Engineering design education: some implications of a post-positivist theory of design cognition

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ABSTRACT

Engineering design education presumes a theory of design cognition and most existing theories are essentially positivist in their epistemologies. This paper looks at those emerging post-positivist perspectives on engineering design cognition that include the human aspects of designing which have been excluded by positivist research perspectives. The paper describes how the constructivist, physiological approach of Bastick provides a better picture of engineering design cognition, and explores its implications for alternative ways of educating engineering design professionals.

1. BACKGROUND

Engineering design education both presumes and depends upon theories of design cognition. Until recently, most theories of design cognition have been based on the application of positivist research perspectives. This poses a contradiction. Positivist research perspectives exclude human subjective issues, but designing is essentially a subjective human phenomena[1-7]. The positivist focus of research into design cognition usually limits the outcomes to:

- Theories of design cognition as a deterministic and mechanistic process
- Theories of design cognition that include human issues via a Jonesian[8] 'black box' process
- Theories that focus on the physical characteristics of the design problem and solution
- Logical decision-making theories of design cognition that include human interests by quantifying the qualitative aspects of design problems, and their contexts, processes and solutions.

The consequence of this situation is that each of these paths excludes the essentially human aspects of individuals' design cognition. Dilnot[9] concluded that when researchers analyse design in terms of the design problem, its solutions and the relationships between them, then the subject of research, human design cognition, disappears from view (see, for example, Altman[10]).

2. HUMAN DESIGN COGNITION

The main characteristics of designers' cognition are:

- It is a human value-laden activity
- It occurs within individuals
- It presumes a human value-laden context
- It is intended to change humans' environment
- It is intended to affect humans
- It is different from routine or logical cognition (else why use the term 'design')

Perceiving design cognition this way requires a revisiting of the epistemological and ontological basis of the phenomena. Some of these philosophically foundational issues emerge in the following simplified cognitive scenarios:

- The role of 'thinking a new thought'
- The problem of deciding 'when to go on and when to stop'
- The roles of internalised design 'worlds'

The situation of 'thinking a new thought' captures the essence of designing as 'creating something new' and points to the emergence of several concomitant issues. How can creating a new thought be theorised about? How do we identify if a new thought is new whilst it is being created? If one creates the same new thought twice, is the second one still 'creative' - or is it best viewed in some other way, e.g. routine, logical or rational? Each of these questions and their answers raises further questions relating to the epistemologically best ways of representing the internal functioning of designers.

The limits of analysis, that is the limits of the philosophical methodology on which engineering and scientific analysis are based were explored in detail by Rosen[11] in 1980. One of the questions he asked was 'In the case of adding numbers to a sum, how do we know when to go on and how do we know when to stop? He concluded that it depends on a non-rational activity—which he denoted by the term 'intuition'—that lies beyond the logical activities involved in adding. Rosen's analyses point to designing having a non-rational basis on which the rational elements depend. In practical design terms,, the characteristics of Rosen's 'adding' example are present in, for example, deciding just how much engineering or other analysis is necessary to guarantee the design and safe operation of an engineering artefact.

The final scenario concerns the role of internalised 'design worlds' as the contexts in which emergent design solutions are tested in designers' imaginations[12]. The characteristics of these design worlds are different for different designers because each designer has a different character or personality, and consequently focuses, emphasises, ignores and values different issues. The details of the prior experiences and ideologies of individual designers are different, they construct their internal design worlds differently, and this contributes to which design solutions emerge. The implication of this for design research and education is that theory-making about design cognition must take this into account: that is they must appropriately include individual designer's personal development.

The above scenarios indicate that there is considerably more to understanding engineering design cognition, and educating engineering designers, than can be obtained from focusing on the engineering details of artefacts. This is as it should be — the physical attributes of

artefacts are already addressed in Engineering, and the informatic issues relating to those physical attributes are addressed in Information Science — education relating to *designing* is a different issue.

3. POST-POSITIVIST APPROACHES TO DESIGN COGNITION

The main post-positivist approaches that align with research into design cognition are; social constructivism, the post-positivism of Karl Popper, phenomenology, hermeneutic analysis, and individual constructivism. Each of these perspectives focuses on human design cognition differently and through a different set of epistemological and methodological instruments. For example, the social constructivist perspective of Berger and Luckman[13] focuses on the way that society and social groups influences the way that an individual constructs their knowledge, their world view and the ways of manipulating knowledge and information. In many ways this is useful to educating designers especially in areas such mentoring, organisational design style, safety cultures etc. Its weakness is its lack of focus on the internal processes of designing.

The 'post-positivism' of Karl Popper is perhaps the earliest of the post-positivist approaches (Popper lays claim to be the person who 'killed' positivism[14]). Much of Popper's post-positivism (presumably named before other post-positivist epistemologies appeared) lies at a different epistemological level from more recent post-positivist perspectives. This appears in the useful way that he separated theory, objective issues and subjective issues into three relatively incommensurate 'worlds'. This insight clarifies many aspects of design cognition. For example, Popper's three worlds analysis suggests that observations about a designer (objective external world) do not define the subjective experiences or values of that designer (subjective internal world), nor what theories may be constructed about them (theory world). Thus Popper separates:

- Theories of design cognition
- The subjective experiences of design cognition
- The observable outcomes of design cognition

Much of the utility of Popper's post-positivism is in its role in avoiding the accidental conceptual and theoretical conflation that occurs in disciplines such as design research in which there are extensive terminological problems and an imbalance of attention to epistemological detail[15-18].

The recent increase of attention to phenomenology as the basis for design research has occured mainly through the work of Coyne and associates[2, 19]. The ontological argument for a phenomenological basis for design research is strong, particularly where it is allied to discourse analysis and hermeneutics. A phenomenological perspective focuses on the existence or 'being' of each designer in their individual circumstance. In other words, it explores design cognition in an individual situation as a moment to moment flow of phenomena experienced by the designer and others. This approach, and its associated analytical methods, is intended to offer the greatest insights into the phenomena being researched. The weakness of the phenomenological approach for research into design cognition is its relative neglect of theory-making because of its emphasis is on understanding through being.

Hermeneutic analysis is a methodology and epistemology that originated in the extensive critical linguistic and cultural analyses necessary to make sense of ancient texts whose writing was situated in cultures about which little is recorded[20]. In essence, hermeneutic analysis treats any situation or data as a 'text' that must be decoded according to its socio-cultural context, and the concepts and modes of discourse of the situation or that prevailed when the data was created. In this sense, hermeneutic analysis includes the main features of other post-positivist approaches, but its 'textual' and language-based metaphor is limiting for research into design and can create unnecessary complexity — particularly when texts, language, culture and the individual construction of knowledge have other epistemological roles.

Individual constructivism is the post-positivist perspective that pragmatically aligns best with research into design cognition. It is perhaps best known through works of Guba, Lincoln and associates[21]. The main feature of individual constructivism is that it assumes that each person has a different position on situations and ideas. That is, each person constructs his, or her, knowledge on the basis of previous experiences, their values and their personal predispositions. Individual constructivism is the most useful epistemological basis for theorising about design cognition because:

- The essential aspects of design cognition are human subjective functions
- The act of design cognition occurs within and by individuals
- Exploring the individual construction of knowledge, values, world view and design cognition allows the inclusion of insights from phenomenology, hermeneutics or social construction. In this sense and situation, it subsumes the other post-positivist epistemologies
- It separates epistemological issues in a similar manner to Popper
- It offers a means of going beyond Popper's worlds (an issue that is left for another time)
- It allows the epistemologically justified integration of scientific information about physiological and neurological human functioning

This idea that each individual's realities are constructed underpins each of the other post-positivist perspectives and is implicit some of the literature of design research. For example, the purpose of Liddament's[22] use of hermeneutics is to explore individual designer's perspectives on knowledge and information. The weakness of individual constructivism is that it must depend on other approaches, post-positivist and scientific, for the detail of specific analyses.

4. BASTICK, INTUITION AND DESIGN COGNITION

One approach that is grounded in individual constructivism is Bastick's[23] theories of intuition, though and action. Bastick's position is unusual in that that he argued for the epistemologically justified application of scientific information about physiological and neurological human functioning to an individual constructivist model of cognition based on intuition. Before reviewing the main characteristics of Bastick's theory of cognition it is necessary to expand on the role of intuition and why addressing intuition is important in a constructivist model of cognition. First it must be said that intuition is expressly excluded by positivist perspectives of design cognition, but it has not been completely ignored in the

literature of engineering design[24, 25]. The role of intuition, however, has been implicated in many of the rational aspects of cognition and Rosen[11] has argued that intuition is epistemologically foundational in any explanation of creativity and synthesis because of its roles in:

- Justifying the closure which is necessary for validating theory (see also Walton[26]).
- Differentiating between creative activities and processes that can be routinised or formalised.
- Explaining activity which is not routine.

Rosen's arguments, align with those presented by Stegmüller[27], Kant[28], Indurkhya[29] and Guba[21], and give considerable support to the notion that intuition is an epistemologically essential aspect of theories of human design cognition.

Bastick focused on the role of intuition in thinking and acting. Bastick's theories of intuition and cognition are complex and he has supported each element of his arguments by a substantial amount of evidence which is not replicated or summarised here due to lack of space. In essence, Bastick used physiological considerations to develop a theory that combines the subjective aspects of an individual's constructed realities with their logical rationality. Bastick argued that thoughts and cognition are mapped onto individual's bodies as feelings and, vice-versa: feelings result in associated thoughts. The term 'feeling' is used by Bastick to mean 'that which individuals physically feel'. That is, he ties feeling to physiological issues such as skin sensation, muscle tone and tension, endocrinological balances, blood pressure, heartrate and body kineasthetics. From Bastick's perspective, what are commonly called 'feelings' (for example, fear and hope) are labels given to particular subsets of the above.

The usefulness of Bastick's theory for design research lies in his explanation of the role of body-feeling in problem solving activities. Bastick argued that when an individual brings a problem to mind it results in a pattern of feelings in their bodies. Then, as the individual thinks of various solutions, their body simultaneously holds the feeling patterns of both problem and solution. When a satisfactory solution is found, the body-feeling mappings cancel leading to a collapse of muscle tension – the 'Aha!' response. Bastick argued that it is this collapse of muscle tension (and other physiological changes) by which the individual knows whether they have found a solution and how good it is. This human-centred approach contrasts with informatic attempts to explain solution identification in terms of the physical and functional properties of the problem and solution.

The usefulness of Bastick's theories extends to the role of empathic understanding in cognition — an important issue in situations in which not all the aspects can be satisfactorily quantified. Bastick argued that, when an individual perceives a situation thoughts and feelings occur together, and the designer conceives the object or situation in emotional terms (again it is necessary to take a bigger perspective on emotion as for feelings). For example, an engineer might see a shape as 'strong' independently of information about its physical properties, and use this understanding in designing — a phenomena common to several domains of engineering design. For example, in the way that automotive stylists and architects use emotive language to describe shapes and curves[3, 24, 25, 30], and in industrial design[31].

Bastick's theory brings out the need to view knowledge storage in terms of 'body-memory' rather than the 'storage of information in the brain' because thoughts are associated with a

corresponding physiological set. In addition, his theory implies also that relationships between body-memories are stored, and that cognition consists of parallel streams of thought-body activities.

5. IMPLICATIONS FOR EDUCATING ENGINEERING DESIGNERS

Bastick's inclusion of intuition, feeling and body-memory offers new perspectives on engineering design education. It suggests changing the focus onto engineering designers' individual experiencing, and away from engineering theories and theories of design process. The argument that engineers should be less theoretical and better grounded in engineering artefacts is not new. Bastick's model, however, offers an more detailed picture of design cognition and by this opens up the context of engineering design education for better targeted initiatives.

Popper's three worlds model assists with separating out the different epistemological aspects of the educational context and identifying where Bastick's theories may be applicable. For example, the three worlds of engineering are:

Theory world	Engineering theory, design methods
Subjective internal world	Each individual's experiences of designing – reflective practice
Objective external world	The public observed consequences of engineering

A complete education of an engineering designer would be expected to address all of these worlds and the relationships between them. For example, it is difficult to see how a competent engineering designer could use engineering theory without reference to the body of knowledge gained about how engineering artefacts change human environments – in fact, that is their purpose. Similarly, Rosen's and Bastick's analyses indicate that the quality of decisions and intuitions that guide the design of new artefacts depend on the designer's sensitivity to a rich stock of feelings, human values and stored body memories gained from experience both of engineering and as a participating human being.

In short, the implication for engineering design education is a move towards praxis rather than theoria or techne[32]. This allows an exploration of the ways that feeling and values and physiological issues, including all the recent neurophysiological brain research, impinges on human designing of engineering artefacts. This is no small issue because it has become clear that there are considerable number of unforeseen adverse affects of technological designing that can be attributed to a lack of skill in areas other than the technical. To argue that the social, environmental and ethical factors are the business of others, or to argue that these factors need to be quantified, is to ignore the fact that these issues are all brought together and determined in individual designers' minds. To be a designer, or to train designers, is a non-trivial pursuit because of the influential ways that designed objects affect us as individuals, our societies and our descendants. Issues of feeling, human values and experiencing are especially important in educating engineering designers to support the proper intuition, analysis and design of socially, environmentally and ethically beneficial devices and systems.

To conclude, I would like to acknowledge that in many ways these are not new ideas. In 1970, Jones[8] argued that designers are similar to artists, using

the capacity of a skilled nervous system to respond quickly to an intuitively held picture of the real world . . . when they have to find their way through a number of alternatives while searching for a new and consistent pattern upon which to base their decisions.

Similarly, Motard[33] noted pointed to the importance of feelings, experience and the biologically sensual aspects of design memory for design cognition. He concluded that:

An engineer would be hampered in his ability to design things if he had not experienced the material world first hand and distilled this experience through a kind of contemplation until it penetrated his entire being. The more perceptive the individual and the more sensitive, the more effective potentially, in the multidimensional pattern of design under constraints. Discovery and intuition might then have a physiological enhancement elicited from the fabric of the visual, aural and tactile experience and the 'feel' of physical situations.

REFERENCES

1. Franz, J.M., *A critical framework for methodological research in architecture.* Design Studies, 1994. **15**(4): p. 443-447.
2. Coyne, R.D. and A. Snodgrass, *Rescuing CAD from Rationalism.* Design Studies, 1993. **14**(2): p. 100-123.
3. Goldschmidt, G., *On visual thinking: the vis kids of architecture.* Design Studies, 1994. **15**(2): p. 158-174.
4. Holt, J.E., *The designer's judgement.* Design Studies, 1997. **18**(1): p. 113-124.
5. Petroski, H., *Preface.* Research in Engineering Design, 1992. **4**: p. 1.
6. Valkenburg, R. and K. Dorst, *The reflective practice of design teams.* Design Studies, 1998. **19**(3): p. 249-272.
7. Reich, Y., *A Critical Review of General Design Theory.* Research in Engineering Design, 1995. **7**: p. 1-18.
8. Jones, J.C., *Design Methods: seeds of human futures*. 1970, London: Wiley-Interscience.
9. Dilnot, C., *Design as a socially significant activity: an introduction.* Design Studies, 1982. **3**(3): p. 139–146.
10. Altman, C.J., *et al.*, *A comparison of freshman and senior engineering design processes.* Design Studies, 1999. **20**(2): p. 131-152.
11. Rosen, S., *The Limits of Analysis*. 1980, New Haven: Yale University Press.
12. Schon, D.A. and W. G, *Kinds of Seeing and their functions in designing.* Design Studies, 1992. **13**(2): p. 135-156.
13. Berger, P. and T. Luckman, *The Social Construction of Reality*. 1987, England: Penguin Books.
14. Popper, K., *Unended Quest*. 1976, Illinois: Open Court.
15. Love, T., *Social, Environmental and Ethical Factors in Engineering Design Theory: a*

Post positivist Approach. 1998, Perth, Western Australia: Praxis Education.
16. O'Doherty, E.F., *Psychological Aspects of the Creative Act*, in *Conference on design methods*, J.C. Jones and D.G. Thornley, Editors. 1964, Macmillan: New York. p. 197–204.
17. Ullman, D.G., *A Taxonomy for Mechanical Design.* Research in Engineering Design, 1992. **3**: p. 179-189.
18. Hubka, V. and W.E. Eder, *Theory of Technical Systems*. 1988, Berlin: Springer-Verlag.
19. Coyne, R., *Creativity as commonplace.* Design Studies, 1997. **18**(2): p. 135-142.
20. Jary, D. and J. Jary, eds. *Collins Dictionary of Sociology*. . 1991, HarperCollins Publishers: UK.
21. Guba, E.G., *The Alternative Paradigm Dialog*, in *The Paradigm Dialog*, E.G. Guba, Editor. 1990, Sage Publications: London. p. 17-27.
22. Liddament, T., *Metamorphosis of Design Vocabulary.* Design Studies, 1996. **17**(3): p. 303-318.
23. Bastick, T., *Intuition: How we think and act*. 1982, England: John Wiley and Sons.
24. Tovey, M., *Styling and design: intuition and analysis in industrial design.* Design Studies, 1997. **18**(1): p. 5-32.
25. Tovey, M., *Intuitive and objective processes in automotive design.* Design Studies, 1992. **13**(1): p. 23-41.
26. Walton, D., *The Closure problem in practical reasoning*, in *Contemporary Action Theory*, G. Holstrom-Hintikka and R. Tuomela, Editors. 1997, Kluwer: Dordrecht.
27. Stegmüller, W., *The Structure and Dynamics of Theories*. 1976, New York: Springer-Verlag.
28. Kenny, A., *Descartes to Kant*, in *The Oxford Illustrated History of Western Philosophy*. 1994, Oxford University Press: Oxford. p. 107–192.
29. Indurkhya, B., *Metaphor and Cognition*. 1992, Dordrecht: Kluwer Academic Publishers.
30. Tovey, M., *Automotive stylists design thinking: Visual creativity and CAD*, in *Research in design thinking*, N. Cross, K. Dorst, and N. Roozenburg, Editors. 1992, Delft University Press: The Netherlands. p. 87-98.
31. Smets, G.J.F. and C.J. Overbeeke, *Expressing tastes in packages.* Design Studies, 1995. **16**(3): p. 349-366.
32. Reich, Y., *Transcending the Theory-Practice Problem of Technology*, . 1992, Engineering Design Research Center, Carnegie Mellon University: Pittsburgh.
33. Motard, R.L., *Design Theory: a chemical engineering view*, in *Basic Questions of Design Theory*, W.R. Spillers, Editor. 1974, North-Holland Publishing Company: Amsterdam. p. 143–146.