonstrators' that emerged from synthesising: the findings from the Design Studies; the most important Use Cases (in both user value and knowledge maturing terms); addressing key TEL priorities as identified by another European project called PROLEARN; and, ensuring that all key socio-technical aspects, namely *content, people, semantics* and *processes*, were suitably covered.

3.4.3 Development and interaction in context

All stages of development of the MATURE Demonstrators were performed by design teams including technical and user-representatives, who were addressing an authentic problem or opportunity in their work-based contexts, such as Careers Advice (the UK Connexions organisation) and online training (a software company called STRUCTURALIA in Spain). Also fundamental to MATURE is the emphasis on, often creative and open-ended, social and collaborative processes within these authentic work-based Communities of Practice (CoP). All of the current Demonstrators, at a high-level, can be conceived as a means to harness or catalyse interactive knowledge maturing processes involving individuals, social and semantic software tools and a work-based CoP.

3.4.4 Evaluation approach and initial findings

These Demonstrators are all undergoing a combination of contextually tailored and common evaluative methods. This evaluation framework [39] assesses the Demonstrator applications in terms of the degree to which they solve a problem scenario, their usability within the user groups and the degree to which they support learning as knowledge maturing. A first phase of formative evaluation linked to

participatory design activities has been completed. These have typically led to the specification of concrete and acceptable user-system scenarios and refined user interfaces that will collectively support longer and more embedded knowledge maturing activities.

4. Discussion and implications

In addition to illustrating and validating our approach of DLD across various TEL initiatives, we can also report some interesting implications.

Firstly, the way in which the principles of DLD can be adopted and mapped to such a diverse range of TEL initiatives represents a significant generality test of the approach, as a paradigm, or 'meta-methodology' for TEL design.

Secondly, all these projects, in embracing the interplay and co-evolution of design and digitally mediated practice, demonstrate the need for faster and more responsive 'design-development-evaluation' cycles, which is likely to become increasingly common, to ensure that TEL research leads to research-led innovation.

Thirdly, accepting that not all TEL initiatives can fully accommodate all the principles of DLD, and may cover each with varying degrees, such initiatives could apply the paradigm more descriptively, as a lens to understand which DLD aspects have been covered compared with what might need greater attention (e.g. the theory, the design, the authentic application, or the evaluation).

Finally, three of these initiatives include a re-working of Vygotskian ideas about the nature, form and operation of new types of technology mediated ZPD. The DDG and some aspects of the MATURE initiative adopt a more 'traditional' dialogue-based stance on this, but with a different conception of 'the more learned other' to accommodate the ways in which peers can often 'co-scaffold' one another in semi-formal or informal ways, through mediating technologies, where this may be in response to an emergent problem. Whereas the ACD approach, whilst retaining the notion of the ZPD, gives greater emphasis to the role of the technology itself, and how this can give greater clarity and cohesion to temporal and causal aspects during interactions between co-learners. This re-working of Vygotskian ideas to conceptualise and design highly social and technology mediated learning activities could have wider exploitation, in relation to developing and evaluating applications of social software for learning in general, i.e. can social media produce a ZPDpt that takes the participants to higher levels of understanding and produce new and powerful artefacts? In other words, can the likely establishment, or not, of a ZPDpt, be a discriminating factor as to whether a social software interaction leads to learning and knowledge development. This could be particularly relevant as future TEL work will, inevitably, continue to embrace developing ideas in Web Science, that at their heart conceive the web as predominantly a 'social machine' [36]. Therefore, a DLD perspective that harmonises Vygotskian or Bahtkinian ideas with developing web-technologies could be a way of realising 'social learning machines'.

5. Conclusions

This article has developed, exemplified and tested the paradigm of Deep Learning Design, which aims to embrace the new possibilities provided by our digitally enriched landscape whilst avoiding the sort of technological determinism that is unhealthy for learning. Two of the included projects that are exemplars of this approach (DDGs and CETL-RLOs) have been successful and led to sustainable innovations because they focused on design to address clear problems and did not seek to introduce favoured technologies in search of an application. Instead they have matched technologies to problems and then refined their approach in light of comprehensive evaluations. The two later examples (ACD and MATURE) have a related motivation, namely exploiting emerging technologies to realise new forms of learning and scope out new directions for TEL that need to be considered in near-future develpments. All these approaches have developed designs within complex and changing contexts, where they have justified and demonstrated our somewhat sophisticated notion of DLD. We argue that this level of sophistication of the DLD framework will always be the case with 'real' TEL solutions, with no or very few 'off the shelf' solutions, because our learning problems, opportunities and solutions in the Web 2.0 landscape and beyond will always be co-evolving. A related trend is that advances in Web Science and the notion of the future web as a 'social machine', means that future TEL will inevitably require 'social learning machines', and DLD is arguably a very useful paradigm for developing these

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