CREATIVITY IN KNOWLEDGE WORK: A PROCESS MODEL AND REQUIREMENTS FOR SUPPORT

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ABSTRACT

This paper is concerned with the requirements of computer support for creativity. Our objective was to understand the creative process in knowledge intensive work and to draw from that the constraints and possibilities for helpful human-computer interaction. A study of a scientist using a knowledge support system is described. We present the process model of support for creative knowledge work and show how it can be used to specify HCI requirements for computer support.

INTRODUCTION

There are many ways of characterising the nature of creativity. In this paper, we consider creativity in the context of scientific work, first, as a human creative process, where the individual's knowledge develops as new insights emerge during investigative activities and second, as a creative product, which can take the form of new knowledge or published results of the investigations.

Human tasks can range from the routine and well defined to the exploratory and unpredictable. In the main, the procedures involved in routine tasks can be predicted whereas, creative activities often lead people along new and less predictable paths. By the very nature of creative work, we cannot describe everything that takes place in advance and this makes the modelling task somewhat challenging. In particular, the application of knowledge that is highly expert, distinctive in character and constantly evolving is a feature of the way creative people work. It is the knowledge intensive aspects of creative work that has been the focus of our recent studies.

The aim of our research has been to identify the requirements of computer systems that might support creative knowledge work. The starting point was to try to understand something about the human creative process and to draw from that guidance about the possibilities for helpful human-computer interaction. Our approach was to consider specific instances of possible creative activities in relation to interaction with a particular form of computer support. From that we moved towards an understanding of what the requirements for support systems might be.

In this paper we report upon a study of a scientist using a system that supports the knowledge intensive aspects of scientific work. The example we draw upon here is one where a phonetician used a knowledge based system for the capture and extension of Speech Science. A scientist is an example of the class of people who are "knowledge workers", that is to say the prime concern of their work is to manipulate or generate knowledge. In particular, the knowledge worker not only transforms existing knowledge for others with whom they work or associate but are themselves changed by that process [9]. It is this quality of knowledge work that is relevant to providing support for creativity.

Computer-based support systems for knowledge workers are known as Knowledge Support Systems (KSS) [6]. One of the key characteristics of a KSS is that it allows the end user, in this case the scientist, direct access to the domain knowledge in the system without using the underlying programming language. This is vital because using and extending knowledge is the central concern of such a user. We present a process model of support for creative knowledge work that has arisen from the findings and then show how it can be used to specify requirements for computer support at each stage in the process.

CREATIVITY IN KNOWLEDGE WORK

There has been a growing interest in creativity in recent years. One challenge is to find a scientifically describable explanation of creativity. Boden proposes two categories of creative ideas, concepts, artifacts and styles of thinking: those of historical creativity (H-creative) and psychological creativity (P-creative) [1]. In the former case, ideas are novel with respect to the whole of human history, i.e. ideas that are first credited with originality. Psychological creativity, on the other hand, occurs within the individual mind, i.e. the person experiences the idea as fundamentally new whether or not others have had the same idea. That person may not be aware of other similar ideas or, indeed, may not recognize the social significance of the idea at the time of its creation.

In Science, creativity is usually acknowledged to be of the H-creative type. If ideas or concepts are recognized as being original contributions to the field, they have, in effect, been accepted into the canon of knowledge by the scientific community. On the other hand, the creative process whereby the scientist achieves new insights, is framed or constrained, by the scientific methods and validation techniques used. There are, however, many examples of a broader and richer pattern of human thinking and action in the generation of scientific knowledge [1,14]. There are many ways of accrediting scientific knowledge. It may be perceived as the product of the scientific community itself which validates claims of new knowledge [10]. What is valued as original knowledge may be dependent for its discovery on recognition by the dominant peer group [11]. By contrast, Simonton, argues that all forms of creativity, especially those in scientific domains, share a common basis for discovery and invention [15].

Scientific knowledge work provides an opportunity for studying the creative process. In order to understand creativity in the context of actual scientific research, there is a need for longitudinal studies of scientists carrying out their investigations in a realistic context. In this way, we can gain more insight into the ways ideas are generated, considered and pursued. In modern science, the use of sophisticated technological tools is becoming standard practice. It is important to include them in any study of scientific process.

Our approach has been to examine scientific knowledge work of the P-Creative type whilst acknowledging that H-Creative criteria are a means of evaluating the outcomes. For that purpose, the use of a KSS, where the knowledge is being captured interactively by the scientist, facilitates the research process in both ways. This is because the knowledge is being made explicit in the system and therefore subject to further scrutiny both by the scientist who compiles it and any other investigator. If creative work is taking place, the knowledge will be constantly emerging in the mind of the scientist as the experiments progress and results are assessed. Working with incomplete knowledge, by its very nature, involves creative thinking and continuous reflection.

Interaction with Computers in Scientific Research

The process of interaction between an expert and a knowledge system can be more than simply capturing knowledge in machine-usable form. Creative insights, some of which can be represented in the system, may arise in the mind of the human investigator during the interaction. That interactive process, when part of a broad spectrum of scientific investigations, can provide a mechanism for evaluating, refining and devising ideas. In such tasks, the role of interactive systems incorporating visualization and knowledge-based techniques deserves particular attention.

Scientific knowledge workers can be provided with powerful methods for studying and evaluating their source material using computer support. Graphical techniques for marking up visual phenomena and expressing knowledge about that data in rule form are available. The need for and use of visualization of data in the scientific domain is now well established.

Visualization is concerned with the viewing and manipulation of source data. With the advent of advanced 3D graphical computing environments [5], the scientist or engineer or designer may view and manipulate high quality domain specific data such as aircraft models, molecular structures, brain scans or architectural models. The facilities for changing the parameters, and hence the "view", enables the such knowledge workers to explore the visual data in order to understand and interpret it more effectively.

In the context of the research reported here, where the visual data is the continuous speech utterance (represented as a spectrogram wide band signal), visualization is widely recognized to be an important means of expressing humanly perceived knowledge to a computer system [4]. In the KSS used in the study described below, the visualization of such data is combined with explicit rules about the associated knowledge that has been compiled by the scientist. The scientist expresses his or her interpretation of the visual data using graphical methods and this then becomes a formal description of expert knowledge about the visual data that is incorporated into the knowledge system.

To enable the scientist to express knowledge to the system in a domain specific language, a bridge between the representation of visual data and the representation of scientific theory in the form of rules was made available. In effect, the visual data analysis and interpretation is combined with methods for capturing formal domain knowledge as rules. The scientist uses graphical interaction techniques to annotate visual data and to specify the knowledge gained from studying the data. That specification is then automatically incorporated in a knowledge-base without the user having to use the underlying code. Having assimilated the results from the exploration of the visual data and the knowledge base, the scientist can continue to advance existing knowledge further as the analysis and interpretation progresses. The aim is to reduce the constraints upon the scientist's explorations and unpredictable courses of action.

COMPUTER SUPPORT FOR SCIENCE: A STUDY

In this section we describe the results of a study of a scientist's practice and the role of a Knowledge Support System in that process. The aim was to identify the key features of human computer interaction in the use of a KSS for scientific knowledge work. The characteristics of the observed process are used to hypothesize about requirements for computer support to creative knowledge work.

The goal was to gather as rich a set of data as possible within the constraints of the normal working situation: i.e. this was a study of on-going scientific activities rather than a selection of experimental tasks. The study methods employed were those of direct observation, monitoring and interviews over a continuous period of six months. The whole data set included observations of the scientific activities and interactive process including video and audio recordings of the detailed work. It also included the scientist's own reflections upon her scientific goals and methods and the experience of interacting with the KSS. A full account of the study methods, data analysis and results is described by Candy et al [2].

The scientist's main goal was to study the contribution of a set of visual features to the identification of continuous speech data. The scientist's method was to analyse visual source images (spectrograms) and then test the findings by an identification from a knowledge base. The annotation of the visual data allowed the scientist to express what were perceived to be the basic facts about the features of the speech images. These were expressed in machine-readable form. In effect, they represented a set of hypotheses about the data which were analysed using the existing knowledge base. This analysis generated an identification of the speech utterance in the form of a phoneme lattice.

In this way, the scientist captured knowledge in a rigorous form and, in the process of externalising it and having the machine process it, identified *implicitly* held knowledge. The scientist identified unexpected features of the visual data and revised her current expectations (theories) about the interpretation of that data. The results are described by O'Brien [12,13].

The large volume of speech data that could be examined and evaluated in a very short space of time using the KSS had an influence on the scientist's research strategy. Possible new avenues of investigation were devised and then pursued. This began with the designing and recording of an entirely new set of visual speech data with more complex features. In turn, this strategy gave rise to insights into the knowledge being applied to the data, and the methods and tools being used to carry this out, including the design of the graphical techniques being used.

The process of designing, analysing and testing data was, in the first instance, primarily a linear one. However, as the investigations proceeded and the testing of the knowledge captured in the system took place, it became iterative. When inconsistencies and unexpected results arose, the scientist moved between image analysis, testing and refining the rules, in parallel. The key activities in the whole process are described briefly below. In general the overall order of the three main stages of the process followed a stable pattern within which changes in the scientist's modes of thinking and action took place.

Visual Data and Testing Existing Knowledge

The scientist's first task was to identify the features of continuous speech recognisable in the visual image of the speech utterance. Initial knowledge about the relationship between visual features, and their contextual relationships, and speech events had already been expressed as rules in a knowledge base. A set of such rules that applied to certain speech phenomena was then selected and, by asking for an analysis of the data, tested for accuracy. The identification successes or failures were then evaluated by the scientist.

The results of the analysis by the knowledge base appeared as a set of all possible hypotheses for each segment of the speech utterance image. The scientist considered the whole utterance first to see if there were discernible patterns across the complete image that warranted particular attention. Following that, each segment was assessed one by one and the rules applied to each identification examined by the scientist. Movement back and forth between the whole image and the close ups of individual segments took place continually. This stage gave rise to refinement in rules with further testing: the cycle of test, refine, modify and test was applied repeatedly.

Multiple Views in Visual Data Interpretation

The analysis of the speech image was a cyclical process which involved very close scrutiny of that visual data. In the main, it was a routine procedure where the intention was to base all judgements on visual criteria only. A rapid segmentation in the time dimension across the whole image was followed by the application of criteria to obvious features which were labelled with appropriate graphical objects. Once completed, this paved the way for further attention to the uncertainties and ambiguities identified previously but reserved for later assessment.
Where unpredictable features occurred, this prevented a routine response and the typical pattern of graphical annotation was disrupted. The scientist's judgements were affected by this and also by the quality of the visual data. Without clarity of visual information, speculation as to the likely character of the features arose, with frequent reference to high level knowledge (e.g. knowing that some patterns occur always even though they are not visible on the image). Alternative views of the visual data that gave support to "intuitive" opinion (e.g. low frequency energy distribution graphs and cross-sectional profiles) were used frequently to arrive at a judgement more quickly.

In summary, the KSS supported rapid graphical interaction with the visual images. This was then recorded for later use at the testing stage when the user asked for an identification of the annotated speech utterance by the knowledge base. The marking of the visual features using colour, blocks and lines appeared to heighten the scientist's awareness of the finer details of the image. The overlaying of alternative quantitative information about the visual data supported more reliable judgements. The speed, quality and quantity of visual data access was vital as multiple images were required simultaneously and the interchange between them needed to be quick and fluent. Unpredictable features were identified that could not be marked up using the standard techniques and the scientist used an improvised solution. This often led to a need to refine existing rules.

Revising and Creating New Rules

Having evaluated the results of the knowledge base identification, the scientist could then change the rules or add new ones according to the fresh insights which arose during this process. For example, having identified the need to take account of the effects of contextual variants on the recognition of particular visual features, new rules were created, tested and evaluated about those effects. In total, the process was an iterative one in which ideas were applied, abandoned or refined as the discovery of new insights took place. When a solution, in the form of a refined rule, proved impossible to achieve, the existing rule or rules was typically discarded. It was then that the whole problem was reformulated and an entirely new rule created.

In a series of experiments, the eventual outcome was that the scientist advanced her own understanding of the speech science knowledge she was using. A number of issues were also identified that required further investigation. For example, the need to be able to structure rules in groups and hierarchies was recognized but how to achieve this depended on a much clearer understanding of how the domain knowledge should be applied.

Observations on the Role of the Knowledge Support System

The KSS contained within it a set of constraints within which the scientist set out to achieve certain goals. The extent to which the scientist moved beyond the boundaries of those constraints and created new concepts can be seen as an indication of the creativity involved. Whilst we have concentrated on the P-Creative aspects, H-creative results arose that were documented in published material [12].

The methods of interaction were designed to enable the knowledge worker to manipulate the visual source data and the knowledge base in a flexible manner. Many questions that were unforeseen in the early plans arose. The fact that the scientist was able to use the system to extend the scope of her experimental studies beyond the original intentions enabled her to evolve her understanding of the knowledge being applied.

The fact that the feedback on the knowledge being applied was rapid and immediate was useful but that was not the main advantage. The rules were created and then evaluated against the source data under scrutiny by requesting an identification. This implied that the speech knowledge captured was tested rigorously. Because it represented the current state of the scientist's thinking, the continual process of confirmation or refutation as the results of the identification process were produced was quite powerful. This was a form of *support* that challenged the scientist's hypotheses and forced a response at the knowledge level not merely the surface interaction. A more detailed discussion of the above results is to be found in [2].

The findings of the study gave rise to a new framework for computer support to creative knowledge work. In the kind of knowledge work reported above, there are discernible stages in the process that reflect the progressive nature of the investigations that went on. Because knowledge work of this kind involves changes of mode within each stage, this needs to be reflected in the support system. For that purpose, we need to have a model of the overall process and, within each stage, a set of requirements for the system design that supports each mode of activity. The process model is described in the next section followed by proposed requirements for supporting the different modes of human activity.

A PROCESS MODEL

The creative scientific process observed in the above study may be described in terms of three main stages which the knowledge worker moves between: generation and invention, exploration and evaluation and the consideration of constraints and requirements (Figure 1). Our particular focus is on the interactions between the knowledge worker's actions and those of the KSS as derived from the study.

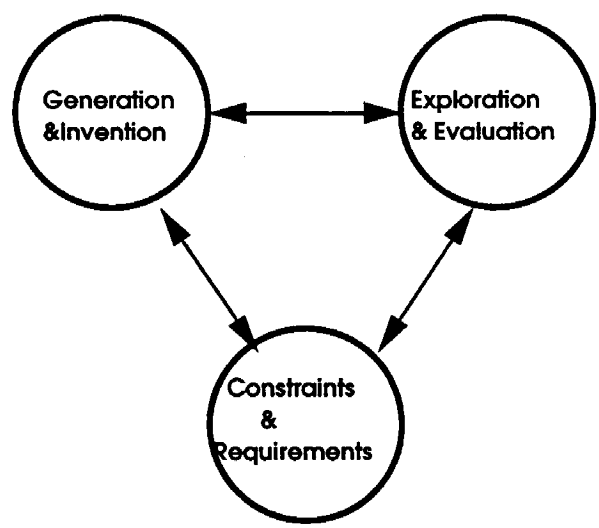

Figure 1 A Process Model

Taking each of those in turn, we can decompose them and consider the roles of knowledge worker and KSS more specifically. The exploration and evaluation activity consists of examining the data, evaluating and refining the rules (Figure 2). In this case, the balance between human and computer system shifts during the process. Whilst the human examines the data and refines the rules that the system presents, the data is analysed by the system according to the existing rules which are, as a consequence, evaluated by the human.

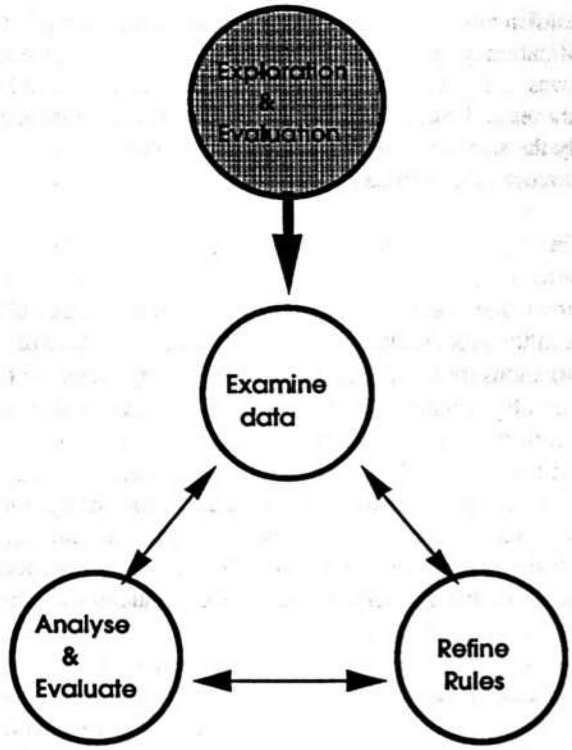

Figure 2 Exploration and Evaluation

Generation and invention involves, in addition, moments of insight and the creation of new rules (Figure 3). Both of these are human activities. In particular, any insight obtained is an insight of the human understanding.

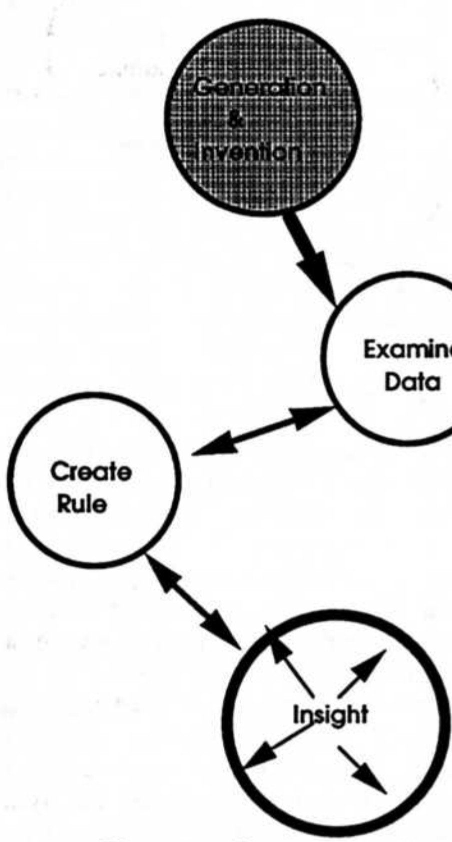

Figure 3 Generation and Invention

The consideration of constraints and requirements, on the other hand, involves receiving and clarifying them, revising, and possibly negotiating, the revisions (Figure 4). Here, then, the system presents the existing constraints and requirements, the human revises them and the resources of both are employed in the process of considering and negotiating plausible revisions.

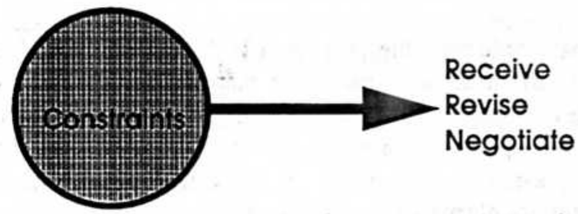

Figure 4 Interpretation and Reformulation

We can now place the findings from our study in relation to the Process Model [2,6]. The requirements proposed in the section below are drawn from a scientific knowledge work example. We can hypothesize that they may also be applicable to creative knowledge work in general. With that proviso, we present a structured view of proposed requirements for a knowledge support system.

HCI REQUIREMENTS AND THE MODEL

Criteria for the requirements to support creativity have been proposed by Fischer [7] in the context of the Design domain. Fox [8] identifies desirable attributes for decision support such as the ability to reflect upon knowledge and the investigation process, to reason about the inferencing methods used and the need for explanations to be couched in domain familiar descriptive objects. We have drawn upon such comparative work and extended the ideas in the light of our studies and experience.

What follows is proposed as a structured checklist for HCI designers of systems intended to support knowledge workers. Not all requirements will apply in every case but for the system designer each one implies a question to be addressed. The modes within each stage of the process are considered in turn. Some requirements apply to more than one mode and are, therefore, repeated. Where this occurs only the headings appear.

Exploration and Evaluation

Examine

- Holistic View

Holistic views of high quality visual data that can be manipulated and annotated should be available to the user.

- Multiple Representations of Data

Access to multiple representations of the data which can be used to support the user's judgements should be provided.

• Visual Data Annotation

Annotation of high quality visual data which can be incorporated into the knowledge activity should be provided.

• Concurrent Processes

Access to the different forms of visual data and the methods for knowledge base interaction should support concurrent use and enable the user to switch between activities fluently and quickly.

Evaluate

• Multiple Representations of Knowledge

A plurality of representations should be available so that new knowledge structures that emerge as a result of changes in the user's understanding can be readily incorporated into his or her activities.

• Feedback

Evaluation of knowledge by rapid feedback should be supported.

• Domain Specific Evaluation

Domain specific support to evaluation with explanation about negative and positive results should be available.

Refine

• 'Natural' Graphical Interaction

Interaction with knowledge in the system should use graphical techniques and draw upon images and terminology natural to the user and the domain orientation.

•Knowledge Modification and Evolution

Accessible and powerful methods for modifying the knowledge base should be provided so that the user can refine existing rules and add new rules incrementally at any time during the on-going tasks.

Generation and Invention

Examine

• Holistic View

• Multiple Representations of Data

• Concurrent Processes

• Evaluation of Evolving Knowledge

Support for evaluation of the evolving knowledge in progress should be provided. The user must be able to ask why or why not about the results of any request for evaluation and receive an explanation that is expressed in domain specific terms.

Create

• Creating Objects

Facilities for creating graphical objects or icons in addition to pre-specified objects that can be used to express knowledge about new visual features should be provided.

•Knowledge Modification and Evaluation

Accessible and powerful methods for modifying the knowledge base should be provided so that the user can define, modify and add new rules incrementally at any time during the on-going tasks.

• Comparative Evaluation of Knowledge

Support for comparative evaluation of the knowledge in the system should be available. The user should be able to create and evaluate selected rule sets with different variables against identical experimental criteria allowing immediate comparisons of their performance relative to each other and to a standard rule base.

Constraints

Receive and Revise

• 'Natural' Graphical Interaction

•Knowledge Modification and Evaluation

• Comparative Evaluation of Knowledge

Negotiate

•Knowledge Modification and Evolution

• Visual Data Annotation

• Comparative Evaluation of Knowledge

In summary, for the interaction between user and knowledge system to be effective at the more creative end of the spectrum, it must support the extension of knowledge and be in accordance with the user's domain orientation. Depending on the context, there will be variations on the basic set of requirements. However, some features are likely to be vital : for example, working directly from visual source data (e.g. X-rays, scene drawings), having suitable graphical methods for marking the visual data and being able to describe domain specific ideas in an accessible and appropriate way. Other support to knowledge analysis and evaluation, such as being able to access statistical packages and carry out tests, may also be necessary. In particular, the interaction must not be constrained by the need to use the notation of a particular programming language whilst, nevertheless, providing access to the full power of the system's functions and facilities especially in respect of the domain knowledge.

CONCLUSIONS

The objectives of the work reported were to identify requirements for the design of creativity supporting systems. It is clear that such support systems must be designed to provide the maximum flexibility for the user to handle and extend knowledge. A need to make available different forms of representation of the knowledge was identified. A plurality of approaches is essential if the scientist is to be able to consider and control a number of knowledge sources. The findings of the study have given rise to a process model which enables us to delineate the role and function of Knowledge Support Systems at each stage in the process and to identify the specific requirements. The findings are not proven to be generic but sufficient evidence exists for us to hypothesize that they have a broad applicability to the design of systems that support creative, knowledge intensive tasks. The ideal system is a fully fledged workbench that provides a repertoire of tools and resources to support the emergence of new knowledge. Studies have been carried out in Design and a KSS applied in that domain [3].

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REFERENCES

1. Boden, M.A. The Creative Mind : Myths and Mechanisms: London:Weidenfeld and Nicolson, 1990.

2. Candy, L. O'Brien, S.M. and Edmonds, E.A. End user manipulation of a knowledge based system : a study of an expert's practice. International Journal of Man-Machine Studies, Volume 38, No 1, 1993, pp 129-145.

3. Candy, L. and Edmonds, E.A. Artefacts and the designer's process: implications for computer support to design, Journal of Design Sciences and Technology Volume 3, 1, pp 11-31, 1994, Hermes.

4. Cooke, M., Beet, S. and Crawford, M. Visual Representations of Speech Signals. John Wiley & Sons, Chichester, England, 1993.

5. Earnshaw, R.A. and Wiseman, N. An Introductory Guide to Scientific Visualization. Berlin Heidelberg: Springer-Verlag, 1992.

6. Edmonds, E.A. and Candy, L. Knowledge support for conceptual design: the amplification of creativity. In Proc. HCI Int. 1993, pp 350-355 Amsterdam: Elsevier.

7. Fischer, G. Creativity enhancing design environments. In Gero, J.S. and Maher, M-L (eds), Modelling Creativity and Knowledge-Based Creative Design, pp 269-282, Hillsdale, New Jersey: Lawrence Erlbaum, 1993.

8. Fox, J. Symbolic decision procedures for knowledge-based systems. In Knowledge Engineering, Applications II, 1990, pp. 26-55: McGraw-Hill, New York (ed)Adeli, H.

9. Kidd, A. The marks are on the knowledge worker. In Proc. Human Factors in Computing Systems, CHI'94, Boston, ACM Press, pp 186-191, 1994.

10. Knorr-Cetina, K.D. The Manufacture of Knowledge: Pergamon Press, Oxford, 1981.

11. Kuhn, T.S. The Structure of Scientific Revolutions. Chicago: University of Chicago Press, 1970.

12. O'Brien, S.M. Spectral features of plosives in connected-speech signals. International Journal of Man-Machine Studies, 1993, Volume 38, No 1, pp. 97-127.

13. O'Brien, S.M., Candy, L., Edmonds, E.A., Foster, T.F. and McDaid, E. End user knowledge manipulation systems: the speech knowledge interface. In Proc. of 20th Annual Computer Science Conference, Agrawal, J.P., Kumar V. and Wallentine, V. (eds), 1992, ACM Press, pp 359-366.

14. Roberts, R.M. Serendipity: Accidental Discoveries in Science. New York: John Wiley & Sons Inc, 1989.

15. Simonton, D.K. Scientific Genius: A Psychology of Science. Cambridge University Press, Cambridge, 1988.

16. Sternberg, R.J. ed. The Nature of Creativity: Contemporary Psychological Perspectives. Cambridge: Cambridge University Press, 1988.