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Socio-Technical Action Simulations for Engaging with Engineering Designers[1]

The knowledge and experience gained through the academic and professional training of engineers and technicians in the human aspects of their disciplines --or the lack of it --have their influence through the roles they may occupy in three main fields of professional activity: the design of equipment and products, the design of manufacturing systems and the operational management of work systems. In each of these, engineers and technicians are subject to constraints imposed by the organization for which they are working which, in turn, is subject to the requirements of its customers. Engineers, and other professionals to whom they are related in a total system, who fail to take account of human aspects, or who take a restrictive or simplistic view of human attributes, needs and behavior, ultimately have their roots in a training that is dominated by a technological imperative. The equivalent in a training for personnel or human resource managers is to ignore the technical characteristics and requirements of production systems.

This paper presents the course of an action research to develop a practical facility--an action simulation in educational socio-technology--for introducing postgraduate

[1]A new paper.

engineers with varied disciplinary backgrounds, and other related professional managers and specialists, to a common understanding of the organizational design of manufacturing systems. The range of considerations in the action simulation is conveniently indicated by the (UK) Institute of Production Engineering's definition of manufacturing systems engineering (MSE) as a "... comprehensive production discipline which optimizes the use of men, machines, materials (including information), and money ... by the simplest integrated combination of processes, machine systems, tooling systems, people, organisational structures, information flows, control systems and computers, with a competitive balance of technology and methodology."

The Presenting Problem

In the mid-1970s training endeavors in the socio-technical approach were changing from formal didactic learning methods to more experiential learning on field sites involving learning by doing, rather than the more simplistic observation of the expert in action or practice in exercises to develop skills of application (van Beinum, 1975; Emery and Emery, 1974). Advances in this direction require the participation of organizations prepared to involve their employees in learning by jointly doing something creative about their mutual concerns. But the possibility of participation in real-life work redesign or design is, for students, the exception. Opportunities to engage at the primary work system level are few; they arise unpredictably in time; they may be geographically inconvenient; variety may be restricted and few can participate. The process of organizational change may be so extended that the likelihood of a student being able to see it through is minuscule. Moreover, the risks to external company participants, students and the training institution attendant upon involving people in training in the real-life problems of others are all too evident, but are probably more apparent than real.

This was essentially the situation facing staff at the Cranfield Institute of Technology who were trying to develop more effective methods of introducing postgraduate students of industrial engineering and production management to socio-technical methods in work system design (Emery et al., 1967; Kember and Murray, 1991). Conventional teaching methods involving formal lectures, researched case studies, seminars on personal work experiences, field observations and surveys and, exceptionally, "possible" future work-related changes had failed to provide useful, practical socio-technical learning opportunities of a kind analogous to the technical experience of, for example, engineers and ergonomists in laboratory or workshop. There were special exercises and experiments, but these were concerned with either aspects of technical task performance using real objects (e.g., electrical equipment assembly) or exercises typical of methods used in social system training to illustrate particular aspects of group organization (e.g., different kinds of communication patterns). Lacking were opportunities for gaining hands-on experience of integrated socio-technical operations in quasi-real life production settings which could be experimentally manipulated and critically evaluated.

To overcome the obvious problem of physical access, in limited time, to a significant variety of operating work organization designs and to lay the base for practical training in design and change under protected conditions, the only viable course was to develop, as a socio-technical laboratory, one or more perceivably realistic, face-valid, practical simulations of typical manufacturing systems. In these simulations students (and others) could occupy active work roles appropriate to various organizational designs and scenarios. This would have the advantage that, unlike field engagements, all students could have direct experience of much the same situations--as well as intentionally contrasted experiences.

It was uncertain to what extent it was possible to design a learning system to enable trainees to experience, both cognitively and affectively, the diverse nature of the interdependence between the social, the technical and the influence of organizational context and contingencies and, in addition, to develop a stance toward design that is seen as collaborative and explorative between disciplines rather than exclusive and prescriptive. The antecedents for such a learning system were two-fold--technical simulations including management games both for predictive purposes and for training (Elgood, l984) and experiential methods in social systems training (Bridger, Vol. I; Miller, Vol. I).

In the organizational field, these approaches had been substantially oriented toward management task performance and, as such, had implicitly contained elements of a socio-technical nature, but in neither had this been more than marginal. With some notable exceptions (Shackel and Klein, l976) in which simulations featured both the technical and the organizational, the primary focus of simulation methods was "technical," as in computer-based complex decision-making exercises. The human content of the simulated situation might be limited to persons as cyphers; the role relationships and organization structure of the decision makers might be ignored or, at best, simple and mutually affective relationships between the operators of the system and the operands in the system simulated might be overlooked. Technical simulations involving organizational role playing as an explicit area of concern were more common at the level of the individual, relatively rare at the primary work group level and exceptional at departmental and company wide levels.

Experiential methods of social system training were, and are, many and varied, but those of particular relevance for action simulations are task-oriented and deal with inter personal relations in the "here and now" and make some use of laboratory- like experiments and application exercises relating to external situations. Sometimes the latter method engaged directly with people actually involved, but more usually there was recourse to representation through role playing. Social systems training of this kind is typical at the small group level but may also deal to some extent with inter-group relations and with social aggregate phenomena. Task-oriented social system training explicitly represents the technical system as human tasks; the physical reality of the technology is absent or, rarely, presented in simulated form.

That a specifically social-technical form of experiential learning might be derived from simulation and task-oriented social system methodologies was supported by the example of a noncomputer business game--"The Happy Hunting Indian Band Corporation" of British Columbia Research, developed from "The Enterprise Corporation" game (source not known). The game, built around a simulated production process and organization, producing "spacecraft" by folding printed paper blanks, was designed to provide participants with affective and other experience in a traditionally organized work system and opportunities to redesign the organization of the whole system. The scope for alternative production methods, work organization structures and company-environment scenarios was evident and in action the game was capable of making lasting impact. Its artificiality, however, limited its use to making "points" rather than helping to solve problems. Construction kit materials (e.g., "Lego") had a similar use in simulating assembly and "one-off " production processes, but did not present a sufficiently acceptable technical challenge to which engineers could respond. Without an adequate technical "anchor," they found themselves trying to deal with, to them, uncomfortable, intangible issues like frustration, warped communications, bad feelings, dissatisfaction--issues which they saw as the concern of others with different disciplinary backgrounds.

Practical Parameters and Conceptual Basis for Action Simulations

Realistic action, or role playing, simulations of productive work organizations can be designed to provide four incremental levels of experience for students:

- In operative, supervisory and managerial roles in one or more types of manufacturing system, each with one or more varieties of primary work unit organization.
- Carrying out socio-technical analyses of such systems, monitoring and making comparative evaluations of production, behavioral and attitudinal data.
- Participative re-design of work systems, e.g., to meet changed requirements.
- Implementation and operational evaluation of organizational changes.

The particular kinds of simulated system that need to be developed depend on several practical considerations:

- Whether the course (or simulation-based experience) is self-contained and continuous, or discontinuous (e.g., one day a week), or linked to some other course. The latter two considerations may constrain choice of product and production process.
- The time orientation of participants--to gain understanding of the past, an

ongoing experience, or as a preparation for the future? The difference between the first and second is between "there and then" and "here and now" in terms of the interpretation of experience. The third, which has connotations of prototyping a new design, is about discovering the nature of the future in the present, which may require the relaxation of some reality constraints.

• The likely setting in which a simulation is to be used--classroom, laboratory, workshop, factory--may technically constrain what can be attempted. Artificiality arising from a mismatch between technology and environment may affect the perceived reality of the simulation.

When it comes to choosing possible production systems for simulation, their technical characteristics have to be assessed in relation to the foregoing considerations. Table 1 illustrates ten decision areas that may be used in searching for production systems to simulate or in assessing the compatibility of design options with each other and with training objectives. In designing a manufacturing simulation with a low level fabrication or assembly technology, the most important requirement is for a nontrivial, realistic, obviously engineered and seemingly required product. The technical production process should be sufficiently complex to permit alternative methods of production and alternative forms of organization to be devised, yet not so demanding of operative skills that they cannot be acquired rapidly by most people.

A second main requirement is that the work roles and work relationship structures

Table 1

Manufacturing System Action Simulation: Examples of Technical Design Options

Decision area	*Design options*	*Decision area*	*Design options*
Product	Real object with market Real object without market Model (toy) Paper abstraction	Unit operations	Transfer (supply, buffer, stock) Reductive (drilling, milling, cleaning) Additive (assembly, welding, blending) Changes of state (bending, molding, cooling) Inspection and rework
Technology level	Powered tool Powered hand tool Simple tools Manual aids Manual	Skill levels	No training required Picked up on job Minimum training Somewhat specialized
Production system	Continuous flow process (liquid/solid) Production line (fabrication) Assembly line Batch	Size (number of persons)	One unit (7-9) Two units (14-18) Three units (21-27) etc.
Throughput time	Instant Cycles possible in shifts (one, two, many) Continuous	Setting up/ down time	Minutes Hours Days
		Materials and components	Reusable Consumed
		Costs: capital	Low Medium High

of different primary work units should be relatable within a common conceptual framework that permits of systematic and objective comparison in the same terms, e.g., a typology based on activity relationship, role differentiation, task dependence and goal dependence (Herbst, 1974). The possibility of, for example, measuring work relationship structures and interaction patterns within and between groups affords some comfort to "hard" scientists in a "soft" field.

The third requirement is that simulated primary work units be embedded in an appropriate simulated organization structure of management, supervisory and specialist roles, which controls the running of the primary unit in line with its own policies through creating different operating conditions (e.g., raw material supply, demand for product, labor supply, etc).

This calls for both prepared scenarios and a creative response to unplanned events during their running (e.g., absences, disputes). The simulated wider organization needs to be more realistic than ideal in its structure and functioning. Simulated primary units can also be ideal, internally consistent types or--as in real life--internally inconsistent in some respects, giving rise to undesired consequences, e.g., a misfit between the structure of a wages system and task performance requirements. In each case the criteria underlying the particular design decision need to be explicit.

An Action Research in Prototyping a Simulation

The initial task of designing and building a prototype socio-technical action simulation of a small manufacturing unit was given to a group of graduate students taking a master's degree in Industrial Engineering and Production Management. They had previously opted to specialize in ergonomics and work organization. Teaching was by conventional methods, the limitations of which have already been mentioned. Students each carry out an individual project in the "engineer" role, applying existing knowledge and techniques to solve specific problems, and together, take part in a substantial, industry-based, problem-oriented group project. Ideally, the choice of the group projects would be negotiable, the type of solution open rather than predetermined and the methods used discretionary, rather than preselected (Cherns, 1976). The student roles were those of consultant or action researcher, depending on the nature of the problem. In these terms the simulation design project had both kinds of relationship, with the university institution as client in the shape of their teachers.

The student group which was to design and build the simulation could call on the services of technicians, fellow students as volunteer subjects and teaching staff as "external" advisers. The group was also wholly responsible for creating an organization to manage the group project and carry out the work. The group members were therefore involved in two levels of learning: applying their knowledge from lectures, etc., to designing a real work system for the group project in which they had roles and the task for which the project had been established, designing a simulated manufacturing system (Kember and Murray, 1984). During the course of the project, particularly in the area of alternative organizational options, increased carryover of learning between these levels was observed in both directions.

The members of the project group were three engineering graduates with factory employment experience and two industrial psychologists of whom one had an engineering background. The mixture of disciplines was fortuitous and during the later organizational design phases was important in highlighting the differences between individual cognitive styles and what individuals presented as ideal organizations (Kilmann and Mitroff, 1976).

The broad structure of the project was predetermined by teaching staff and had three phases. The first was an on-site socio-technical scanning and analysis of the systems in a local factory for fabricating and assembling electromechanical controls, followed by more detailed studies of relatively small production units within it. This was to give all group members a common reference experience for Phase 2, the design, construction and testing of a simulated system within given constraints. In the third phase (and subsequently with other project groups), the simulation was to be run with volunteer student groups (and if possible with workers from the field-site factory) both to facilitate further development and to assess whether preliminary hypotheses as to behavior and attitudes exhibited in different forms of simulated work organization were confirmed. For these purposes three types of work organization were prescribed by teaching staff:

- The *unit production* model, in which individual "craftsmen" carried out all tasks required to produce a whole product.
- The *production line,* in which workers, in sequence, engaged in simple, repetitive short cycle tasks.
- "Autonomous" *group working*, in which the self-regulating group could, for example, decide the production method within limits set by the available technology; the allocation of individuals to roles; role exchange; etc. (Gulowsen, 1971).

The initial briefing for Phase 2 covered the reasons for needing to develop a simulation and explained the necessary conceptual and practical parameters. As an introduction to action simulation methodology, the group ran a primary work-group version of the Enterprise Spacecraft game and, in a prototyping model, tried to simulate different methods of organizing the assembly of toy automobiles using Lego materials. An early decision was taken by the group that in order to engage the interest of engineers, the simulation should call for the exercise of hands-on technical skills. Other things being equal, the higher the technology used in the simulation the more attractive it would be. This pointed to a fabrication of solid objects rather than an assembly process, a chemical flow process being too specialized and not within the competence of the design group. The main problem in the simulation construction was deciding on a product item that had substantial versatility with regard to production technique, required multistage manufacturing, had low cost and could be realistically produced under different forms of work organization. Some 16 product ideas were considered and rejected by the project group, and the choice of the ultimate product was a matter of inspiration. The sequence of events, which proceeded in three phases, was somewhat as follows:

- An engineer member of the group recalled that as a child he had made a "flying toy" out of scrap metal. There was a concurrent need for giveaway toys for a staff children's party. A group decision was quickly taken to design and develop a product--the "Cranfield Flyer"--like the flying toy. A basic technical method of construction was produced.
- The risk to children of possible poor workmanship was realized. A plastic coating process was invented to cover all surfaces. Coatings in different university colors could be used for "marketing."
- It was recognized that bench hand-tool production methods would be used in reality to produce quantities of objects similar to the core component--a propeller, for example--with varying specifications for experimental work in aeronautics. The propeller was redesigned to exploit this as a "required" range of "real" products.

From the initial decision onward the project group had little doubt about the "correctness" of their choice of product. The choice not only fitted the requirements of the action simulation but it "connected" the simulation to the immediate institutional environment, so that it would be more likely to be perceived as "fitting in"--Cranfield has a history and reputation in aeronautics. Whether this, and continuing helicopter activity on the airfield, gave rise to the engineer's initial suggestion is a matter for conjecture.

Normal bench handtools (e.g., drills, metal cutters, files) were used to fabricate the propeller from an aluminum alloy blank, through a variable sequence of nine operations, taking in all 12 man-minutes per propeller. Work relationship structures and work role descriptions for each type of work organization were drawn up for seven to nine participants. Scenarios and procedures were prepared and iteratively developed in a series of runs of the simulations, using groups representing a wide range of age, cultural background, engineering and industrial experience. A basic 10-session, nominally 30-hour course evolved to provide a learning experience of the primary group in the workplace, where the roles occupied and the organizational structures are studied (Murray and Kember, 1991). Kolb's (1976) experiential learning model summarizes the learning process provided by the course (Table 2). The structure, content and duration of the course, particularly the number and length of simulation runs, are tailored to participant needs.

Several critical experiences contributed to the design. In the first three sessions, the ergonomically poor, low-level technology employed worried some engineers who would press for technical improvements and upgrading, suggesting ways of bringing this about. As these would have organizational and other implications within the wider context, consideration of them was referred to the group's own design session (session 8) and, when judged feasible, suggestions were implemented.

Although most engineers had some experience of both the Individual and Production Line types of organization which represented extremes on a continuum of skill

Table 2

Outline of the Ten-Session Course Structure

Session	Main activity	Learning process
1	Assessment of skills, preferences and training	Concrete experience
2	Roles in "individual" type of organization	Concrete experience
3	Roles in "line" type of organization	Concrete experience
4	Roles in Modified Line	Concrete experience
5	Feedback, comparative analysis of performance	Observations + reflections
6	Comparative socio-tech analysis of structures	F(Im concepts + generalizations
7	Instruction in redesign methodology	Form concepts + generalizations
8	Group designs own organization	Test implications in new situations
9	Group runs own design	Test implications in new situations
10	Feedback on performance; redesign, rerun	Test implications in new situations

content and variety, they found it hard to conceive of the possibility of variants. To introduce the idea of options, a Modified Line was introduced (session 4) in which simple changes (e.g., in layout) could lead to changes in the work relationship structure.

Some engineers took a skeptical view (in session 5) of qualitative observations on production performance, behavior and attitudes. Subjective estimates of the quality of finished products would be challenged--a common "scientific" defense against accepting interpretations about the significance of organizational changes. (Equipment was later constructed to measure quality.) Similarly, video recordings removed much argument about behavioral observations.

To reduce the likelihood of carbon-copy designs, the production task given to the group in the new design session (8) needed to be changed (e.g., greater product variety, mix changes, anticipated market difficulties), implying the need for flexible and robust designs to be able to respond to uncertainty.

A main problem in the design sessions (8 and 10), particularly for groups who had had little exposure to case material, was to detach them from consideration of only line types of organization. In such cases it was important for teaching staff not to infringe on the group's autonomy by intervening at the design stage, but to delay intervention until feedback and redesign. When it was possible to have two or more groups in the same course, they could be balanced or could be compared to reflect certain differences (e.g., in experience or cognitive style). When put into "competition" with each other, engineers were able to see a range of design preferences and solutions and hence actually experience the many options in the way work can be organized with a given level of technology.

An unexplored topic in running an action simulation course is how best to take account of differences in the cognitive styles of participants, i.e., how they prefer to take in information and make decisions. Kilmann and Mitroff (1976; Kilmann 1983) found that individuals with fundamentally differing cognitive styles have fundamentally different conceptions of what constitutes an ideal organization. This fact has profound implications for organizational design. All individuals use both sensation and intuition as modes of perceiving at different times, but tend to develop a preferred mode, the strength of which may differ among individuals. This is also the case for the decision-making modes, thinking and feeling.

Individuals who prefer to take in information via the senses (sensation) and who are most comfortable with details and facts may have greater doubts about the fidelity of the simulation model than those who prefer to take in information by means of their imagination, by seeing the whole gestalt (intuition). In an engineering institution which students have chosen to enter and for which the successful outcome is a higher degree, logical impersonal analysis (thinking) may be a more likely way of reaching a design decision than a subjective, personal process (feeling). Nonetheless, in an action simulation, with its novelty, some may well make design decisions based on personalistic value judgments, particularly if this is their preferred style. Combining the two perceiving modes (sensation [S] and intuition [N]) with the two decision-making modes (thinking [T] and feeling [F]) results in four Jungian personality types with differing cognitive styles: ST, NT, SF, NF.

To judge from a comparison (Table 3) between engineering and finance/commerce undergraduates (quoted in Myers, 1962), it seems likely in a teaching simulation that the cognitive styles of engineering students may not only vary among themselves, but may differ modally from those in other disciplines. Manifestly, the cognitive style of the engineering designer should be considered in relation to the influences that shape the technical and human organization--but it may be suggested that it should extend equally to all stakeholders who influence and participate directly in the design process. It is not a question only of singling out engineers, or other disciplinary or functional groups, for separate action simulation-based training in work organization design. It is also necessary to provide them with complementary designing experiences other than through role playing other functions, in quasi-real multifunctional organizational settings in which participants can encounter the cognitive styles and organizational ideals of others. Particularly apposite would be use of the strategic choice approach (Friend and Hickling, 1987), which offers a range of practical methods enabling people

Table 3

Comparison of Cognitive Styles*

Student group	Sensation thinking	Sensation feeling	Intuition feeling	Intuition thinking
2188 engineering students (Cornell, MIT, RPI, 1962-64)	24%	11%	22%	43%
488 finance/ commerce students (Wharton School, 1956 & 57)	51%	21%	10%	18%

* Data abstracted from Myers (1962), table, p. 64. Columns indicate modes of perceiving/decision making.

of different outlook, discipline and skills to analyze interconnected problems and to work adaptively toward decisions.

The original student project group--and others that succeeded it--produced a viable simulation that reproduced the necessary and sufficient conditions for the manufacturing situation it sought to model. The propeller fabrication simulation was right for the immediate needs of the particular institution. Different products and production technologies might be better suited to other colleges, polytechnics, etc., located in areas with different industries. At the beginning, it had been thought necessary to develop simulations of a range of other production systems (e.g., for process industry and for assembly), but use of the fabrication simulation was, in practice, found sufficient to facilitate training in the basic aims and methods of socio-technical design. However, other action simulations were developed for use in individual research projects of production scheduling and office-work organization.

Action Simulation of a High-Tech Manufacturing System

A major postgraduate engineering student group project used the work organization action simulation course for general training, prior to assessing the implications for job and organizational structure of a suggested staged introduction of a full flexible manufacturing system (FMS) in an actual company (Cranfield, 1984). Conventional engineering and socio-technical design philosophies were compared, and it became apparent that approaching prototyping in a more socio-technical way would be an economically effective method for exploring the organizational impact of a sequence of technical changes (Kember and Murray, 1988). Useful as the "propeller" action simulation is as an initial teaching and training facility, its low-tech image is a limitation to its attractiveness and usefulness to engineers in an increasingly high-tech computerized world. More and more, the nature of information technology is requiring production and manufacturing engineers to become involved with the design of whole systems rather than with the replacement of single machines.

Against the background of the FMS group project, a further project was undertaken to demonstrate the practical feasibility of an action simulation of an FMS as an example of computer integrated manufacturing that would enable managers and designers to recognize and explore person/machine interface and organizational issues, options and problems before design decisions in the technical system are finalized.

A flexible simulation of an FMS, i.e., one which could cover a range of configurations, was constructed, and a Mark I working prototype of manifest interest to engineers was demonstrated (Cranfield, 1989). The simulation (a small parts FMS that made prismatic components for aircraft) was not a replica, but included features from several installations and the literature (Gerwin and Leung, 1980; Gunn 1982). Something of its nature may be inferred from the sequence of design decisions taken iteratively: product; production process and routes; physical layout; material flow; information flow via computer network; likely variances and where they are generated and likely to be detected; "company" organization; operating scenarios; key variances and control patterns; operator tasks; primary group and support system work roles.

The design had to create a valid perceptual experience for a range of possible participants and call for the exercise of conceptual skills in addition to limited manual activity. In the action simulation itself, what are simulated are the visible and other perceptible aspects of the product and production process and not the actual production process itself (which is supplied in a scenario). The process takes place in "black boxes" which input and output products in course of production and emit appropriate signals. This makes the modular design generic and capable of adaptation to many different kinds of product and production process.

For realism, an FMS action simulation must operate in some representation of the real world of business conditions and requirements, which is mediated through an explicit wider organization structure of roles and positions. Many functions may impinge directly or indirectly--and quickly--on the running FMS (e.g., computer programming, scheduling, personnel, marketing, etc). Many more "external" people may interface with the FMS than operate it directly, and so socio-technical design of advanced manufacturing systems is relatively more concerned with meso- and macro-system level functioning. For consistency, the technology used, as well as the organization at such levels, may well need to be simulated to facilitate multifunctional design approaches and training.

Conclusions

What has been advocated in this paper is the introduction into graduate level engineering education (and where appropriate into in-house management training) of the integrated socio-technical systems approach to the design and management of work organizations in manufacturing industry. Crucially, in addition to conventional teaching methods, basic training in work design should be experiential, making use of work organization action simulations, initially with low level technologies, to elucidate principles before moving to more advanced simulated or real manufacturing systems. For the better appreciation of differences in cognitive style which affect the design process, some integrated training should take place with other technical and nontechnical disciplines or professionals with whom engineers have to work, or to whom they have to relate in manufacturing work organization design.

Short of such integrated education and training, action simulations can be used as introductory familiarizing or "sensitizing" events for all people likely to be involved in a specific real design or redesign operation. Ideally, the action simulations should be generically as similar as possible to the real options.

Moving from the generic to the specific, a more socio-technical approach to prototyping could be envisaged to enable engineers, jointly with other stakeholders, to explore design options and test out ideas in a way analogous to the use of engineering prototypes, e.g., the organizational implications of conventional computer simulations of manufacturing systems could be tested. A move toward explicit socio-technical prototyping would facilitate the participation of operators and others in the design and commissioning process, the selection of potential operators and the initial stages of operator training--all social system aspects of direct concern to the engineering designer of manufacturing systems.

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