Teaching and Learning Language and Content in the Digital Age with Pedagogy for Conceptual Thinking and Meaning Equivalence Reusable Learning Objects (MERLO)

Masha Etkind[1], Uri Shafrir[2]
[1]Ryerson University, [2]University of Toronto (Canada)
metkind@ryerson.ca, uri.shafrir@utoronto.ca

Abstract

The important role of conceptual thinking in learning language and for deep comprehension of a knowledge domain is now widely recognized. Still, traditional pedagogy and learning assessments focus on memorization of facts and procedures, presented through structured items such as true/false and multiple-choice questions. In contrast, teaching and learning of language and content in the digital age is facilitated by pedagogy for conceptual thinking that focus learners' attention on meaning. Conceptual thinking enhance ways of thinking that explore patterns of equivalence-of-meaning among ideas, relations, and underlying issues; and understanding of multiple representations of meaning that are encoded, in addition to natural language, also in other sign systems. Evolution of pedagogy for conceptual thinking follow insights from several recent developments, including the emerging digital cyber-infrastructure of networked information that facilitate searching for patterns of content and structure of concepts - labelled patterns in human experience. This led to the emergence of concept science, a novel generic methodology for parsing and analysing concepts, applicable to the various knowledge domains and professions, with tools for recognizing, representing, organizing, exploring, communicating, and manipulating knowledge encoded in controlled vocabularies of sublanguages. Research in neuroscience and brain imaging provide experimental support to the semiotic construct 'representational competence', demonstrating that exposure of learners to multi-semiotic inductive questions enhance cognitive control of inter-hemispheric attentional processing in the lateral brain, and increase higher-order thinking.

1. Concepts

In addition to the communicative use of language in everyday life, language is also used by specialists to encode and to communicate knowledge. This was rooted in careful observations that eventually resulted in awareness and recognition of regularities in the environment.

Concept science is a novel generic methodology for parsing and analyzing concepts, applicable to the various knowledge domains and professions; with tools for recognizing, representing, organizing, exploring, communicating, and manipulating knowledge encoded in controlled vocabularies of sublanguages that emerge and evolve in all knowledge domains through scholarly research aimed at clarifying and refining content.

Concept science document the evolution of content and structure of concepts and categorization, knowledge representation and use [1]; [2]. This process is echoed in Einstein and Infeld's [3, p. 13] comment on the need not only to define, but also to continuously refine, controlled vocabularies in scientific sublanguages.

Certain words, used to describe such regularities, acquire over time specific meanings that differ from their meanings in the general use of language. The use of 'code words' is a common practice in all disciplines and in all domains of knowledge for eliminating ambiguity and defining conceptual content in precise terms that allow clear demarcation between the known and the unknown. They are unique names of concepts. 'Code word' in scholarly discourse is a lexical label of a concept that act as proper name of a regularity; an organizing principle behind a collection of facts in context; an invariant; a pattern in the data. Lexical label is often one or more common words (often nouns and noun phrases) used to label a recognized pattern in human experience and to communicate a well defined meaning. The use of 'code words' as lexical labels of concepts differs from the use of these same words in natural language in two important ways:

1. Lexical labels of concepts do not encode the literal meanings associated with their constituent words in the common use of the language; each such label encodes a connoted meaning, rooted in the regularity being considered, that differs from the literal meaning of the word(s).
2. Lexical labels of concepts cannot be replaced by synonyms; rather, each label functions as a proper name of the signified concept.

Insiders who share the code know that lexical label of a concept serves similar function to that of a proper name. In contrast, 'outsiders' who encounter a lexical label, do not associate it with a discipline-specific meaning; they assume that the label is just a word in natural language, and therefore may be substituted by a synonym.

1.1 Knowledge Repository (KR) and Interactive Concept Discovery (InCoD)

Exploring building blocks of concepts require access to a comprehensive collection of full-text digital documents. Such a *Knowledge Repository (KR)* may contain all relevant digital documents: primary sources; monographs; technical reports; databases; etc. Such KR opens new research and pedagogical horizons to scholars, instructors and learners; allowing exploration of particular conceptual situations from different points of view, represented in different ways by a variety of authors of different documents in KR shifts the emphasis to experiential learning with *Interactive Concept Discovery (InCoD)*, a novel semantic search tool. It is an intuitive, interactive procedure that allows the discovery of elements of the building blocks underlying the lexical label of a concept within a particular context in a knowledge domain, namely, co-occurring sub-ordinate concepts and relations; it guides the user to construct concept maps that clearly identify internal conceptual structure. A user begins constructing his/her Individual Index by identifying the lexical label of a particular concept; then conduct *Key Word In Context (KWIC)* semantic search of this lexical label; and evaluate the consistency of appearance of 'candidate' co-occurring concepts and 'candidate' relations across different documents in the KR. In successive iterations, the user:

- read/annotate/tag/link found documents
- mark/save lexical labels that are 'candidates' for inclusion in the Individual Index
- evaluate the degree of relevance of a particular document to the conceptual situation under consideration, and note different representations that share equivalence-of-meaning
- construct Concept Maps - optional graphical representations of lateral and hierarchical links between concepts and their building blocks

Sequential stages of construction of such Individual Index's and Concept Maps document the process-outcomes of sequential research/learning episodes; reveals the user's consistency of 'drilling down' for discovering deeper building blocks of the particular concept; and shows deeper levels of comprehension of conceptual content. This digital record may be saved in a learner's *e-Portfolio as an authentic, evidence-based demonstration of mastery of knowledge*.

2. Meaning Equivalence Reusable Learning Object (MERLO)

Meaning equivalence is a construct that denotes commonality of conceptual meaning across different representations within and across sign systems. MERLO is a multi-dimensional database that allows the sorting and mapping of important concepts through multi-semiotic representations in multiple sign systems: target statements of particular conceptual situations, and relevant other statements.

Each node of MERLO database is an item family that includes: a Target Statement (TS) that describe a conceptual situation and encodes different features of an important concept; and several other statements that are organized by the following two sorting criteria:

- shared equivalence-of-meaning with TS
- shared surface similarity with TS

Further analysis reveals that:

- statements in quadrant ***Q1*** are *similar in appearance* to TS, and *share equivalence-of-meaning* with it.
- statements in quadrant ***Q3*** are *similar in appearance* to TS, but *do not share equivalence-of-meaning* with it.
- statements in quadrant ***Q2*** are *not similar in appearance* to TS, but *do share equivalence-of-meaning* with it.
- Finally, statements in quadrant ***Q4***, although thematically relevant to TS, are *not similar in appearance* to TS and *do not share equivalence-of-meaning* with it.

Collectively, a comprehensive collection of such item families may encode the conceptual mapping that covers the full content of a course (a particular content area within a discipline; for example, 'functions' in mathematics). Fig. 1 is a template for constructing an item family anchored in a single target statement.

MERLO pedagogy guides sequential teaching/learning episodes in a course by focusing learners' attention on meaning. The format of a MERLO assessment item allows the instructor to assess deep comprehension of conceptual content by eliciting responses that signal learners' ability to recognize, and to produce, multiple representations, in multiple sign-systems, namely, multi-semiotic, that share equivalence-of-meaning.

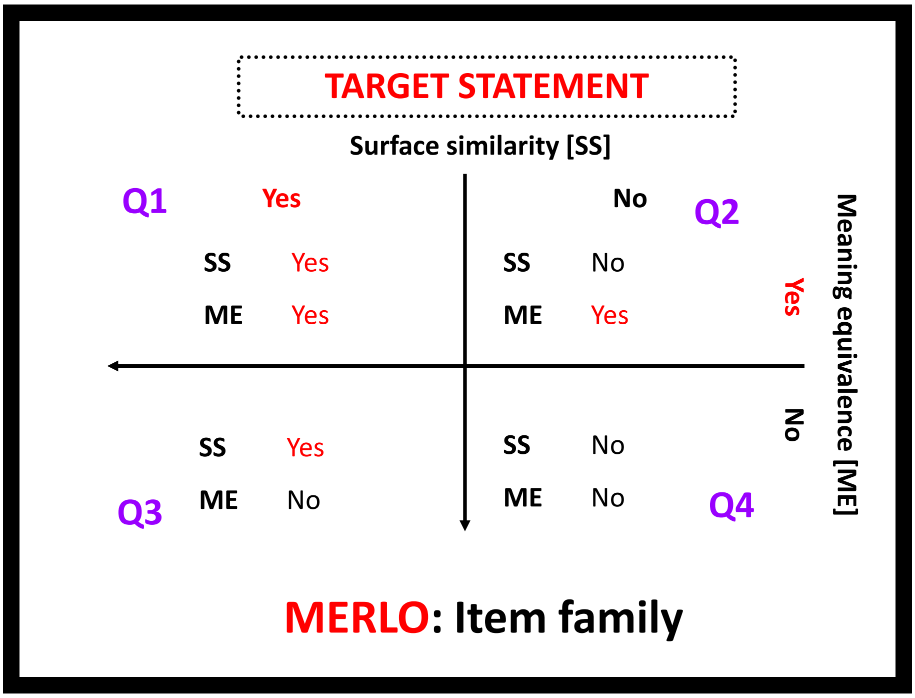

Figure 1: Template for constructing an item-family in MERLO

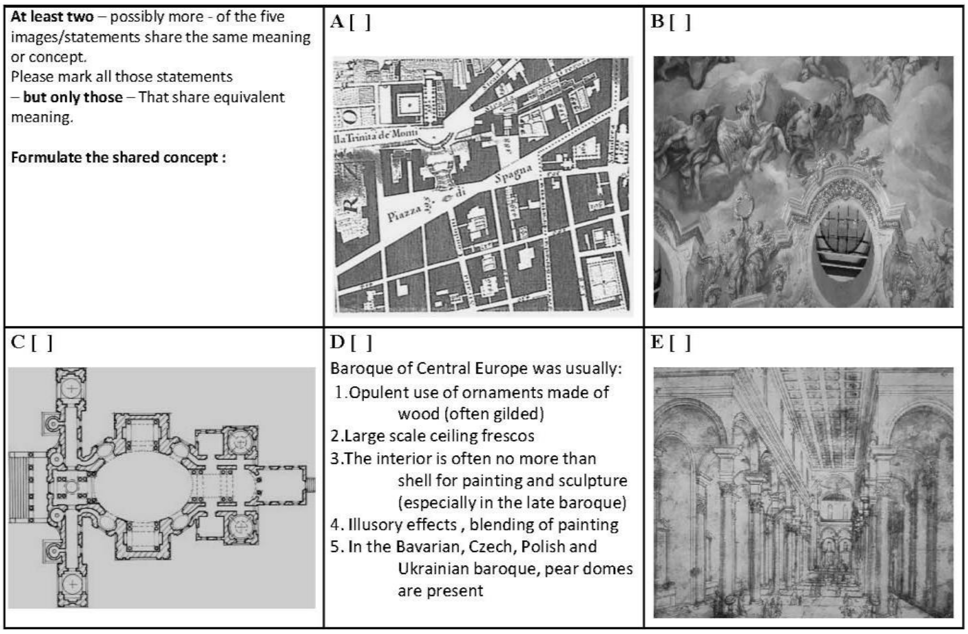

Figure 2. Example of a multi-semiotic MERLO item (history of architecture)

A typical MERLO assessment item contains 5 unmarked statements: unmarked TS (Target Statement) plus four additional (unmarked) statements from quadrants Q2; Q3; and Q4. Our experience has shown that inclusion of statements from quadrant Q1 makes a MERLO item too easy, because it gives away the shared meaning due to the valence-match between surface similarity and meaning equivalence; therefore Q1 statements are excluded from MERLO assessment items.

Fig. 2 is an example of a MERLO item in history of architecture that includes 5 representations (at least two of which share equivalence-of-meaning), in the following sign-systems: urban plan (A); photograph (B); orthogonal drawing (C); text (D); 3D sketch (E).
Task instructions for MERLO assessment are: At least two out of these five statements – but possibly more than two – share equivalence-of-meaning.

- *Mark* all statements – *but only those* – that share *equivalence-of-meaning*
- *Formulate* and write down briefly the *concept that guided you in making these decisions*

2.1 MERLO diagnostic scoring algorithms

Learner's response to a MERLO item combines two formats:

- *recognition:* multiple-choice/multiple-response
- *production:* short answer

Subsequently, there are two main scores for each MERLO item: *recognition score;* and *production score*. Specific comprehension deficits can be traced as depressed recognition scores on quadrants Q2 and Q3, due to the mismatch between the valence of surface similarity and meaning equivalence in these quadrants (Fig. 2).
However, the interpretations of Q2 and Q3 scores are very different:

- Depressed score on Q2 indicates that the learner *fails to include within the Boundary of Meaning (BoM)* of the concept certain statements that do share equivalence-of-meaning (but do not share surface similarity) with the target; such depressed Q2 score signals an *over-restrictive (too exclusive) understanding of the meaning underlying the concept.*
- Depressed score on Q3 indicates that the learner *fails to exclude from the Boundary of Meaning (BoM)* of the concept certain statements that do not share equivalence of-meaning (but that do share surface similarity) with the target; this depressed Q3 score signals an *under-restrictive (too inclusive) understanding of the meaning of the concept.*

Production score of MERLO test items is based on the clarity and accuracy of the learner's written description of the conceptual situation described in the item, and the explicit inclusion in that description of lexical labels of relevant and important concepts and relations.

2.2 Cognitive control of inter-hemispheric attentional processing

Recent research in neuro-science and brain imaging, revealed the benefits of enhancing cognitive/executive control of inter-hemispheric collaboration in the human lateralized brain for attentional processing of multi-semiotic conceptual situations. Results of research in neuroscience and brain imaging on cognitive control include numerous studies, by different researchers, in different experimental contexts, and may be summarized as follows [4]:

- *Increase in task processing complexity is facilitated by engaging both hemispheres*
- *Inter-hemispheric collaboration facilitate processing of multi-semiotic tasks*
- *Cognitive control of inter-hemispheric attentional processing enable cooperation between the hemispheres in response to multi-semiotic tasks*
- *Cognitive control of inter-hemispheric attentional processing is trainable*

These results demonstrate that *exposure of students to MERLO multi-semiotic inductive questions enhance cognitive control of inter-hemispheric attentional processing and enhance higher-order thinking*.

3. Results

Pedagogy for conceptual thinking was developed, validated, and implemented since 2002 [4;5] at Ontario Institute for Studies in Education of University of Toronto (OISE/UT); Faculty of Engineering and Architecture at Ryerson University; Russian Academy of Sciences - Ioffe Physico-Technical Institute, St. Petersburg; Independent Learning Center (ILC) of TVOntario; Material and Manufacturing Ontario (MMO) Centre of Excellence; Roots and Routes Summer Institute - RRSI-2012, at University of Toronto Scarborough; Meir Medical Center in Kfar Saba, Israel; Mount Sinai Hospital in Toronto; and M@t.abel national mathematics educational program at University of Turin, Italy; in the following knowledge domains: language (ESL; learning disabilities); social science (psychology; teacher education); history; architecture; mathematics; science (physics; biology); medicine (Evidence Based Informed Consent (EBIC) in obstetrics and gynecology); business (project management; risk management).

4. Conclusions

The results of these implementations substantiate and lead to the following conclusions;

- weekly multi-semiotic MERLO quizzes enhance peer cooperation; cognitive control of attentional processing; conceptual thinking; and learning outcomes
- pedagogy for conceptual thinking and peer cooperation motivate and engage students; this is particularly evident in large undergraduate classes
- conceptual thinking is learnable
- good vs. poor conceptual thinkers score high (low) on deep comprehension of the conceptual content of a course of study, as measured by their marks on an essay written as part of the final exam
- ‘alternative conceptual thinkers score high on deep comprehension of conceptual content, as measured by their marks on an essay written as part of the final exam
- good vs. poor conceptual thinkers score high (low) on deep comprehension of the content of other courses
- pedagogy for conceptual thinking and peer cooperation, when implemented as a regular part of the instructional methodology, replicates the above pattern of results, mastery of knowledge, and higher-level thinking

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