Concept Mapping: Connecting Educators
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ADVANCED CONCEPT MAPPING: DEVELOPING ADAPTIVE EXPERTISE

David Delany
Centre for Academic Practice and Student Learning (CAPSL), Trinity College, Ireland
Email: delanydi@mee.tcd.ie

Abstract. We describe a novel cognitive science-based approach to concept mapping called Advanced Concept Mapping (ACMapping) designed to reliably enhance teaching, learning and research performance in both underperforming and highly accomplished individuals. ACMaps are logically constructed expert-like representations of the conceptual deep structure of a technical domain. The ACMapping methodology was designed around the key observation that expert-novice performance differences are overwhelmingly due to differences in the quality of domain-specific knowledge structures (Chi, 2006).

The motivating assumption behind ACMapping is that the ideal goal of education is to promote the development of adaptive expertise i.e. the ability to apply meaningfully learned knowledge in a flexible and creative manner (Hatano, 1982). Elite performers invariably exhibit adaptive as opposed to routine expertise. To facilitate this goal ACMapping is taught within the context of a novel theoretical taxonomy of educational objectives, the Advanced Critical Thinking (ACT) Framework, a model of the key elements of adaptive expertise.

The skilled meaningful learning process of autonomously constructing expert 'connected understanding' using ACMaps is referred to as 'Knowledge Engineering'. In Knowledge Engineering the learner employs the fundamental thinking skills of abstraction, analysis, synthesis, and inference to explicitly construct integrated, hierarchical, expert-like knowledge structures implied by the surface features of expert productions. The use of the advanced knowledge engineering techniques of Deep Structure Analysis and Heuristic Analysis to 'reverse engineer' the deep-level understanding and adaptive problem solving strategies of elite experts is also discussed.

Trinity College Dublin, Ireland is currently using this accelerated learning approach to enhance the thinking skills of academic staff and postgraduates across the sciences and humanities. We also briefly report on ongoing research into the effect of this training program on student thinking skills and the quality of the research output of scientific research groups.

1 Introduction

Cognitive psychologists distinguish two types of expertise; routine and adaptive expertise (Hatano, 1982). Routine expertise manifests itself in the ability to efficiently solve standard, familiar problems. Adaptive experts, in contrast, exhibit highly developed metacognitive skills that facilitate development of ad hoc problem solving strategies and procedures for non-standard problems (Bransford et al., 2000). Elite experts within a domain are invariably adaptive experts. We believe that the ideal goal of education should be to facilitate the development of adaptive expertise through meaningful learning.

We present an innovative approach to concept mapping called Advanced Concept Mapping (ACMapping) designed to promote the development of adaptive expertise. In order to clearly focus pedagogic attention upon the key aspects of adaptive expertise, ACMapping is taught within the context of a novel theoretical taxonomy of educational objectives, the Advanced Critical Thinking (ACT) Framework. We designed the ACT Framework to provide a normative 'conceptual scaffold' for integrating and structuring the logical and metacognitive thinking skills characteristic of adaptive expertise. Briefly, the ACT Framework embodies the conventional definition of an expert as an individual with superior knowledge and superior problem solving skills (Chi, 2006) augmented with critical thinking skills (abstraction, analyticosynthesis, and inference) and the reflective, metacognitive skills characteristic of adaptive expertise (Baroody, 2003).

This approach is currently being taught to staff and postgraduates in the form of generic and subject-specific accelerated learning courses run by the Centre for Academic Practice and Student Learning (CAPSL) in Trinity College Dublin (TCD). In this paper we briefly review the rationale behind this novel approach to learning and problem solving and outline some of the associated methodologies.

2 Nature of Expertise

Expert-novice differences in performance are overwhelmingly due to differences in the quality and extent of domain-specific knowledge structures, or schemata, held in long term memory (Chi, 2006). Novices typically possess fragmented, non-hierarchically organised knowledge structures, whilst expert knowledge structures are generally highly integrated and hierarchically organised around deep principles within their domain (Chi, 2006). The superior comprehension, problem solving, recall and learning abilities of experts arise directly from their superior knowledge organisation (Bransford et al., 2000). The conventional progression from novice to expert, as described by research in cognitive psychology, is therefore typified by a qualitative transformation and a quantitative extension of the individual's knowledge structure, as illustrated in Figure 1A.

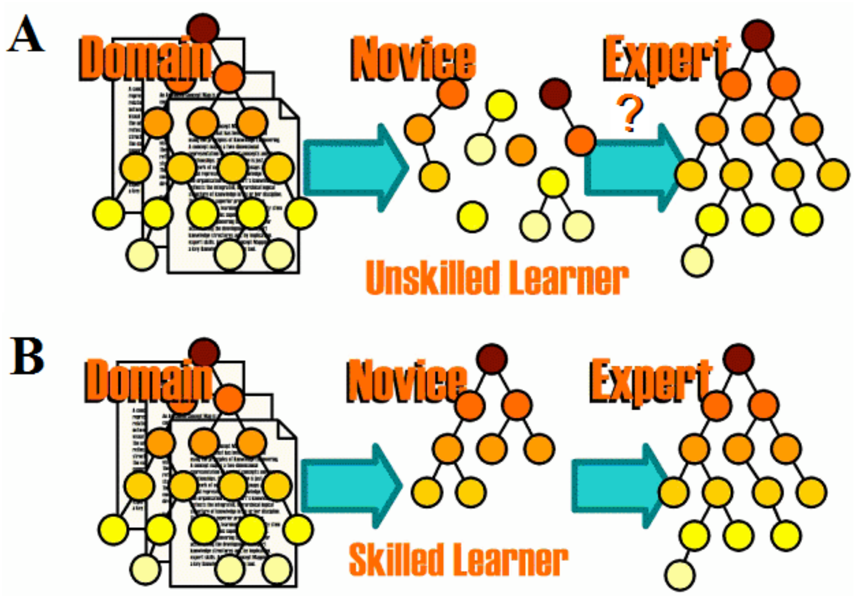

Figure 1. A. The conventional development of expertise. The unskilled learner slowly progresses from early fragmented, non-hierarchical conceptual representations towards the integrated, hierarchical representations characteristic of experts. B. A proposed ideal sequence of development of expertise. The skilled learner uses advanced critical thinking techniques, such as knowledge engineering to construct an integrated, hierarchical, 'mini-expert' representation from the earliest phases of learning.

We argue that this conventional developmental trajectory of performance is founded upon an inherently unskilled approach to learning and is, consequently, both inefficient and unnecessary. An ideal alternative progression based upon the skilled learning approach advocated in this paper is depicted in Figure 1B.

3 Critical Thinking Skills and Advanced Concept Map Construction

Since the latent conceptual structure of technical domains, such as physics, economics, and psychology are logically organised, and the development of expertise within a domain is largely the process of internalising this latent conceptual structure, we devised Advanced Concept Mapping (ACMapping), a modified version of the concept mapping approach (Novak and Cañas, 2006), to expedite this process. ACMaps explicitly extend the traditional constructivist focus of concept maps (Ausubel et al., 1978) to include the use of the logical thinking skills of abstraction, analysis, synthesis, and inference to critically and creatively construct and restructure knowledge representations. *Prima facie* support such an approach includes evidence that the deliberate use of abstraction to drive thinking upwards towards more integrative conceptual levels is associated with enhanced levels of learning transfer in domains as diverse as mathematics (Kaminski et al., 2008), motor skills (Judd, 1908), and analogical reasoning (Gick and Holyoak, 1983). Significantly, Aristotle considered this ability to 'see similarities between dissimilars' as the 'mark of genius' {Aristotle, 1996}. The techniques outlined here are also designed to enable problem solvers to systematically transcend apparent limitations in human creativity (Ward et al., 2004).

3.1 Construction of ACMaps

The standard steps for building an ACMap are:

- SELECT
  1. Identify key concepts
  2. Organise related concepts into small groups
- CONNECT
  3. For each group link the terms into a logical micro-map
- INTEGRATE
  4. Link the micro-maps into a larger concept map (where necessary, inferring implied concepts)
  5. Edit and evaluate the macro-map for logical soundness
  6. Search for creative cross linkages between distal concepts

The explicit use of critical thinking skills to actively infer the existence of deeper integrative relationships and concepts is simply illustrated in Figure 2. This figure shows how an organizing principle of business can be extracted from a basic definition of 'capital' taken from an introductory business studies dictionary.

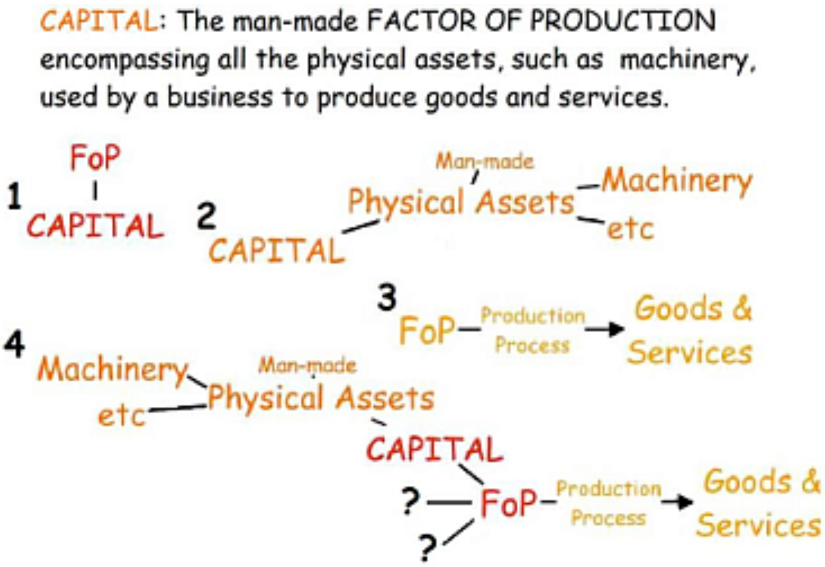

Figure 2. ACMapping in action: Mapping ‘Capital’ 1. This first micro-map clarifies that capital is defined in terms of the more abstract concept of factor of production (FoP). 2. Capital is also a type of physical asset, of which machinery is an example. 3. Although a superficial reading suggests that capital is used to produce goods and services, micro-map 1 implies that it is more accurate to say that FoPs are the appropriate level of generalization at which to describe inputs to the production process. 4. This point is amplified when the micro-maps are merged to produce the final map. Capital is seen to be simply one of several types of FoP that feed into the production process. In this macro-map the key organizing feature that naturally emerges is the fundamental business concept of the production process. Note that this structure is logically implied by the definition and that minimal prior knowledge is required to elicit a fundamentally deeper understanding. Note also that although ACMaps generally follow the CMap convention of top-bottom hierarchical organization they optionally augment this scheme with left-right hierarchies as well. For visual clarity and speed of development, relationship labels are optional in ACMaps.

4 Knowledge Engineering

We refer to the process of explicitly modelling expert knowledge and problem solving heuristics in order to accelerate domain learning as knowledge engineering (a pedagogic variant of the definition traditionally used within artificial intelligence). Thus defined, it is closely related to the notion of knowledge recovery (Hoffmann et al., 2007), the process of extracting meaningful information from documents and other resources and representing them as concept maps. The key differences lie in the directed application of informal logic to extrapolate latent conceptual deep structure, and the goal of fostering adaptive expertise.

A corollary to deep structure integration is conceptual restructuring driven by the discovery of logical flaws or explanatory limitations in superficially coherent knowledge structures. The fundamental importance of such restructuring to human cognition is indicated by its ubiquitous presence across the gamut of problem solving activities: from the humorous surprise of suddenly 'getting' a joke, and the revelatory 'aha!' moment of insight problem solving, to the magisterial sweep of Kuhnian paradigm shifts within the sciences (Kuhn, 1996).

An interesting ‘advanced’ application of knowledge engineering is that of Reverse Engineering of Expertise (RevEng). RevEng is the use of knowledge engineering techniques to expose the latent knowledge structures (deep structure analysis) and problem solving heuristics (heuristic analysis) of elite experts for the purposes of comprehension, evaluation, and extension. By abstracting away from the surface details of the productions of domain virtuosos, the underlying declarative and procedural structures utilised by an elite expert can be inferred and made explicit. The utility of such an approach is highlighted by the remarkable historical improvements in both the average and peak performance levels within domains as diverse as physics, chess, and music. These improvements have largely been driven by advances in education and training methods made possible by explicating the mechanisms by which the feats of elite experts are accomplished (Ericsson and Charness, 1994). The Reverse Engineering of Expertise approach simply places this approach on a more systematic footing.

The potential effectiveness of the knowledge engineering approach for improving thinking and learning skills is suggested by the results of a recent pilot study in which first year Humanities undergraduates demonstrated significant pre-post gains on an untrained test of critical thinking ability ($t_{0.05(19)} = -2.25$, $p = 0.036$, 2-tailed) following a 14 lecture ACT course (Delany, 2008).

Since the citation impact of a paper is correlated with conceptual depth (Chen, 2004), we are currently also conducting research on the effects of subject-specific instruction in knowledge engineering on the conceptual depth and quality, and citation impact of the research output of scientific research groups within TCD.

5 Summary

In this paper we have reviewed an innovative cognitive science-based approach to developing elite expertise. This method is based upon the use of informal critical thinking skills of abstraction, analyticosynthesis and inference to explicitly construct visual representations of expert-like deep structure knowledge from the earliest stages of learning within a field. Although this approach has obvious implications for enhancing the effectiveness of student-centred learning, and improving the quality of lecture and curriculum design, perhaps the most exciting possibilities are raised by the prospect of extending the abilities of accomplished individuals.

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