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Understanding the Technology Enhanced Learning Environments from A Cognitive Perspective

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Abstract

This conceptual paper discusses some principles for powerful learning environments based on a cognitive perspective. Throughout the paper, it is argued that the accommodation of different individual cognitive preferences is crucial for its alignment with the human cognitive architecture. The paper concludes that in order to be aligned with the human cognitive architecture, TEL (technology enhanced learning) environments should provide supportive visual and interactive multimedia, self-assessment tools, instructional guidance about the purpose of the learning environment and how to operate it. Based on the prior research undertaken in this area, the paper concludes that a more evidence-based model for deriving the positioning would allow the learning professionals to move from a framework to a genuine taxonomy.

Keywords: Powerful learning environments, Cognitive, TEL

1. Introduction

With the proliferation of ICTs (information communication technologies) in the educational settings, radical changes have already taken place in the design and delivery of the learning experience. Contrary to the popular belief, one of the main challenges in this new era of learning is how to bridge the divide between technology and the learners themselves rather than the divide in terms of access to the ICTs. In order for technologies to be useful, effective, cognitively demanding and engaging the underlying cognitive and psychological mechanisms should be taken into consideration.

The problem addressed in this paper can be summarized as follows:

"How can the design principles for powerful learning environments be integrated into TEL (technology enhanced learning) and make it aligned with the human cognitive architecture?"

The paper first provides an overview of the TEL environments along with its potential benefits and underlying architecture and then discusses the design principles of powerful learning environments by taking into account the cognitive load theory.

2. Definition and Potential Benefits of TEL Environments

TEL refers to the use of technology to support and enhance learning practice. TEL environments enable access to a range of materials, learning tools and communication facilities, so they can be ideal constructivist learning environments that enable the students to become more actively involved in developing their understandings. From a constructivist perspective, a learning environment can be defined as 'a place where people can draw upon resources to make sense out of things and construct meaningful solutions to problems' (Wilson, 1996). Long-term understanding can be fostered through meaningful contexts and interactions that reflect how knowledge is developed and used in the real world. Increased learner responsibility, opportunities for reflection, a focus on realistic tasks, purposeful collaboration with tutors, exposure to multiple perspectives and going beyond purely abstract definitions of a subject domain are the main characteristics of constructivist learning environments (Grabinger & Dunlap, 1995: Jonassen, 1999).

3. Importance of Cognitive Architecture for TEL

As Dror (2008) asserts, computers have augmented the computing power of our brains to such an extent that being deprived of one's computer may feel like the loss of one's own cognitive capacity. Similar to the non-cognitive technology's (cars, planes…etc.) impact on our lives cognitive technology will affect our brain development and capacities (Dror, 2008) so that our minds may eventually be reshaped and consequentially, how we think and learn may be changed. Indeed, the human mind seems to work like the World Wide Web in a dynamic, creative and unpredictable way.

With regard to the area of educational technologies the critical question to be asked is whether technology can enhance learning given these potential harms and benefits. For learning to be successful, it must conform to the architecture of the mind and take into account the information processing capacity. By using the correct mental representations and engaging the cognitive system, information must be conveyed in such a way so that it can be easily acquired. A major challenge is how to translate the theoretical and academic research into practical ways to utilise technology so as to enhance learning. By bridging research about the brain into ways of using learning technologies sophisticated learning programs can be created and by taking into account the architecture of cognition efficient TEL can be facilitated (Dror, 2007). To exemplify, one should recognize that there is a trade-off between the ability to build knowledge according to the learner's cognitive structures and the extra cognitive load associated with giving learners more control. Intrinsic cognitive load arises from the complexity of the learning material which is not an inherent property of the material, rather it arises from the interaction between an individual's domain knowledge and the information content. On the other hand, extraneous cognitive load is generated by the representational format of the learning material (text or diagram). So, while text-based format may cause a high extraneous load a diagrammatic format would require lower extraneous loads. As Dror (2008) suggests, when designing for e-learning, restricting the navigational freedom could free up cognitive resources for knowledge acquisition. Besides, information content should be kept as simple as possible to facilitate learning.

As is the case with every technology, there are some benefits and harms referred as "gold mines" and "land mines" by Dror (2005) in cognitive technologies. In terms of gold mines, active learning can be facilitated via TEL by maximising the interaction between the material and the learner. By activating the cognitive mechanisms of learning such as attention, depth of processing the learning goes beyond a mere exposure to information. Besides, by giving the learners control over the presentation of the material- different preferences for visual, auditory, text may exist- higher levels of engagement and participation may occur. In terms of land mines, reduced mental effort and work in learning due to providing too much to the learner may decrease the depth of processing of the learners and result in reduction of the memory of the learned material (Dror, 2008).

As both human cognition and technology have their own weaknesses and strengths the key to constructing the most efficient systems would be through understanding the characteristics of human cognition and technology and then integrate their advantages. For instance, psychological and cognitive contextual elements may distort the judgements of human beings whereas technologies are non-biased. In this way, technology and human beings can cooperate rather than being overestimated. As Dror (2008) suggests, rather than conceptualising both technology and human cognition as competing, we can give consideration to the weaknesses and strengths of both and how they can complement each other.

Moreover, as Clancey (1995) asserts, in order to change the practice of TEL a better understanding of how models relate to human knowledge must be achieved. The insights of the cognitive, computational and social sciences can be related to each other if the thoughts of managers, scientists and trainers regarding the models and computer tools can be changed.

The widespread use of TEL is being launched without an adequate theory to relate perceptual processes to conceptual learning. As Clancey (1995) asserts we cannot assume that problems are merely texts and diagrams as problems may consist of much more than comprehending text. We must not assume that the world is given as objects with inherent properties and that concepts are named properties stored in a memory. To understand the learner's point of view better, we must focus on how people create representations, perceive symbols, and attribute meaning (Clancey, 1995). In terms of lesson planning, the focus has been so far on logical prerequisites based on the idea of composition and refinement of descriptions. To step out of this "representational flatland", we must understand learning as a process of multimodal recoordination during interaction with physical materials (Clancey, 1995).

According to Clancey (1995), equating human knowledge with descriptions eliminated the grounds and origin of belief, and greatly oversimplified the complex processes of coordinating perception and action. The dialectic process of the learner's participation can be modelled by schema transformations of assimilation, refinement in which descriptions are combined in an individual mind. Yet, such a theory may not account for individual differences as it assumes that there is one objective world of features perceived by everyone. Knowledge consists of more than descriptive models and successful teaching consists of more than manipulating descriptive models (Figure 1.0).

So, according to Clancey (1991), the focus should be on the physical mechanism that supports learning, in other words how the brain works. He states the following answers regarding this question:

- Human memory is not a place where representations are stored.
- Human learning does not consist of retrieving and applying structures and then storing back modifications that remain unchanged until their next use.
- Knowledge cannot be reduced to presentations, descriptions of the world or of behavioural routines.
- Although cognitive science representations are necessary and useful they should not be identified with the mechanisms inside human brains. These knowledge-level theories are necessary for describing the combined system of

people behaving in an environment. Yet, this is different from describing the neurophysiological system inside individual heads.

- Representations are inherently perceptual and given meaning by a subsequent perception of them.
- Perception is not a peripheral process, but integrated as one process with behavior and learning.

4. Conceptual Frameworks for Aligning TEL with Cognitive Architecture

Cognitive theories and design models play a crucial role in the discussion of the powerful learning environments. The most relevant notions are the cognitive modes and the most commonly used design models. Since there is a variety of design models used commonly and all of which cannot be explained in one single paper the 4C/ID model and the model-framed learning model has been selected as most relevant ones concerning this topic.

4.1 Cognitive Theories

Within the cognitive perspective, the cognitive load theory claims that working memory includes independent auditory and visual working memories that have a limited capacity (Chandler &Sweller, 1992). Human-beings have separate systems for representing verbal and non-verbal information and meaningful learning occurs when a learner selects relevant information in each store, organizes the information in each store into a coherent representation and makes connections between corresponding representations in each store (Figure 2.0).

In terms of design principles, the cognitive view emphasises interactive environments that support the construction of understanding, the experimentation of broad principles and reflection. An ownership of the task, scaffolding, guided discovery, opportunity for reflection, ill-structured problems are the main design principles for constructivist learning. So, TEL environments can be seen as an activity system where coordinated learning can be automated by a computer-based tutorial or created by the learners themselves depending on its design.

Although the following list is not exhaustive these principles should mainly be taken into account to achieve this purpose (De Corte, 2003):

- *Scaffolding learners to decrease their cognitive load:* A simple-to-complex sequencing of categories of learning tasks can reduce the intrinsic aspects of cognitive load. Besides, meaningful learning can be promoted by stimulating learners to compare the solutions to the different learning tasks and to abstract more general knowledge for solving a wide range of problems (high variability).
- *Making high element interactivity information easily accessible in long-term memory:* To help novice learners construct the necessary mental models ad cognitive strategies supportive information should be presented before learners start working on the learning tasks. A cognitive schema may be constructed in long-term memory that can be activated in working memory during task performance. Retrieving this schema during task performance is less cognitively demanding than activating the externally presented complex information in working memory during the task performance.
- *Making low element interactivity information directly available in working memory:* For novice learners to automate schemata for recurrent tasks they need to practice in a learning process known as knowledge compilation where the information which is active in working memory is embedded in highly domain-specific representations. Presenting procedural information precisely when it is needed so that it is fully integrated with the task environment may also prevent spatial split attention effects. Such effects arise when multiple sources of information must be mentally integrated to follow procedural instructions.
- *Freeing up processing resources for non-recurrent tasks:* After a consistent skill is introduced in a learning task repeated short practice sessions are used to automate the performance of the consistent skill and free up cognitive resources that can be deployed by the learner to cope up with the learning task.

4.1.1The 4C/ID model

The following TEL design principles should be taken into account for each of the four components of the 4C/ID model:

- *Fidelity principle:* A high-fidelity environment refers to an environment that is very close to the real task environment whereas a low-fidelity environment merely offers the opportunity to perform tasks with no attempts to mimic the real environment. For novice learners, a high-fidelity task environment contains irrelevant details that may deteriorate learning.
- *Training-wheels principle:* In order to support learners, their performance is constrained to make sure that they cannot perform actions that are not necessary to reach the performance goals.
- *Completion-strategy principle*: This principle states that novices benefit more from studying worked examples while experienced learners profit more from solving the equivalent conventional problems.
- *Redundancy principle:* The presentation of redundant information has a negative effect on learning because finding out that the information from different sources is redundant is a cognitively demanding task for learners.
- *Self-explanation principle:* For meaningful learning to occur multimedia should be associated with deep processing and invite learners to self-explain information.

- *Self-pacing principle:* Giving learners control over the pace of the instruction may facilitate elaboration and deep processing of information.
- *Signaling principle:* Learning may be improved if the learner's attention is focused on the critical aspects of the learning task or the presented information. As this reduces the need for visual search and frees up cognitive resources that may be devoted to schema construction and automation.
- *Modality principle:* Auditory text and narration techniques to explain visual diagrams, animations, or demonstrations, result in better learning than single mode presentations.
- *Component-fluency principle:* Drill and practice on one or more routine aspects of a task may have positive impacts on learning and performing the whole task.

So, powerful learning occurs when a learner is involved in both verbal and visual processing as well as integrating the corresponding components of the verbal and visual models. Multimedia presentations should not contain too much extraneous information in the form of words or sounds, should represent the verbal and non-verbal steps in synchrony and should present words and pictures using modalities that effectively use available visual and auditory working memory resources (Mayer, Moreno, 1998).

4.1.2 Model-framed Learning (MFL)

Another learning model that shares the view that learning should be associated with multiple representations and examples to promote generalization and abstraction is the model-framed learning (MFL) model suggested by Milrad, Spector and Davidsen (2003).

MFL is a realization of the cognitive flexibility theory (CFT) through system dynamics and distributed technology and provides learners with the opportunity and challenge to become model builders, to exchange and discuss models with peers, and to experiment with models to test hypotheses and explore alternative explanations for various phenomena (Milrad, Spector and Davidsen, 2003). CFT shares with situated and problem-based learning the view that learning is context dependent, so multiple representations and examples must be provided to promote generalization and abstraction processes (Milrad, Spector and Davidsen, 2003). In MFL, there are three stages of learner's cognitive development (Table 1.0):

- Problem-orientation: Learners are presented with typical problem situations and asked to solve them.
- Inquiry-exploration: Learners are challenged to explore a complex domain and asked to identify causal relationships and underlying structures.
- Policy-development: Learners are immersed in the full complex system and asked to develop rules and heuristics to guide decision-making.

MFL advocates learning with models as an instructional approach to introduce learners to a new domain. According to this model, learners are usually presented with a problem scenario and asked to construct diagrams, which may serve to center thinking around meaningful problems and facilitating small group collaboration (Milrad, Spector and Davidsen, 2003). As learners become more competent in a subject area they can make the transition from learning with models to learning by modelling. The two principles for making this transition is that learners need to appreciate that there exists connections between the system structure and system outcomes and that they should fill in parts of an existing model which is consistent with the observed behavior. This linking of structure to behavior and creating structures to account for behavior are important stages of powerful learning (Davidsen, 1996). By allowing the construction of such models, TEL environments enable the learner to hypothesizing about potential causal relationships and then test these hypotheses so that they can build up their understanding. Representing causal relationships, formulating hypotheses about those relationships, identifying the key factors in a system, developing policies to guide decision making all represent patterns of expert behavior (Milrad, Spector and Davidsen, 2003).

Both 4C/ID and MFL (Table 2.0) fulfil the following principles for instruction (Merrill, 2001):

- Principle of problem centeredness: Learning is effective when learners are engaged in solving real-world problems.
- Principle of learner activation: Learning is effective when existing learner knowledge is activated as a foundation for new knowledge and skills.
- Principle of demonstration: Learning is effective when desired knowledge applications and skills are demonstrated for learners.
- Principle of application: Learning is effective when learners are required to apply new knowledge and skills.
- Principle of integration: Learning is effective when new knowledge and skills are integrated into the learner's world.

5. Conclusions

In order to be aligned with the human cognitive architecture, TEL environments should provide supportive visual and interactive multimedia, self-assessment tools, instructional guidance about the purpose of the learning environment and how to operate it. Identifying the kinds of online leaning support that may be required for different types of learners and clearly communicating the tasks and activities of students with regard to their online participation may further enhance the effectiveness of TEL environments.

In order to design powerful learning environments, instructional designers should also thoroughly explore and interpret the problem and combine a wide range of possible solutions with a wide range of factors while using context knowledge. Besides, more time should be taken for prototyping and evaluation. Use of a highly interactive and collaborative design approach involving a cooperation with stakeholders is also essential for a successful design. Designing should be viewed as a social process and should be communicated with users and stakeholders.

The main goal of this paper was to describe the design principles in order for TEL environments to be aligned with cognitive architecture. It has been attempted to show how these design principles have been derived from the cognitive perspective and also to frame this account within the familiar 4C/ID design model. Yet, a more evidence-based model for deriving the positioning would allow the learning professionals to move from a framework to a genuine taxonomy.

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Appendix

Table 1. Computational media to support deep learning (Milrad, Spector and Davidsen, 2003)

Complex thinking component	**Cognitive skills**	**Learning tools & strategies**	**Computational media Support**
Problem-orientation	Identifying main ideas Inferring Hypothesizing Reflection	Mental models Concept mapping Modeling *Problem-based learning*	Model builder
Inquiry-exploration	Planning Determining criteria Concretizing Group discussion Collaboration	Construction Manipulation Visualization *Inquiry-based learning*	Software such as Lego Robotics
Policy-development	Hypothesis formulation Identifying causal relationships Inferring Synthesis Predicting Group discussion	Model building Simulation *Decision-based learning*	Web based simulations

Table 2. Important stages in MFL and 4C/ID models with regard to cognitive development (Milrad, Spector and Davidsen, 2003)

Learning Activity	**MFL**	**4C/ID**
Introduction to the domain	Problem-orientation	Whole task introduction
Familiarizing with the system	Problem-orientation and learning with models	Part- or whole-task practice with prerequisite knowledge
Identification of causal relationships	From problem-orientation to inquiry exploration	Part-task practice and algorithmic methods
Elaboration of causal relationships	Inquiry-exploration with learning with models and by modeling	Whole-task practice and heuristic methods
Reflection on the whole system	From inquiry exploration to policy development with learning with models and by modeling	Heuristic methods
Understanding and solving new problems	Policy-development and learning by modeling	Whole-task practice and heuristic methods

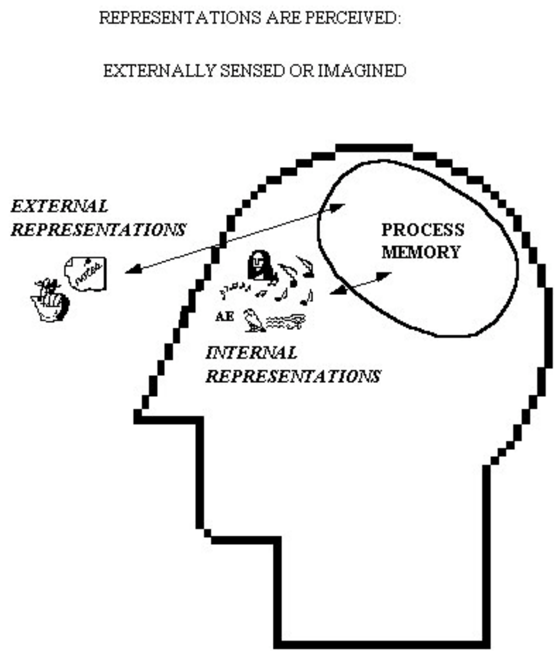

Figure 1. The Meaning of a Representation (Clancey, 1991)

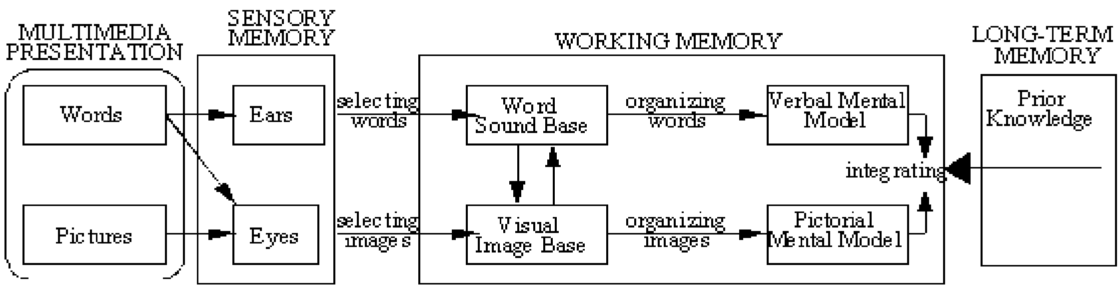

Figure 2. Depiction of Cognitive Load Theory (Mayer, Moreno, 1998)