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A proposed universal model of problem solving for design, science and cognate fields

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ABSTRACT

A modestly generic, innovative, problem solving process with roots in the study of design and scientific research problem solving is presented and motivated. It is argued to be the shared core process of all problem solving. At its heart is a recognition of five foci or nodes of change vital to the process (changes in problem and solution formulation, method, constraints, and partial solution proposals) together with a bootstrap marked by the formation of higher order knowledge about problem solving in the domain in tandem with the solving of specific problems, the essential feature of all learned improvement. None of these elements is entirely original, but the way they are made explicit and developed (rather than folded into fewer, more abstract, boxes) is argued to provide fresh understanding of the organisation and power of the process to deal with complex practical problems.

1. Introduction

In this paper a newly articulated, general model of innovative problem solving is presented, one that grew out of research into problem solving in both science and design, and the basic bio-organisation of learning.[1] The model provides a suite of structured memories and non-formal strategic decisions whose integral organisation and unity is central to its cognitive power (see below). Its distinctive merit lies in the way it lays out this cognitive basis of the problem solving process, making more explicit and informative the nonformal processes and decisions that underlie problem solving, and opening them all to more directed research.[2] The model arguably applies to all innovation, whether in design, science, law, ethics, criminal investigation and elsewhere, thus providing a *universal problem solving* [UPS] process.

For instance, the proposed UPS process shows how scientific revolutions can take place as an inherent part of rational scientific method, instead of being Kuhn's irrational orphans (see below). More generally, scientific revolutions typically initially present as ill-specified or ill-formed problems, with uncertain or vague problem and solution concepts and methods, and this no doubt lies behind their seeming insolubility compared to routine research. Yet these kinds of problems are at the foundation of pioneering design innovation, research, police sleuthing, and intelligent life generally - for instance, how to marry well, run a country, become a saint, throw a good party. Intelligent people regularly manage to solve such problems more or less satisfactorily. The UPS process proposed here, while not a formal algorithmic panacea, is able to render that capacity intelligible.

2. Developing a universal problem solving process

2.1. The DCM shell

The outer form of the proposed UPS process model emerges from design research. It is succinctly summarised by Dorst and Cross, following Maher (Dorst & Cross, 2001; Maher, Poon &

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[1] See respectively (Christensen & Hooker, 2000, 2002) - bio-organisation, (Farrell & Hooker, 2007a, b; 2009) - science, (Farrell & Hooker, 2012, 2013, 2014, 2015) - design.

[2] The model renders factors explicit, informative and modestly generic, rather than implicit within the still more abstract categories of the traditional formal approach, e.g. (Kistner et al., 2014). In the latter a great deal of interest to understanding the problem solving process is either implicit or outside that framework. For example, often changes of partial solution proposals will occasion change of methods (implicit) and reformulation of problem/solution is equivalent to changing problem space (external) - see banking and other examples below. However, wherever formalisation is practicable, for example within various parts of engineering design, the model will specialise to it.

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Boulanger, 1996): exploration of successive partial solution proposals leads to reformulation of the problem and/or of the solution criteria, including of operative norms, and thus to new partial solution proposals, and so on. This process continues until problem formulation, solution criteria and partial solution proposal are brought into a mutual fit that delivers a sufficiently valuable solution.

Consider, as a simplified example, the brief to design a new bank branch. For a standard rectangular 'shop front' design, previous design experience will have provided a range of standardised lay-outs of teller positions, 'back room' functions such as financial advice, and so on, typically in linear sequence. An initial partial proposal might then be a sketch of a specific standard way of fitting these banking functions into the present site, say, alotting equal space to each function. If this works, the proposal is elaborated to completion. If there are minor problems, small variations in the proposed layout will be tried until one elaborates satisfactorily. However exploration may instead show that the bank site is too small and too square for standard linear lay-outs to work. This in turn shifts the design problem from 'Which variant of standard branch design works best?' to 'What branch designs best suit a small, square site?' and the solution from 'A standard branch design that is optimised for the site' to 'A design for small square sites that best utilises those spatial features.' These reformulations will in turn suggest new partial solution proposals to explore, for example one that offers several shorter rows of financial functions, or one row around three sides of the square. And so on around until a combination of problem, solution and design proposal emerges that is extendable to a complete design and delivers sufficient value.

2.2. Enriching the DCM shell

From the point of view of understanding and managing innovative problem solving, the DCM form is a useful beginning, but it does not go nearly far enough. An enriched DCM shell is sought that captures the process structure and organisation crucial to understanding the nature and power of the problem solving process that DCM misses.

The proposed enrichment of the DCM shell arose from work on the biological organisation of intelligence (note 1) where adaptability, the capacity to adapt one's adaptive processes to the context, emerged as a major organisational transition. In the UPS process model, adaptability will be realised in the construction of higher order generic knowledge about solving a class of problems, knowledge that emerges from experience in solving specific problems from this class. The higher order knowledge can then be applied to adapt the problem solving strategy to solving further specific problems of the same class (e.g. how to identify ecological trophic webs) and, of often greater import, may also contribute to solving other classes of problems (e.g. identify industrial trophic webs). And so around. Taken together, these two processes (first order to higher order, and reverse) define a *bootstrap* that is the core of any knowledge improvement.[3]

These ideas were then applied to modelling scientific research, specifically to a study of the development of research into the language capacities of apes from its inception to the emergence of a mature research domain (note 1). Across this turbulent period ape language learning problems turned from seemingly ill-defined and insurmountable into puzzles solvable with newly standardised methods. Essentially, criticisms of earlier methods, such as teaching apes language by direct instruction in symbol use, raised wider questions about what genuine possession of a language was and how it could be validly tested, especially while avoiding unconscious human cuing and the like. DCM-style, these critiques led to re-conceiving both problem and solution - but this was via the entry of new methods and new constraints for generating, propagating and evaluating new kinds of partial solution proposals, important features to be made explicit in the UPS here.

Over a period of decades ape language research underwent a revolution, a radical transformation of not only theory, test data and conclusion, but of constraints, methods, problem formulation, and solution criteria. Like the DCM, that happened through a repeated returning to earlier visited aspects to re-modify them in the light of later developments elsewhere. For instance, method shifted from *in situ* immediate human judgement about ape language competency to use of video-taping of instructor-ape interactions to allow more careful analysis for genuine language use, and for detecting human cuing. More profoundly, method sfifted to video-taping ape-ape interactions within a significantly ape-run laboratory environment where ape social structure inherently required understanding symbols in order to function. This took the problem solving process beyond DCM capability, and beyond the formal representation of the standard approach, because it became a process that cumulatively mapped, evaluated and re-ordered the relevant possibilities for conducting such research. Let us see how.

2.3. Enrichment (A): framework possibility nodes

The DCM shell recognised three nodes (or kinds or dimensions) of possibilities for conducting problem solving: possible problem formulations, solution formulations, and partial solution proposals. These all applied directly to the study of ape language research. However, that research also added two further possibility nodes: possible investigatory methods (e.g. human versus machine reward delivery) and constraints characterising the experimental set-up (e.g. that apes cannot vocalise human language phonemes). A bundle of possibilities, one from each node, represents one possible way to frame the investigation of the problem to hand. The aim then is to so equip these five nodes that together they make possible both the DCM-style guidance of node alterations that drives the problem solving process in each case, and the integration of experience across trialing specific problem solvings so as to form the higher order knowledge of problem solving that completes the bootstrapping of problem solving expertise. Consider further the two new nodes.

2.3.1. The method possibility node

Returning to the bank branch example, method change becomes important as soon as deeper change is introduced. Suppose that to relieve congestion a basic constraint is relaxed to allow the bank branch design for the small square site to expand from a standard single-level street front arrangement to a multi-story space. Then the methodological focus shifts from compression of banking functions on to a small square to functional organisation and customer flow pathway analysis across several floors. An aim might still be to minimise average transit time, but there are now new degrees of freedom, including spreading customers across staff on different floors to reduce waiting times. Indeed, such shifts in method may lead the bank design further and further away from the conventional sequential design, even to include in the flow design some valued communal functions (e.g. ground floor parking, or child minding facilities as with Umpqua regional bank, Oregon, USA) and interaction with appropriate non-banking functions (e.g. via rental of office spaces on various floors offering design,

[3] This provides an articulated version of Simon's learning by doing (Ericsson, 1996; Simon, 1996; cf.) made possible by locating it within the specific process organisation of the USP model.