# SOCIO-COGNITIVE ENGINEERING: A METHODOLOGY FOR THE DESIGN OF HUMAN-CENTRED COMPUTER SYSTEMS

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**Abstract:**
*We propose a general framework for socio-cognitive engineering that integrates software, task, knowledge and organizational engineering. The framework has been refined and tested through a series of projects to design computer systems to support training and professional work. In this paper we provide an account of the least-explored part of the framework, that of organizational engineering. We describe a series of workplace studies of radiology training that have provided requirements for the design of a computer-based training system for neuroradiology. The structure of the workplace studies and the framework for socio-cognitive engineering can be applied widely to the design of human-centred technology.*

**Keywords:** human-centred systems design; organizational engineering; computer-based training; radiology.

## 1 Methodology: Socio-cognitive Engineering

We use the term ‘socio-cognitive engineering’ (or ‘human-centred systems design’) to indicate the process of describing and analysing the complex interactions between people and computer-based technology, so as to inform the design of interactive systems that support human learning, knowledge management, decision making and creativity. This builds on previous work in user-centred system design, soft systems methodology [Checkland and Scholes, 1990], socio-technical and cooperative design [Catterall et al., 1991], [Greenbaum and Kyng, 1991], [Sachs, 1995] and the application of ethnography to system design (see Rogers and Bellotti [1997] for a review). It goes beyond user-centred design in systematically drawing the cognitive, social and organizational sciences into the design process. We extend previous work by providing an integrated framework for socio-cognitive engineering.

## 2 Methods: “Building-block” Framework

We have developed a framework for socio-cognitive engineering (see table 1). It provides the system designer with a means to understand and organize the process designing human-centred technology. Rather than viewing the design process as a flow chart we have taken a “building block” metaphor. This has the advantage of showing clearly how the component activities of design can interlock and support each other.

The four “pillars” indicate the main processes of software, task, knowledge and organizational engineering. To construct a successful integrated system requires the designers to consider all the building blocks, but it is not necessary to build systematically from the bottom up. A design team may work on one “pillar”, such as knowledge engineering, up to the stage of system requirements, or they may develop an early prototype based on a detailed task analysis but without a systematic approach to software engineering. Each block specifies one type of design activity, but how that activity is carried out depends on the particular subject domain and training situation.

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|---|---|---|---|---|
| *Maintain* | Installed system | New task structure | Augmented knowledge | New organizational structure |
| *Evaluate* | Debugging | Usability | Conceptual change, skill development | Organizational change |
| *Integrate* | Prototype System | | | |
| *Implement* | Prototypes, Documentation | Interfaces, Cognitive tools | Knowledge representation | Communications, Network resources |
| *Design* | Algorithms and heuristics | Human-computer interaction | Domain map, user model | Socio-technical system |
| *Interpret* | System Requirements | | | |
| *Analyse* | Requirements | Tasks: goals, objects, methods | Knowledge: concepts, skills | Workplace: practices, interactions |
| *Survey* | Existing systems | Conventional task structures and processes | Domain knowledge | Organizational structures and schedules |
| | *Software Engineering* | *Task Engineering* | *Knowledge Engineering* | *Organizational Engineering* |

Table 1. A “building block” approach to socio-cognitive system design.

The design activities are modular, allowing the designer to select one or more methods of conducting the activity, according to the problem and domain. For example, the usability evaluation could include an appropriate selection of general methods for assessing usability, such as heuristic evaluation or cognitive walkthrough, or it could include an evaluation designed for the particular domain.

One important aspect of the framework is that when a new technology, such as a training and decision support system, is incorporated into the workplace it will engender new knowledge, new tasks and ways of working, and new organizational structures. These become contexts for further analysis and design. Email is a prime example. The use of email in offices opens up new pathways of communication and access to new sources of knowledge. It can also profoundly affect the working day and the management of a company. These changes need to be analysed and supported through a combination of new technology and new work practices. Thus, the building blocks must be revisited both individually to analyse and update the technology in use, and through a larger process of iterative re-design.

## 3 Application: Computer-based Training in Neuroradiology

The domain in which we demonstrate the approach of socio-cognitive engineering is the design of a knowledge-based training system for neuroradiology. MEDIATE is a joint project between the University of Sussex, De Montfort University, Leicester, the University of Birmingham, and the Institute of Neurology, London. Its aim is to address a need identified by the radiology speciality for a more structured approach to reporting and training. One outcome of the project is the MR Tutor, a training system to assist radiologists in interpreting MR images of the brain, particularly images presenting diseases that are acknowledged to be difficult to differentiate. A prototype system has been developed in the Java programming language.

The MR Tutor combines an active tutor with a responsive support system. It is based on a constructivist approach to learning, in which the trainee is helped to acquire a well-structured method for describing abnormal features of images by engaging in an active process of case-based reporting. The MEDIATE team has devised a structured image description language (IDL) for MR neuro-images. The language is image-based, covering the visual appearance and anatomical locations of the image abnormalities. An archive of around 1200 cases, fully annotated using terms of the IDL and accompanied by clinical information and confirmed diagnoses, forms the knowledge base of the Tutor. At present some 40 of these cases have been included in the prototype system and we have recently developed a semi-automated method of transferring further cases and their descriptions.

The MEDIATE team has followed the socio-cognitive engineering methodology to develop a usable prototype training system. The software, task, and knowledge engineering aspects of the MR Tutor are described in [Teather et al., 1994], [Sharples, et al., 1995], [Sharples et al., 1996], [Sharples et al., 1997]. Formative evaluations of early prototypes of the MR Tutor have indicated its general usability and training effectiveness.

## 4 Organizational Engineering

This paper addresses the Organizational Engineering aspects of the design of the MR Tutor. The aim of the project was to investigate how the MR Tutor system could fit into the daily schedule of a trainee radiologist and to determine whether it might be accepted by the medical profession in the United Kingdom as an aid to training. Initial questions that the project addressed included: what would be the most appropriate configuration and location for a training system (portable?, based in the reporting room?, library?); to what levels of general or specialist medical training would the system be suited?; how does reporting of cases fit into other demands on the time of a trainee radiologist?; is there a standard method of teaching radiological reporting, within a hospital and across hospitals?; what do trainees and consultants perceive to be the main issues and problem areas in conventional training?

Similar questions face designers of technology for other areas of training and decision support and they often remain unanswered until the system is adopted for use, when the designers and adopters discover unforeseen problems, such as a lack of integration with the curriculum or an inappropriate location for the equipment. By addressing these questions through workplace investigations, within a general methodology for analysing situated activities and how they might be assisted by technology, we have been able not only to provide answers to these specific questions but also to address more general issues of embedding computer-based systems in the workplace.

The project involved:

a) developing practical and appropriate methods of organizational analysis;

b) applying the organizational analysis through a series of workplace studies of radiology training in two UK hospitals;

c) using the outcome of the studies to produce design recommendations for the MR Tutor.

Through the project we have developed a multi-level approach to organizational engineering, based on the work of Plowman et al. [1995], whose purpose is to inform the design and deployment of new technology in the workplace. It is descriptive, but is also concerned with the consequences of intervention (not just how the workplace is, but how it might be). It is designed for situations where there is limited access to the workplace, to experts, and to potential users.

The role of the fieldworker in organizational engineering is both to interpret workplace activity and to assist technology design and organizational change. This addresses the widely recognised problem of ethnographic approaches that, while they can provide an understanding of current work practices, they are not designed to explore the consequences of socio-technical change.

Table 2 shows a multi-level structure for organizational engineering, with level 1 consisting of a survey of the existing organizational structures and schedules, levels 2 and 3 providing an analysis of situated practices and interactions of those for whom the technology is intended, and level 4 offering a synthesis of the findings in terms of designs for new socio-technical systems.

The four levels of the approach give an overview of workplace activity leading to more detailed investigation of particular problem areas, with each level illuminating the situated practices, and also providing a set of issues to be addressed for the next level. These piece together into a composite picture of how people interact with technology in their working lives, the limitations of existing work practices, and ways in which they could be improved by new technology.

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|---|---|
| *Level 1* | *Work structures and schedules* |
| Activity: | study timetables, organizational structures, syllabuses, resources |
| Purpose: | to discover how workplace activity is supposed to be conducted |
| Outcome: | description of the existing organizational and workplace structures; identification of significant events |
| *Level 2* | *Significant events* |
| Activity: | observe representative formal and informal meetings and forms of communication |
| Purpose: | to discover how workplace activity, communication, and social interaction is conducted in practice |
| Outcome: | a description and analysis of events that might be important to system design; identification of mismatches between how work has been scheduled and how it is has been observed to happen |
| *Level 3* | *Conceptions and conflicts* |
| Activity: | conduct interviews with participants to discuss areas of work needing support, breakdowns, issues, differences in conception |
| Purpose: | to determine differing conceptions of work; uncover issues of concern in relation to new technology; explore mismatches between what is perceived to happen and what has been observed |
| Outcome: | issues in working life and interactions with existing technology that could be addressed by new technology and working practices |
| *Level 4* | *Determining designs* |
| Activity: | elicitation of requirements; design space mapping; formative evaluation of prototypes |
| Purpose: | to develop new system designs |
| Outcome: | prototype technologies and recommendations for deployment |

Table 2. Multi-level approach to organizational engineering.

## 5 Results

The MEDIATE studies were undertaken by one researcher over a period of two years. This paper provides only a summary of the main results. The studies identified and clarified issues of importance to the design of computer-based training in radiology, including:

- the need to place computer-based training within a process of patient management. The teaching sequence and the presentation of individual cases should ideally take account of the content and quality of the case notes, and the recipients and purposes for which the radiological report will be used.
- providing a system that can be used within the limited and unpredictable time available for self-study, indicating the need for software implemented on a portable computer with the facility to rapidly save and resume a session;
- the need for a system that is authoritative, and perceived to be so by trainees and consultants. In general, radiologists have less confidence in the quality of computer-based material than information provided in book form.

## 6 Implications

The major contribution of the project reported in this paper has been to propose a framework for socio-cognitive engineering, as a contribution towards a science of interactive system design. We have described a realisation of the aspect of that framework that has been least explored, that of organizational engineering. The findings of the project are applicable at different levels of generality.

The workplace studies from the MEDIATE project provide a clear set of recommendations for the design of computer-based (and conventional) training in radiology, indicating the importance of patient management, the perceived lack of authority of computer-based information, and the disputed role of case notes in the reporting process.

Each level of the studies was successful in providing an agenda of issues to be explored at each subsequent level, and for examining personal and organisational conflict in terms of mismatches of expectation between course managers and trainees, between the prescribed curriculum and situated practice, and in the differences in practice between institutions.

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