Part III: Towards Knowledge and Technology Creation Support

7 Decision Support versus Knowledge Creation Support

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7.1 Summary

After introductory remarks on interactive computerized decision support and the concept of supporting creativity, this chapter briefly describes the history and the current status of decision support, the differences and similarities between decision support and creativity support, and how the conclusions from earlier chapters can be applied to the problem: upon what objects shall we concentrate creativity support. Then we turn to a more detailed meaning of the concept of *Creative Environment.* While the concept of *Ba,* as proposed by Nonaka, can be understood as a place and space in which knowledge is shared, created and used, including *physical* space, *virtual* space, and *mental* space, the *Creative Environment* should include not only all aspects of *Ba –- physical*, *virtual*, *mental* – but also *informational, social* and *psychological* aspects; above all, however, the *Creative Environment* can be understood as a computerized system for enhancing creativity. This chapter concludes with a discussion of existing and needed *Creative Environments* and, in particular, describes needed work on constructing such environments for *Web knowledge acquisition, Debating, Experiment design and support, Virtual laboratories, Road-mapping, Brainstorming, Gaming,* and *Distance learning and teaching*. The chapter ends with concluding comments.

The limited space of this book makes it impossible to describe all possible developments of *Creative Environments* in detail that they deserve and would be possible even today. Thus, we decided to make only very short comments on possible *Creative Environments;* we intend to write a separate book on this subject.

7.2 Decision Automation versus Computerized Decision Support

The novel approaches, the new type of micro-theories of knowledge creation that appeared during last decade of the 20^{th} Century and the first years of the 21^{st} were motivated by the need for a better understanding of knowledge creation processes in the micro scale, because it was realized that such understanding is necessary in a knowledge-based economy. This revolution came from diverse disciplines. Epistemology in its pure sense contributed only by the theory of basic, revolutionary knowledge creation, while management science contributed the theory of organizational knowledge creation in market-oriented organizations; systems science, as represented by this book, contributed to the integration and further development of such theories, e.g., to the theory of normal knowledge creation in academia, universities and research institutes. Computerized decision support, which can be considered part of systems science as discussed in the previous chapter, was an important source of some of these theories, such as the *Shinayakana Systems Approach* or *Rational Theory of Intuition.*

> The historical motivation for computerized decision support to contribute to knowledge science is based on an old issue and dispute in decision support community: *decision automation* versus *interactive decision support.*

Decision automation is old and venerable tradition; as indicated in the last chapter, the entire period of industrial civilization started with J. Watt's improvement of the steam engine that was, in fact, an engineering feedback system applied to an older type of steam engine and thus a prototype of decision automation. Automation of any industrial process up to the construction of robots relies on measurement, feedback by comparing the actual measured behavior with a given desired set value, scenario or trajectory, and an automated decision as to how to correct the actually observed behavior of the system. Such principles can be naturally generalized to decision automation in a computer. Since the goal of computer science was to make computers more and more intelligent, it was natural to assume that they would eventually take over decision-making and decision automation, either from other type of machines (usually in a closed-loop system as in engineering control systems and robotics) or even from people (usually in an open-loop system, as assumed by early approaches to management and to operational research).

This type of positivistic approach to management was supported by the early development of economic decision theory, which reduced human decisions to the maximization of a utility function (in some cases called a value function). Thus it seemed sufficient to determine the utility function appropriate for a given application and to maximize it in a computer in order to give computerized decision support. This was equivalent, however, to nothing other than decision automation hidden by an earlier (possibly interactive) specification of the value function. In other words, this approach is based on the following two-stage *non-recursive* procedure:[1] first, a specification of an objective (represented by the utility function determined before the actual problem analysis is done), and second, looking for the best possible value of the selected objective. In the language of control engineering, this would be called an open (-loop) system.

While such an approach was fully admissible for the automation of engineering systems, it led to severe doubts and critiques when applied to actual decision support for people. In management science and sociology, this lead to the total critique of the *hard systems approach* by the *soft systems approach,* denying the possibility of using computerized mathematical models in decision processes at all, as described in the preceding chapter. These critics, however, neglected to inform themselves about the parallel development of *soft computing techniques in hard systems science,* in particular, of consistently *interactive decision support.* Such decision support also denied – principally on the grounds of *human sovereignty* – the use of detailed mathematical models of human preferences – called *preferential models,* see, e.g., (Wierzbicki et al. 2000), for supporting the decisions of individual people. Instead, such decision support replaced detailed, preset preferential models with diverse principles governing the interaction between the human user and the computer.

On the other hand, such decision support fully accepted the use of computerized mathematical models to represent the diverse other types of knowledge – so called *substantive* or *core models* – needed for decision support. The important feature of this approach is its support for a learning process, i.e., for modifications of the preferential models based on diversified analyses of the two (preferential and substantive) types of models combined for the analysis. Although mathematical optimization is used in both (open-loop and interactive) approaches, its role is very different. In the first one it provides "the best" solution for a given optimality criterion;

[1] That is, without any influence of the second stage on the first one. In social sciences such a procedure is also called *linear*, but the term *non-recursive* is less confusing (possible confusion might concern the mathematical *linearity* of models applied in such a procedure).

in the second it provides a (possibly large) set of solutions, each corresponding to a preferential model, which is dynamically changed by users upon analysis of previously obtained solutions.

This consistently interactive decision support concentrated the attention of researchers, on two particular areas. One was *knowledge representation by mathematical models,* needed for such decision support. The other was *computer interaction with a knowing human subject,* particularly the reasons why a human decision maker might prefer quite different decisions than those suggested by a computer. Precisely the second stream of reflection has lead to the *Shinayakana Systems Approach* and to *Rational Theory of Intuition,* and thus to this entire book; but the first stream of research resulted in the possibility of applying developments from decision support in creativity support. After all, creative decisions are also a type of human decisions; if we interpret computerized decision support elastically and broadly enough, we can extend its principles to support creative processes.

7.3 The Meaning and History of Decision Support

The terms *Decision Support (DS)* and *Decision Support System (DSS)* are widely used both in research and in practice, but there is no general agreement about their meaning. In a very broad sense, *DS* can be anything that helps to make a better decision, from a cup of tea to a side-conversation that may prompt an *Enlightenment* or *Heureka* effect. In many real life situations, decisions are made based primarily on experience (that includes but is not limited to explicit knowledge) and intuition. For example, a good skipper controls a sailing boat by commanding her course and trimming sails without explicitly considering the laws of aero- and hydro-dynamics; however, in order to be a good skipper, one has to master these laws, then forget them but be able to recall their properties whenever necessary. On the other hand, many drivers control a car successfully without even understanding the basics of car construction.

In a more commonly used sense, the term *DS* is interpreted as an effort to apply science for understanding and managing an organized system. *DS* is actually needed in diverse situations in various fields, including business management, engineering, environmental management, medicine, investment, banking, and risk management. The variety of such situations includes, for example, making strategic decisions at the business corporate level, the strategic and operational planning of means aimed at improving environmental situations, operational water management, solving engineering design problems, diagnosing illnesses, planning *exante* and *expost* risk management of natural catastrophes, organizing military operations and supply chain management.

Decision Support Systems (DSS) are computerized tools used to aid in decision-making. *DSS* that serve such diversified purposes obviously have a variety of different features. Even more confusion is created, because *DSS* are designed and applied for similar purposes in diverse scientific communities and then called by different names. Terms such as *Management Information Systems (MIS), Strategic Information Systems (SIS), Expert Systems, Intelligent Decision Support Systems* or *DSS* are used interchangeably to denote similar methodological approaches and types of application. On the other hand, the term *Decision Support System* is usually applied in a generic sense, including a diversity of very different methods and tools.

The use of the concept of *DSS* actually evolved with distributed computing which started about 1965 and made it practicable to build large-scale *MIS* in large companies, then to augment them with diverse methods and tools to aid in decision making. However, many researchers believe – somewhat narrowly – that the history of *DS* began in the late 1930s or early 1940s, following the earlier development of *Operational Research (OR)* in UK. Actually, *DS* (understood as science-based support for decision making) has a history of hundreds of years. The key developments in science and engineering and their applications, that built a knowledge base for science-based *DS,* started in the middle of the 17th Century. Let us mention only several milestones from the period before late 1930s:[2]

- The concept of expected value (B. Pascal, 1654)
- I. Newton's method for minimizing a function (1665)
- The concept of normal distribution (A. de Moivre, 1733)
- St Petersburg Problem (D. Bernoulli, 1738)
- Bayes' Rule (1763)
- Lagrange multipliers (1788)
- The principle of utility (J. Bentham, 1789)
- The least squares method (C. Gauss, 1795)
- The concept of war games (von Reisswitz, 1811)
- General solution of linear equations (C. Gauss, 1826)
- General solution of inequalities (J. Fourier, 1826)
- The concept of scientific management (F. Taylor, 1890)
- Gantt charts (H. Gantt and F. Taylor, 1900)

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[2] These dates are only examples of long history – they do not mean that *DS* started with Pascal; probably, we could find elements of decision support even in antiquity, or in Chinese bead slip-stick calculators.

- Pareto optimality (1906)
- Markov chains (1907)
- First applications of the probability theory to telecommunications (Erlang, 1909)
- The uncertainty principle (W. Heisenberg, 1926)
- First applications of probability theory in engineering (T. Fry, 1928)
- Quality control charts (W. Stewart, 1931)
- Probability theory (A. Kolmogorov, 1933)
- Hypothesis testing (A. Vazsonyi, 1933)

And these are only selected contributions; beside them, we should mention dynamic systems theory developed by many contributions since Watt's improvement of the steam engine, leading to the concept of feedback in telecommunications and control engineering, to operational calculus and to analog computers in early 1930s and to diverse concepts of decision automation since that time.

> Thus, *OR* – operational research – is by no means solely responsible for decision support, nor did it originate the concept of optimization calculations, as discussed in Chapter 6.

However, the origins of *OR* were related to the development of British air strategy in 1920s; the rapid development of *OR* was stimulated by military applications, primarily in supporting tactical and strategic military decision-making during the Second World War. The postwar decades of the 1950s and 1960s brought space applications and are considered the *OR Golden Age,* when major theoretical achievements were accompanied by a growing diffusion of *OR* techniques in the private and public sectors. *Linear Programming, Mixed Integer Programming,* and statistical methods have been widely used for, e.g., production planning, inventory control, network analysis, and forecasting.

In the late 1960s companies and organizations started to limit resources for *OR* groups, which have gradually disappeared from most companies, while academic research became less and less concerned with the applicability of the developed techniques. This process can be explained by a *paradigm lock-in:* the unquestionable success of OR was due to the application of techniques developed for well structured military and industrial decision-making processes, in which a decision problem can be adequately represented by a *mathematical programming problem*, i.e., by finding *the best* (in the sense of a given optimality criterion) solution from a set of feasible solutions.

On the other hand, an adequate representation of rationality in policy making, management and engineering practice in the form of an optimality criterion is often impossible. This concern is well expressed by the famous statement published in (Ackoff 1979):

> "More and more people are coming to realize that optimization of all the quantities of life does not optimize the quality of life and that is a limiting objective. In addition, there is a widespread belief that much of the accelerating rate of change is getting us nowhere. [...] Those of us who are engaged in helping others make decisions have the opportunity and the obligation to bring consideration of quality of life – style and progress – into their deliberations. OR [Operational Research] has virtually ignored both the opportunity and the obligation."

This statement was far from being generally accepted in the *OR* community, see e.g., a constructive discussion of the role of *OR* in (Chapman 1988, 1992) and in (Radermacher 1994).

One of the most strongly established rationality frameworks is based on the concept of the maximization of *multiattribute utility (MAU)* – compare, for example, (Fishburn 1964), (Keeney and Raiffa 1976), and (Yu 1985). The *MAU* concept, often also referred to as the *multiattribute value function*, assumes that it is possible to construct a function that maps elements of the criteria set into R^1 in such a way that a larger value of this function corresponds to a stronger preference. There are, however, many fundamental and technical difficulties related to the identification of a value function that adequately reflects the preferences of a decision maker, see, e.g., (Fisher 1979), (Rapoport 1989). Moreover, it has been observed by many researchers, such as (Maclean 1985) and (Tversky and Kahneman 1985), that a decision maker learns about the decision problem during an interaction with a *DSS* and quite often changes his/her preferences or specifies them inconsistently during this learning process. But an even more important reservation for application of the *MAU* concept to decision support was given by Simon as early as (Simon 1957), who pointed out – against all traditional economic concepts – that people look for so-called *satisficing* solutions instead of one that maximizes the expected utility. Also (Galbraith 1967) stressed that *satisficing* behavior corresponds to the culture of big industrial organizations.

The problem of *rational choice* has been extensively discussed in a large number of publications. Discussions of diverse approaches to this problem can be found in (Keeney and Raiffa 1976), (Lewandowski and Wierzbicki 1989), (Rapoport 1989), (Yu 1990), (Sawaragi and Nakamori 1991), (Keeney 1992), and (Stewart 1992). Here, we outline only one, very successful approach originating from the work of Simon (Simon 1958), who formulated a rationality framework called *bounded rationality* or *sat-*

isficing decision making. This framework has been extended further by many researchers; see, e.g., a summary given in (Lewandowski and Wierzbicki 1989). One of the directions in this field, set by (Wierzbicki 1980), is based on the *principle of reference point optimization*[3] in multiobjective optimization and decision support. That principle has been extended in (Wierzbicki 1982, 1984, 1986) to *principles of quasisatisficing decision making* and has been extensively used both in research and in applications, see (Lewandowski and Wierzbicki 1989), (Stewart 1992). In parallel, (Nakayama and Sawaragi 1985) developed a similar method called the *satisficing trade-off method*. Similar approaches and their extensions have also been elaborated and applied by many other researchers, including (Steuer 1986); (Seo and Sakawa 1988); (Korhonen and Wallenius 1990); (Korhonen, Lewandowski and Wallenius 1991); (Korhonen, Moskowitz and Wallenius 1992); (Michałowski and Szapiro 1992); (Sakawa 1993); (Wessels and Wierzbicki 1993); (Lootsma, Athan and Papalambros 1994); (Makowski 1994); (Granat and Wierzbicki 1994).

The above summary illustrates the diversity of paradigms related to *Decision Support.* We will not contribute here to the intensive terminological discussions on the definition of a *DSS;* instead, we refer the reader to discussions such as those presented in (Meister 1976), (Emery 1987), (Davis 1988), (Hopple 1988), (Thierauf 1988, 1993), (Andriole 1989), (Lewandowski and Wierzbicki 1989), (Nagel 1990), (Flood and Jackson 1991), (Silver 1991), and (Janssen 1992). We quote here only the definition proposed in (Emery 1987):

> "A DSS provides computer-based assistance to a human decision maker. This offers the possibility of combining the best capabilities of both humans and computers. A human has an astonishing ability to recognize relevant patterns among many factors involved in a decision, recall from memory relevant information on the basis of obscure and incomplete associations, and exercise subtle judgments. A computer, for its part, is obviously much faster and more accurate than a human in handling massive quantities of data. The goal of a DSS is to supplement the decision powers of the human with the data manipulation capabilities of the computer."

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[3] Which means optimization of a value function called the *achievement function*, but this function is defined relative to a *reference point* given by the decision maker. This is not equivalent to minimizing the distance to the reference point which is used in *goal programming,* see the detailed discussion in (Wierzbicki et al. 2000).

Any *DSS* is actually developed to be a part of a *Decision Making Process (DMP).* A *DMP* is typically composed of many stages;[4] *Decision Support* is oriented either to specific stages or to the entire process. Also, *Decision Support* is oriented toward a specific *user of the DSS;* this might be the final decision maker, an analyst of strategic decisions for a company, a designer, etc.; we shall apply the terms *the user* and *the decision maker* interchangeably.

Very often, *Decision Support* involves abstract (mathematical) models that represent the available (often quite complex) knowledge about the decision situation. The part of this knowledge that is rational and in a sense objective, independent from the decision maker, is represented by a *substantive* or a *core model* of the decision situation; but even a *substantive model* might include simplifications and specifications representing the experience of the user. The other part of the pertinent knowledge concerns the preferences of the user and is represented by a *preferential model.* However, as discussed in the introductory section, the concentration on *preferential models* results in *decision automation* that is often resented by the user; the essence of *interactive decision support* is helping the user to enrich and apply his/her intuition.

Therefore, *interactive model-based decision support* is conceptually distinct from the more traditional data-oriented perspectives of decision support. Quite often, the *DMP* requires not only data processing in the traditional sense, but also the analysis of a large number of logical or analytical relations and processing, or rather *solving*[5] an underlying mathematical model. This, in turn, involves a large amount of data. In such situations, a properly designed and implemented *model-based DSS* not only performs cumbersome data processing, but also provides relevant information that enables the user to concentrate on those parts of the *DMP* that cannot be fully formalized. In effect, *interactive model-based decision support* combines rational knowledge imbedded in substantive models of decision situation as well as used by the programmer of the system to organize decision process, with both rational and a-rational knowledge of the decision

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[4] Similar to *transitions* in the knowledge creation processes analyzed in this book. Compare the description of an analytical decision process in Chapter 2 with the stages defined by Simon and the strategic intuitive decision process defined by Wierzbicki.

[5] The word *solving* is used here to jointly denote two basic approaches to the analysis of mathematical models, namely *simulation* and *optimization*, the latter including *multiobjective (vector) optimization, inverse simulation, simulation with soft constraints* (the more advanced versions of simulation are often in fact based on optimization as a tool), etc.

maker called also system *user* who, according to the *principle of user sovereignty,*[6] is not supposed to be asked about a rational specification or justification of her/his preferences (or about possible inconsistencies in selecting final decision).

A key issue for a *model-based DSS* is its relation to the actual *DMP*. Especially in managerial situations, a decision maker is typically confronted with problems that are dependent on each other and a *DSS* covers only a subset of problems that are considered within the *DMP.* Often part of the *DMP* can not be represented in the form of mathematical models. This has been recognized through the development of *interactive decision support* during the last 25 years; but *interactive model-based decision support* tries to use models mostly for the representation of *substantive knowledge,* avoiding too precise modeling of *preferential* knowledge so as to preserve and respect *the sovereignty of the user*. As described in Chapter 6, *soft system thinking* condemns any use of *hard models*[7] in decision support; but as noted there, this critique does not take any notice of the development of *interactive decision support.* Compare, for example, the discussions in (Flood and Jackson 1991) and in (Wierzbicki 1992b, 1997) for the relationship of these two types of approaches. The *Shinayakana Systems Approach* (Nakamori and Sawaragi 1991) is actually aimed at combining such hard and soft systemic approaches.

In fact, (Hopple 1988) suggested that *human-machine symbiosis is a hallmark of a genuine decision support system*. The characteristic features of a *DSS* listed briefly above are the main necessary conditions for such a symbiosis, but they by no means represent sufficient conditions. A general specification of sufficient conditions for a good implementation of a *DSS* is actually impossible since this obviously depends on the particular environment of a *DMP*. A key element of this environment is the so-called *habitual domain* of the decision maker, see (Yu 1990). A developer of a *DSS* must recognize and understand the *habitual domain* of the decision maker in order to successfully design and implement the *DSS.* More detailed discussions of *model-based decision support* can be found, in (Makowski 1994, 2005) and (Wierzbicki et al. 2000).

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[6] See more detailed discussion in Section 7.5.

[7] However, it in fact uses *soft models,* e.g. *structural models.*

7.4 Current Status of Decision Support

A basic current trend in the development of *DS* is related to the increasing integration of traditionally distinguished *data based* and *model based DSS.* To present this trend, we should note first that the diversified functions of a *DSS* were traditionally divided into two sets:

- Data processing in the traditional sense:

These functions provide selective retrieval and presentation of information previously stored in a database. Such functions are typically supported by a *Database Management System (DBMS)* and are routinely used at most enterprises for many everyday managerial activities such as producing various reports (e.g., periodical and exceptional), answering ad hoc queries, presenting information in diverse forms, etc.

- Model processing:

These functions provide the diversified possibilities of predicting the consequences of some action (implementing a decision or making a choice) or events (actions that are not controlled by a decision maker). In such cases, a mathematical model of the decision situation is constructed and such a model is used for an analysis of predicted consequences as well as for analyzing decisions leading to preferred consequences.

A *DSS* that supports only functions from the first set is called a *data-oriented* or *data based DSS*. Model processing functions require a *model-based DSS* which typically includes also many of the functions of the *data-oriented DSS*.

Increasingly, however, contemporary *data-oriented DSS* have new features that bring them closer to *model-based DSS.* The traditional features of *data oriented DSS* were related to *Structured Query Language (SQL)*,[8] while some of the new features, not supported by *SQL,* include new methods and tools for data processing:

OLAP (OnLine Analytical Processing) allows users to quickly analyze information stored in a *DBMS* that has been pre-processed into multidimensional views and hierarchies. For example, *OLAP* tools are used for

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[8] *Structured Query Language (SQL)* is a language used to process data in a relational database, originally developed by IBM for its mainframe computers. Since the SQL ANSI standard was introduced, SQL has been supported by all relational Data Based Management Systems (DBMS); however, most DBMS have some proprietary enhancements which, if used, cause portability problems. SQL can be used to work interactively with a DBMS, but it is typically embedded within a programming language (such as C++ or Java) to interface with the DBMS.

time series and trend analysis on sales of services. Especially when huge amounts of data are involved (as, e.g., in telecommunications), users can drill down into masses of connection statistics in order to determine what are critical services. Basic *OLAP* summarizes transactions into multidimensional views in advance, so that even queries on huge data sets are fast. More advanced *Relational OLAP (ROLAP)* is able to create multidimensional views on the fly. *ROLAP* is especially useful for analyzing data that has a large number of attributes, where the basic *OLAP* is not as efficient. *OLAP* servers are available for all major *DBMS*.

Data mining, also known as *KDD (Knowledge Discovery in Data),* is a collection of methods (from statistical analysis, machine learning, modeling, and *DBMS*) to explore patterns and thus discover relations hidden in a data set. A more strict definition of *KDD* given in (Frawley et al. 1992) reads: *"The nontrivial extraction of implicit, previously unknown, and potentially useful information from data"*. Data mining is popular not only science but also is increasingly utilized by market companies and governmental organizations. Typical examples of using *KDD* for decision support are market analysis and management (e.g., target marketing, market segmentation, customer profiling, pricing strategies), risk analysis (customer retention, forecasting, analysis of competitors), and fraud detection. *KDD* applied to data in a *DBMS* typically uses *OLAP* and a *data warehouse*.[9]

Many decision situations, however, require not only data analysis, but also exploring knowledge about the relations between decisions and their consequences that need to be represented by mathematical models, and problem solving based on mathematical modeling. Diverse modeling paradigms have been intensively developed over the last few decades. In this development, driven to a great extent by different case-studies, a growing tendency is to focus on specific methodologies and tools. As a result, several types of models, characterized by the types of variables used and the types of relations between them, were developed. These include, for example, *static, dynamic, continuous, discrete, deterministic, stochastic, set-membership, fuzzy, soft constraints* etc. types of models; their purpose is to best represent a specific problem by the selected type of model.

Moreover, different methods of model analysis (such as *simulation, optimization, soft simulation, multicriteria model analysis*) have been developed as the best possible support for various types of model analyses for diverse purposes and users. Finally, because of the growing complexity of

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[9] The term *data warehouse* denotes the implementation of a modern informational database with non-erasable, dated records and multidimensional data access, used to store sharable data extracted from an operational database.

various computational tasks, specialized *solvers,* that is, software systems enabling a specific task of model analysis, were developed. Such solvers have become increasingly more specialized, even for what was originally seen as the same type of mathematical programming problem, e.g., linear programming. Thus, *modeling paradigms* developed; each modeling paradigm embodies a great deal of accumulated knowledge, expertise, methodology, and modeling tools specialized for solving various problems of the type peculiar to this paradigm. Such solvers and other modeling resources, however, are fragmented, available in diversified forms on heterogeneous hardware and software. Thus, using more than one paradigm for a problem at hand became too expensive and time-consuming in practice, although it is highly desirable in theory.

Therefore, another developing trend, or rather a challenge faced by the contemporary developers of *model-based DSS,* is to convert the accumulated modeling knowledge and tools – which are now typically provided as closed modeling systems supporting specific modeling paradigms – into new modeling environment that might be called a *Modeling Grid* [10]. The purpose of the grid is to enable the sharing of modeling resources (models, data, and modeling tools) available on and continuously contributed to global information networks.

In order to present the ideas related to this new modeling environment, we recall first some basic concepts of mathematical modeling.[11] A mathematical model describes the modeled problem by means of variables that are abstract representations of those problem elements that must be considered in order to evaluate the consequences of implementing a decision (these elements are usually represented by a vector composed of many variables). More precisely, such a model is typically developed using the following concepts:

- Decisions (inputs) $\boldsymbol{x}$, which are controlled by the user
- External decisions (inputs, perturbations) $\boldsymbol{z}$, which are not controlled by the user
- Outcomes (outputs) $\boldsymbol{y}$, used for measuring the consequences of the implementation of inputs

[10] The term *Modeling Grid* is used here in the analogy of the general concept of *Grid* – of a network environment enabling access to large scientific databases or other computational resources.

[11] Here we stress again that we use the term *mathematical modeling* in its broad sense of computational science, not in the more specific sense of mathematical logic.

- Auxiliary variables introduced for various reasons (e.g., to simplify model specification, or to allow for easier computational tasks)[12]
- Relations between decisions $\boldsymbol{x}$ and z, and outcomes $\boldsymbol{y}$; such relations are typically presented in the form $\boldsymbol{y} = \boldsymbol{F}(\boldsymbol{x}, z)$, where $\boldsymbol{F}(\ldots)$is a vector of functions

The structure of using a model for decision support is illustrated in Figure 7.1. The basic function of a *DSS* is to support the user in finding values for decision variables $\boldsymbol{x}$ that will result in a solution of the decision problem that best fits his/her preferences $P(\boldsymbol{x}, \boldsymbol{y})$. In order to achieve this one needs to:

- *Develop and maintain a model* that adequately represents the decision situation
- *Organize a model analysis process,* in which the user can (directly or indirectly) specify and modify preferences upon combining his/her own experience and intuition with learning about the decision problem from analyses of various model solutions.

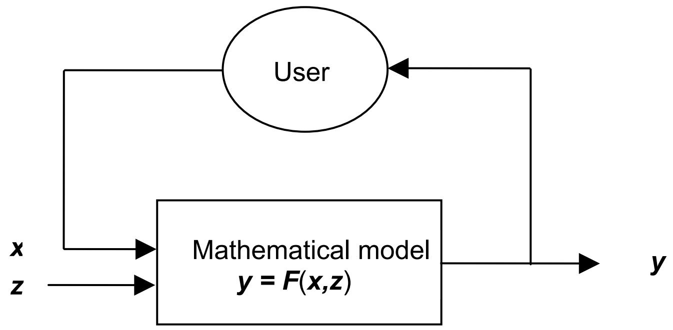

Fig. 7.1. Basic structure of using models for decision support

The development and maintenance of models used for actual decision support must meet diverse strong requirements, such as credibility, transparency, reproducibility of results, ease of integrated model analysis, controllability (by modifying model specifications and data, obtaining diverse views on results, performing an interactive analysis of results), quality assurance, adequate documentation. For applications that involve model de-

[12] Such variables typically constitute a large part of all variables (often a vast majority), but for the sake of brevity we do not discuss them in detail here.

velopers and users working at distant locations, the modeling process also requires a controllable sharing of modeling resources through the Internet. Finally, for models that need large computational resources, an efficient use of computational distributed resources –a *computational Grid* – is also demanded.

A typical model for supporting decision-making often has an infinite number of solutions, but users are interested in analyzing trade-offs between a manageable number of solutions that correspond to diverse representations of their preferences, sometimes called *preferential structures*.[13] Thus, an appropriate integrated analysis should help users to find and analyze a small subset of all solutions that correspond best to their preferential structures, which typically change during the model analysis. For a truly integrated problem analysis one should actually combine different methods of model analysis, such as:

- classical (deterministic) optimization (and its generalizations, including parametric optimization, sensitivity analysis, fuzzy techniques)
- multicriteria model analysis
- stochastic optimization and Monte Carlo simulations
- classical simulation, soft simulation, and several of its generalizations (e.g. inverse simulation, softly constrained simulation)

However, although there are many modeling tools developed and available either as commercial or as *open source* software, they typically support only one, occasionally two such model analysis methods. Currently, no modeling tool supports a complete analysis including all the above methods, and development of separate versions of a model, with tools supporting different modeling paradigms, is typically too expensive. Thus, in most cases model analysis is limited to the use of one or two methods.

A more detailed discussion on model-based decision support, and on modeling methods and tools for *DS* can be found in (Wierzbicki et al. 2000). A special approach called *Structured Modeling Technology* was developed, applicable to collaborative modeling activities of complex problems (Makowski 2005). An overview of modeling paradigms for *DS*, including also a more detailed discussion of the various methods of model analysis, is presented in (Makowski et al. 2003).

Because of the variety of both decision problems and the habitual domains of decision makers, see (Yu 1990), one general method of model-based decision support will never be sufficient. In fact, no single modeling

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[13] User preferences and preferential structures typically change during model analysis, which is yet another argument for an interactive approach to decision support.

paradigm alone is good enough to identify and analyze the diverse policy options that are necessary for making rational decisions in the case of a complex decision problem. Rather, an integration of various modeling methods and tools is needed to provide the best available support for analyzing complex problems.

Lessons learned from applying various modeling paradigms to very diverse types of real-world problems, and the recent abundance of computing hardware and software tools, makes it possible to integrate several methods of a model specification and analysis, and to apply them to large and complex problems. Such an integration calls for a collaboration of specialists who have substantial experience with a particular method. Therefore, one should expect that various integrations of different modeling paradigms will be used more broadly to improve decision-making support in a wide range of practical problems. However, the key role in actual decision making will stay with human decision makers.

7.5 The Difference and Similarities Between Decision Support and Creativity Support

The theory of decision making is more specific than knowledge creation theory; although decision making is already a very broad concept, knowledge creation is even broader one. But there are essential similarities. In both decision making and knowledge creation, we use *structural process models*, specifying distinct stages and transitions. Although distinctly organized as spirals in the case of creative processes, they have also recursive properties as in the case of decision processes. These models can be used to structure computerized decisions or support creativity.

There are also, however, some essential differences:

Some of models of decision processes, particularly the more classical, concentrate only on the rational aspects of decision making. Models of creativity processes, on the other hand, include distinct phases or transitions of an *a-rational* character, *intuitive, emotional, tacit.* These phases and transitions cannot be supported directly in computerized environments, but support of other transitions can take them into account and thus indirectly support a-rational phases or transitions.

This is especially important when supporting phases of group activities, such as *Debate*, or *Brainstorming*; another case is *Socialization,* a fully a-rational group activity that cannot be directly supported by computer technology. *Debate,* which is fully rational, at least in its initial phase – though *Immersion and Double Debate* (see Chapter 3) also have distinct a-rational elements – can be well supported by computer technology and several systems have already been developed for this purpose. *Brainstorming* (see Chapter 4) is a transition from a-rational to rational; although well developed computer systems to support diversified brainstorming processes do exist, they do not adequately take into account the possibility of indirectly supporting the a-rational aspects of this transition.

Finally, there is an essential similarity concerning the role of *the user* - human decision maker or knowing subject:

> *Principle of User Sovereignty:* in both decision support and creativity support, the user must have a fully *sovereign position*. Computer systems must not be able to make final decisions.[14]

While early decision support systems (based on decision automation) often violated this *principle of sovereignty,* and there is a clearly visible trend of violating this principle in general purpose software development (creators of such software often erroneously assume that computer intelligence means freeing the user from making autonomous decisions), creativity support systems will be successful only if they consistently follow this principle. Spontaneous computer intelligence might be very valuable in creativity support, but only as source of suggestions for a choice clearly made by the human user, not as tacit suggestions that it is hoped will be accepted by the user because of sheer inertia.

There is no doubt, however, that the experiences and accomplishments of computerized decision support can and should be utilized for the construction of creativity support software. First examples of such software already exist, such as supporting mind-mapping (graphically presenting structural relations between diverse issues and ideas) or organizing and supporting brainstorming. Much broader software is possible and needed, but the desired expansion requires much more effort both in research and in software development.

[14] This includes also hidden decision-making, by restricting the feasibility set, or hiding some options, etc.

7.6 Key Objects for Creativity Support

The discussions of the concept of *Creative Space* as well as other discussions from earlier chapters indicate that the field of creativity support might be as broad as decision support. Each possible transition between the nodes of *Creative Space* – recall that in Chapter 4 we identified a possible 3^{10} = 59,049 nodes and thus 3,486,725,352 possible transitions – might deserve special support; however, this tells us only that knowledge creation processes are extremely diversified and rich. How should we then choose what creativity support should be designed first?

One way, resulting from the experiences of decision support, would be to develop any creative support mechanism only after its functionality is specified with the help of consultations with future users – the group of knowledge workers who will actually use the creativity support system. Certainly the best way to proceed today would be to develop creativity support systems in the same way as decision support systems, by consulting and fully informing future users about their capabilities. Until creativity support will be more developed, however, we must use also other ways.

A second way is to define selected creativity processes, such as *brainstorming* or *road-mapping* and develop full software packages to support them – see e.g., (Kunifuji 2004), (Ma et al. 2004). We face, however, several dangers on this path. The first might be to lock attention on a specific creativity theory or process dear to the software developer – and we have seen in the earlier chapters that there are many types of creativity processes. The second danger, related to the first, is to miss advantages of diverse conclusions resulting from the analysis of competitive theories and processes. The third danger is known as *toolism:* we run around with a hammer in our hand, looking for a place to apply it, while a scissors might be a better tool for a particular task. Thus, if we follow this way, at least two conditions must be met. One is to select a definite application case together with a specific group of future users and involve them in the specification of requirements for the creativity support system. Another is to discuss competitive theories and methods that we might apply – in an *informed objective* way, as discussed in Chapter 6, and also involving future users.

A third way is composed of several stages:

1) concentrate first on the variety of types of knowledge creation processes,

2) select the type of knowledge creation we would like to support,

3) analyze possible creativity processes for this type of knowledge creation,

4) select creative transitions that are judged most important for these processes,

5) finally, develop creativity support.

If we follow this sequence, it is also important to concentrate on a group of future users and involve them in all selections and specifications along the way; but we motivate them to be better informed about competitive theories and related choices. Thus, we shall describe this third way (at least, its first four stages) in more detail.

The first step is to decide which general type of creative process we should support, using, say, the tree represented in Fig. 7.2 (although all these processes can be represented in *Creative Space,* for the purpose of selection it is better to use a logical tree).

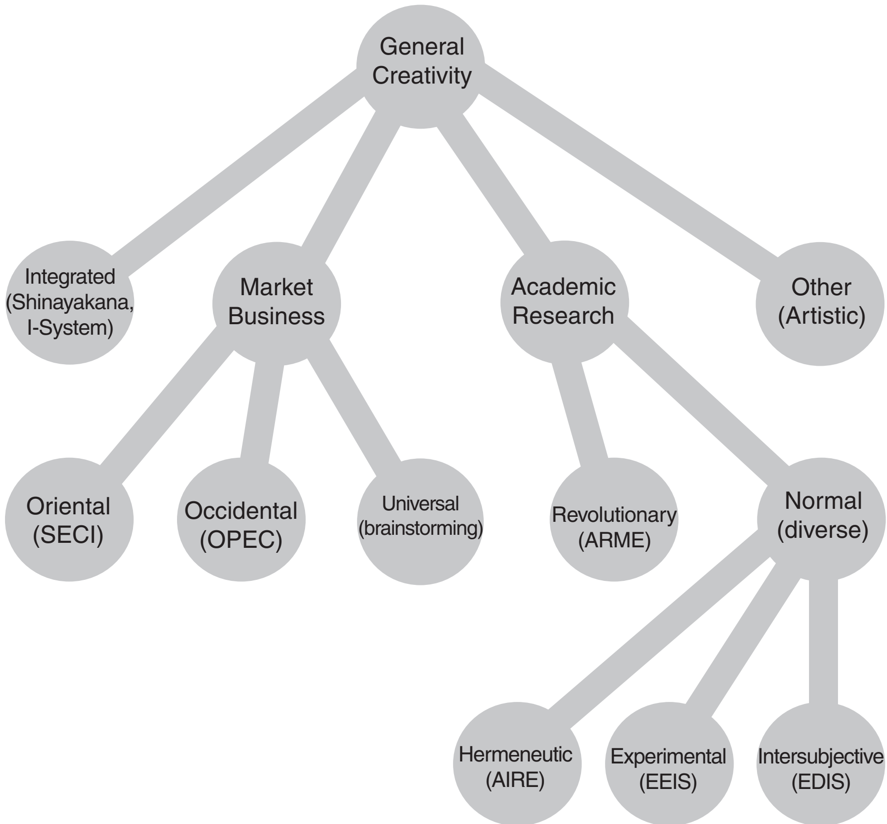

Fig. 7.2. Tree of types of creative processes

Let us suppose that we are interested in supporting academic research in its normal type.[15] Than the next choice would be which partial creative process we want to support in particular – hermeneutic, as represented e.g. by the *EAIR Spiral,* or experimental, as represented by the *EEIS Spiral,* or intersubjective, as represented by the *EDIS Spiral*. For example, a materials science laboratory might be most interested in supporting the transitions of the *EEIS Spiral;* or, just the opposite, might feel that experimental aspects of knowledge creation are well mastered by the laboratory, but they might need support in hermeneutic reflection, in the *EAIR Spiral.* A typical answer, however, particularly if future users are asked such a question directly, might be *all,* or *we do not know.* Moreover, there are several parts of each creative process, transitions between the nodes of creative space involved with each choice.

In Chapter 4, we represented the triple spiral of normal academic knowledge creation as a *triple helix,* stressing its open and recursive character. However, for the purpose of selecting transitions to be supported, it is good to represent all three spirals of normal academic research on one plane, see Fig. 7.3. Then we can discuss the meanings of all transitions with the future users of the creativity support system and ask them for help in selection. We shall briefly comment on possible importance of subsequent spirals and transitions.

The most personal creative process, which is usually individual, is the hermeneutic *EAIR Spiral.* Its basic rational transition, *Analysis,* indicates normal research on sources of knowledge: searching the intellectual heritage of humanity for information and knowledge relevant for our work, in libraries, through the Internet, at scientific conferences, etc. However, *Analysis* is not restricted to such a search; it also means rationally organizing the results of such explorations, comparing different sources of knowledge, looking for particularly interesting points, etc. The development of computerized support of creativity is rightly concentrated precisely on supporting this transition, by a wide variety of methods. One example consists of methods of finding knowledge relevant for a given object of study in resources available on the Web; another includes methods for using increasingly frequent electronic access to classical scientific libraries. There are many other possibilities for supporting this transition.

The *EAIR Spiral's* next transition, *Hermeneutic Immersion,* aims at integrating the results of *Analysis* with all our experience and knowledge of

[15] The term *normal* we use here in the Kuhnian sense of *normal development of science*. The term *academic* includes here not only universities, but also other research institutions and even industrial laboratories in their *normal* research.

the subject, with the tradition of the discipline immersed into our deep memory, into unconsciousness and intuition.

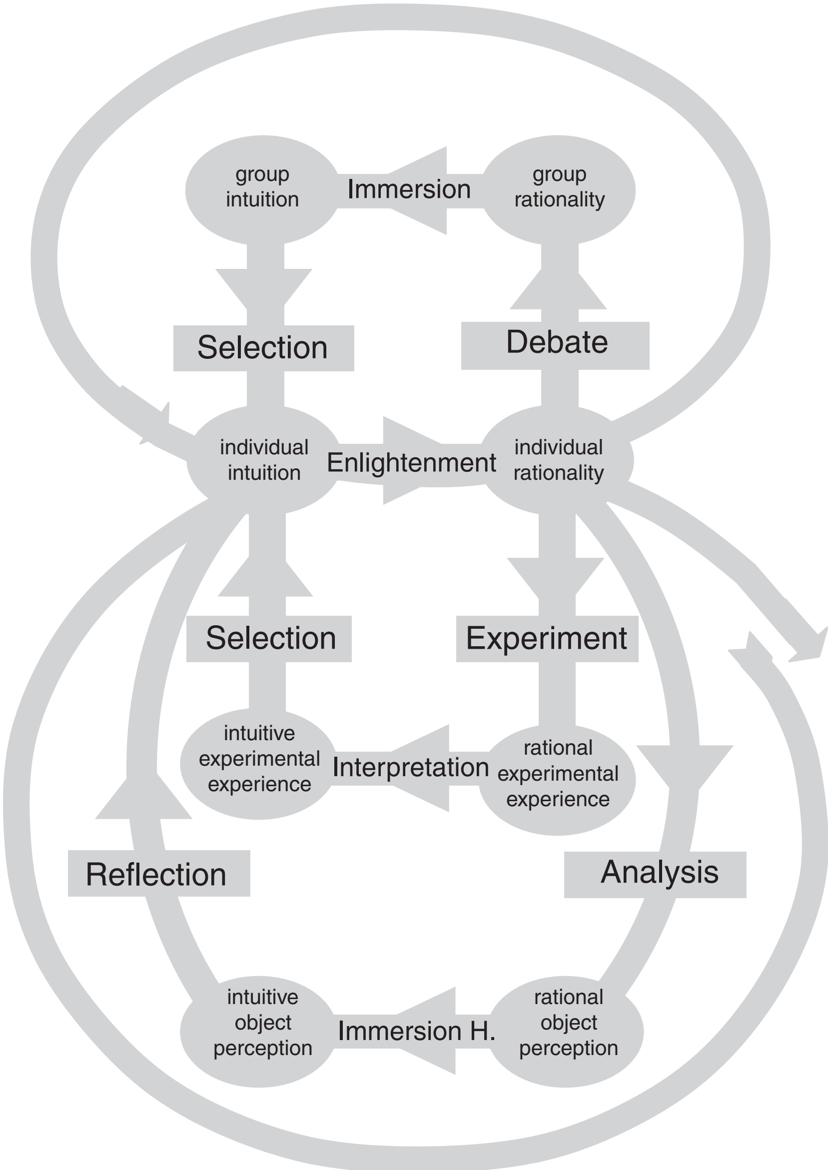

Fig. 7.3. The *Triple Helix* projected: the *EAIR-EDIS-EEIS Triple Spiral*

As discussed in Chapter 4, this immersion can be of two types: *Critical* (which means being critical about the object of study) or *Integrated* (which means trying to empathize with the object of study, e.g. imagining ourselves being a car if we are studying cars). This immersion requires some time to reach into our unconscious intuition, but is necessary to prepare a deep *Reflection,* enriching individual intuition and leading to *Enlightenment* – creating new ideas about the object of study. There is a danger in becoming *Integrated* too much*;* though it helps to achieve an empathic reflection, it might hinder criticism.

Therefore, some methodological advice – coming, for example, from the methodology of historical studies – is to switch between *Integrated* and *Critical,* in order to achieve a truly deep *Reflection.* The quality of *Reflection* in shown in the quality of ideas generated in the *Enlightenment* phase. These transitions illustrate our earlier comments about partly or fully a-rational transitions and the difficulty of their computerized support: how to support *Hermeneutic Immersion* or *Reflection?*

The answer is – not directly, but by designing support for the *Analysis* transition that takes subsequent transitions into account and makes the transition process easier. For example: the computerized support for *Analysis* should have as much *interactivity* as desired for expressing those aspects of *Analysis* that the user intuitively feels are important for *Hermeneutic Immersion* or *Reflection.*

The hermeneutic *EAIR Spiral* is typical for research in arts and humanities, in these cases, even more important than the intersubjective *EDIS Spiral*. However, as we have stressed in various parts of this book, creating technology is essentially an art; thus, it is very useful to adopt *EAIR Spiral* for technology creation. In this case, naturally, it should be used to augment the experimental *EEIS Spiral* and the intersubjective *EDIS Spiral.*

The experimental *EEIS Spiral* is a typical process for hard sciences and technology development, although sometimes it is also used in experimentally oriented social sciences.[16] After having an idea as a result of the *Enlightenment* phase, the researcher wants to test it experimentally. This is done in the phase *Experiment,* but is not necessarily a simple issue. Most experiments are individual, but some require group support; even if the experiment is individual, it requires good *experiment design.* There are quite advanced statistical theories of experiment design, see, e.g., (Tsubaki 2005), which can be used to support experimental creativity. In fact, sup-

[16] In social sciences it is rather difficult to perform fully *active experiments,* as are typical for hard sciences and technology; *passive experiments* involve gathering statistical data, while the typical technique of experimental sociology – using a questionnaire – is also *passive* on the border towards *active.*

porting experimental design might be one of most effective ways to support creativity in experimental work. However, there are also other aspects of experiments that can be supported; a very important one is the possibility of preparing *actual experiments* with help of *virtual experiments,* computer simulations that might help to limit the need for multiple experiments to a few crucial ones. Each discipline of hard science and technology has already assembled many computerized models of diverse aspects that include huge amounts of data, and encode in analytical form various relations discovered in the discipline. Hence a great challenge for future creativity support is using these modeling resources for building *virtual laboratories* capable of supporting diversified virtual experiments.

After an experiment, the researcher evaluates and interprets the experimental results. There are many possibilities for ways to support this *Interpretation* phase; the most standard ones are statistical techniques of regression and factor analysis, accompanied by various techniques for the graphic representation of results. But it must be remembered that *Interpretation* is a partly a-rational transition, hence these techniques play an important, but only a supportive role. Finally, *Selection* is a deeply individual, intuitive and fully a-rational process of choosing such aspects of interpreted experimental results that serve best as the basis of a new *Enlightenment* phase, generating new ideas.

The intersubjective *EDIS Spiral* can be used in any field of knowledge creation – in arts and humanities, in social sciences, in hard sciences and technology – being the basic way of verifying newly created knowledge through *Debate* inside a group. The use of this spiral depends very much on the traditions of the group and of the scientific discipline: some prefer to have a *Debate* in the very early stages of research, others fear presenting an idea before it is fully tested either in a hermeneutic or experimental way. From the point of view of stimulating creativity, *Debate* is useful at every stage of research – in the beginning, in the middle, but certainly also at the end. The principle is the same in all stages: it is the responsibility of the group, in the best old university tradition, to give a good, critical but also emphatic, *Debate* to any of its members presenting new ideas for intersubjective verification; see Chapter 3 for the description of various aspects of a good *Debate.* However, the *EDIS Spiral* stresses also some novel aspects, related to the *Rational Theory of Intuition:* it suggests organizing a second part of the *Debate* after the participants have achieved *Immersion* of the results of the first one into their intuition, which constitutes the *Principle of Double Debate.* Again, *Selection* is the deeply individual, intuitive process of choosing those aspects – this time of conclusions from the *Debate* and possibly from *Double Debate* – that will best help in developing new ideas in the repeated *Enlightenment* phase.

The fundamental transition for all individual spirals in the *Triple Spiral* is *Enlightenment.* It is called alternatively *illumination, aha, eureka,* but denotes generating an idea (bigger or smaller) from unconscious, intuitive knowledge. This transition can be supported by *Reflection* in the *EAIR Spiral, Debate* in the *EDIS Spiral, Experiment* in the *EEIS Spiral,* etc. It has an intrinsic individual character, though it can be also supported by diverse group processes, such as *Debate* or *brainstorming*.

However, the essential point is that unconscious intuition requires time for preparation of new ideas, for *gestation of the idea,* which can be stimulated by *forgetting the problem, sleeping with the problem, emptying your conscious mind, forgetting the prejudices of an expert.* Thus, any creativity support technique should take support for gestation into account, but can actually support it only indirectly. There are two types of such support: one is simply including relaxation (e.g. *going to a tea ceremony*) into plans for the creative process, as in roadmapping; another is indirectly supporting - by the correct organization of the creative processes - the phases or transitions that precede *Enlightenment* and help in gestation. These are the transitions of *Immersion* and *Selection* in the *EDIS Spiral,* the transitions of *Interpretation* and *Selection* in the *EEIS Spiral,* and the transitions of *Hermeneutic Immersion* and *Reflection* in the *EAIR Spiral.*

But such indirect support of gestation might be different in different processes. In the *EDIS Spiral,* it means simply repeating the presentation and debate after some time, according to the *Principle of Double Debate:* giving enough time for the gestation of ideas triggered by the first debate, but not so long that the subject is entirely forgotten, and then organizing the second debate. In the *EEIS Spiral*, it means making breaks between subsequent experiments; sometimes they follow naturally from the need to set up new experiments. In the *EAIR Spiral*, which is the most personal of the normal knowledge creation spirals, it means creating conditions for good *Hermeneutic Immersion* – relaxation after individual studies of scientific literature, after searches in the human rational intellectual heritage, letting your unconscious work before starting essential, intuitive *Reflection.*

After such an analysis of the *Triple EAIR-EDIS-EEIS Spiral* of normal academic knowledge creation, performed together with the future users of creativity support system, we assume that they are sufficiently informed about possible choices. But then, how should we decide which parts of it, which transitions to concentrate on in developing a creativity support system? A natural answer is: by constructing an appropriate questionnaire – or a sequence of questionnaires – and evaluating the answers of future users of the system. Such questionnaires should concentrate on selected main topics, e.g. *Analysis* and *Reflection; Experiment; Debate; Enlightenment;* and *Research Planning.* Such topics indicate the issues to be surveyed, while the answers should indicate those topics upon which future creativity support should be concentrated. First after such clarification of assumed functionality of the future creativity support, the actual work on developing the computerized support system might start. Before we comment, however, on existing and needed work related to this development, we must first discuss the concept of *Creative Environment* in more detail.

7.7 The Concept of Creative Environment

The original concept of *Ba* as a creative environment has a more holistic character than simply computerized creativity support. *Ba* means *place* in Japanese, but is used also metaphorically, starting with (Nishida 1970); in the context of enabling creativity it was suggested by (Von Krough, Ichijo and Nonaka 2000) to denote all conditions required for knowledge creation. *Ba* can be understood as a place and space in which knowledge is shared, created and used, including *physical* space (offices, buildings), *virtual* space (computer network services), and *mental* space (experiences, ideas, emotions).

When we understand *Ba* in this sense, the closest meaning of an English word is *environment,* thus *Ba* can be understood equivalently as *Creative Environment,* just as *AmI* means (at least in Europe) *Ambient Intelligence,* hence *Intelligent Environment.* However, being computer technologists and system scientists, we add here two essential meanings to the concept of *Creative Environment:* the *informational* meaning, in the sense of *informational technologies* explained in Chapters 5 and 6, and the *social* meaning, in the sense of the conclusions of discussions presented in Chapter 6.

While (Von Krough, Ichijo and Nonaka 2000) stress the *virtual* meaning of Ba, they mean by this only the use of existing computer network services for enabling creativity; by stressing *informational* aspects of *Ba* or *Creative Environments,* we concentrate on the *informational technology* (telecommunications, computer science and other related fields) understanding of the word *environment.* In these technological fields, environment means the context in which information technology is developed: the set of protocols, the operating system, the standard languages used. Thus, *Creative Environment* should include all contexts, not only those that enable, but also those that support creativity – in particular, software systems developed precisely for the purpose of supporting creativity. By stressing the *social* aspects of *Creative Environments,* we use the constructive part of the critique coming from *soft systems thinking* – not the erroneous, ideological *anti-hard* attitude, but the correct conviction that formal models cannot express all aspects of human behavior. Thus, *Creative Environments* must also support human interactions – with fellow humans and with informational environments – and be based on a sufficiently deep understanding of complex human nature, thus, among other things, on diversified methodological approaches (or "methodologies" in soft systems thinking).

We thus agree that *Creative Environment* should include all aspects of *Ba: physical*, *virtual*, *mental,* but this is not enough. As we begin the new era of knowledge civilization, *informational* aspects represent the need to be *informed* about the potential of mobilizing modern informational technology for creativity support, and *social* aspects represent need to be *informed* about the complexity of human nature.

Thus, *Creative Environment* has a broad and complex meaning. While we can understand any computerized decision support or even creativity support system as a part of a *Creative Environment,* the broader meaning of this concept includes all creative working environments, in both scientific institutions (such as universities) and business organizations (not only large companies; dedicated software for a *Creative Environment* can be developed for modern small enterprises as well).

7.8 Existing and Needed Creative Environments

Computerized support for creative activities is not new; it started to be developed along with the proliferation of personal computers. An obvious example is the support of the creative activity we all engage in when we write, in this book called the creative transition named *Publication.* The support for this transition was developed by a number of *word processors,* such as MSWord, *text and formulae processing languages,* such as T_EX and related software, and *publishing software,* including *computer graphics* providing diversified computerized support for preparing various types of publications such as books and journals. Because writing is a very broadly used creative activity, the market for writing and publishing support software is enormous; software products in this market are highly developed (although obviously they can be further improved, particularly with respect to the *Principle of User Sovereignty*).

Another obvious example is architectural creativity, a creative activity that requires quite advanced technical support and computer graphics; these needs were addressed quite long ago by the CAD-type software[17]. Applications of computerized support for other artistic creative activities, e.g., related to the *Composition* transition are less frequent, but they have also been seriously studied, see, e.g., (Candy 2004), (Edmonds 2004). In computer science, the contemporary trend toward *human-oriented* information technology resulted in the goal to develop computerized tools that will facilitate the co-evolution of human and knowledge networks in a community, see (Nishida 2000).

However, the support for other types of activities in creative processes is rather limited; the reason might be previous lack of reflection on the types of such processes. There have been some attempts to support creative processes in group decision making or *groupware;* some developments in groupware related to *mind-mapping* (such as Mind-Manager software) or to *SSM* (Soft Systems Methodology) can also be used for creativity support. The creativity support for *brainstorming*, see (Kunifuji 2004), developed partly from this motivation.

Thus, there is an emerging field of developing creativity support software. Any creative transition discussed in this book (and we know that the potential number of them is enormous, even if we listed only a few dozens) might require its own type of creativity support. We can thus enumerate here only a few general types of creativity support software that might be developed more intensively.

1) Web Knowledge Acquisition

Data mining and *knowledge discovery* techniques continue to be intensively developed today, also in relation to the justified expectation that they might be used in future for creativity support – see (Granat 2004), (Ho 2004), (Traczyk 2004). However, here we need a clear concentration of efforts on the requirements that result from some new ideas presented in this book, on the issue of *how to support the hermeneutic EAIR spiral of normal knowledge creation in academia, in particular the Analysis transition.* For this purpose, we should imagine ourselves in the place of a typical researcher who has a research topic, some ideas about it, some keywords, and starts to prepare an *Analysis* of the object of study – that is, to search for all relevant literature in humanity's rational heritage (or even in humanity's emotive heritage, if the subject of study is arts and literature).

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[17] Computer Aided Design

The researcher can use many search engines on the Web; but none of the existing engines is specifically adapted to the task of such an activity – which would mean not only taking into account keywords and entire phrases, but also a semantic description of the contexts. Moreover, a modern researcher would greatly profit from a combination of search engines with support for making notes, bibliographic lists, combining results in *mind-maps,* etc. Such a capability would also indirectly support, either partly or fully, a-rational transitions such as *Hermeneutic Immersion* or *Reflection.* Thus, much has yet to be done in order to develop adequate support for the transition *Analysis.*

2) Debating

There are a number of *groupware* and *brainstorming* products that include support for discussions; there is also elementary discussion support software, starting with electronic *chats* and other simple communication software. However, none of them is designed to specifically support the transition of *Debate* in the *intersubjective EDIS Spiral* of normal academic knowledge creation. Since the theory of debating is well developed (see comments in Chapter 3), the development of special software that supports debate is possible (as illustrated by the dedicated hardware and software for video-conferencing), but also including face-to-face discussions, with diverse modern features (such as electronic boards for documenting presentations and discussions, thus supporting future reflection and the *Immersion* transition, possibly also the *Double Debate*).

3) Experiment Design and Support

Note that classical statistics concentrated mostly on analyzing collected data, coming in a sense from *passive experiments*, less on actively designing experiments or helping in the analysis of data from *active experiments.* Nevertheless, the design of experiments is an old subject of mathematical statistics, related also to industrial quality control – see, e.g., (Tsubaki 2005), (Fang 2005). This knowledge, however, can also be used to develop support for creative activities in the *experimental EEIS Spiral* of normal academic knowledge creation. Such a creative environment should include support for both individual and group experiments by incorporating diverse contemporary statistical tools – factor analysis, linear and nonlinear regression, time series analysis, etc., tailored specifically for the support of *active experiments.*

4) Virtual Laboratories

Experimental statistics and experiment design constitute only a part – though a very important part – of the possible functions to support the *EEIS Spiral.* Another part relates to *virtual laboratories:* actual, *material experiments* might be greatly shortened if they are not only well planned, but also adequately prepared by conducting earlier *virtual experiments.* Such computerized simulations of actual experiments require good mathematical models of the relevant features of the object of research, but today any discipline (at least, in the hard sciences and technology) already has a large variety of computerized, mathematical models, as discussed earlier in this chapter. Constructing specific virtual laboratories might still be a difficult challenge, but we are convinced that they will be more broadly used in near future. Yet another part of the possible functions to support the *EEIS Spiral* is taking into account partly or fully a-rational transitions (*Interpretation, Selection*) in this spiral and such design of the creativity support software that it will indirectly enable also those a-rational transitions.

5) Road-mapping

Beside planning the analysis of the object of study or designing experiments**,** planning the entire creative activity *(creative project)* might be even more important task, critical for achieving its success. In market oriented organizations, planning a new project is typically supported by *road-mapping,* a special methodological approach that starts with the Gantt-chart planning of the timing, resources, and mutual dependencies of separate activities, proceeds to the definition of critical points or elements of the project, to the allocation of time and other resources to project parts, to the discussion of critical conditions of success, etc. A similar approach can be applied in academia for planning creative activities; however, it must be based on a sufficiently deep understanding of knowledge creation processes, that is, take into account typical parts of such processes when planning consecutive activities. It has to take also into account the fact that planning time and resources for creative activities cannot be done with an accuracy typical for industrial applications. Moreover, it would not be sufficient to list all transitions of the *Triple Helix,* put them in a time frame and in a Gantt chart and use this for road-mapping of knowledge creation; such an approach might be a good starting point, but any actual application will need a debate with future users, with actual knowledge creators in the project, regarding what parts and functions of a road-map *they* consider most important and useful.

6) Brainstorming

As already indicated, brainstorming is possibly the most developed part of creativity support (except, naturally, support for *Publication* and *Composition*), see (Kunifuji 2004). However, much further development is possible. First, in the wide literature related to brainstorming it is stressed that both individual and group brainstorming processes are possible; some psychologists even doubt whether group brainstorming is actually more effective than individual, though there are obvious effects of complementarity and synergy in group creative processes. In any case, brainstorming support software should provide both for an individual and for a group option. Secondly, contemporary brainstorming support software do not adequately account for the fact that some transitions in a creative brainstorming process, as described by the *DCCV Spiral* (see Chapter 4), are either partly or fully a-rational; hence, even if it is difficult to support them directly, their indirect support should be taken into account, at least in the organization of entire process. For example, since *Divergence* transition is essentially intuitive, it might gain in quality if ample time for gestation of new ideas is given; it might be useful to generalize the *Principle of Double Debate* to also include *Double Divergence,* give the group adequate time for relaxation after the first round of generating ideas, then organize a second round.

7) Gaming

Gaming supported by virtual reality has had a large market success in entertainment; there also are considerable applications of gaming in teaching,[18] in particular those supported by models of the economic context of the game, see, e.g., (Ryoke 2004). There is also the possibility of a closer connection between gaming and mathematical game theory, see (Wierzbicki 2004). Since gaming is essentially an exercise in imagination, it should be also used to support creativity; but this idea has not yet been pursued further and finding innovative ways to use gaming as a tool for creativity support remains a great challenge to be addressed.

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[18] The usefulness of gaming was actually proven almost 200 years ago, first in military applications, then also in management and business.

8) Distance Learning and Teaching

Although learning and teaching is usually treated separately from knowledge creation, we should stress here that innovative learning and teaching also requires creativity. In Chapter 5 we postulated basic educational reform, involving the use of computer networks and electronic distance teaching forms to support education in developing countries. However, electronic distance learning materials have been developed, until now, on case-to-case basis, and no standardized *environment* for creating such materials is available. Thus we need the development of a *Creative Environment for Distance Learning and Teaching Materials*, well supported by software tools for creating such materials, but also by a methodological approach to learning and teaching that utilizes the special advantages of electronic learning materials, including multimedia support for the relevant combinations of text, sound, graphics and movies. It will be necessary to construct sufficiently fine-grained materials with the sufficiently easy capability to customize needed teaching content, with adequate tests and exercises, even with virtual laboratory experiments whenever needed and possible. This is again a great challenge, but meeting this challenge is necessary for implementing the necessary reform of education.

We see that many of the needed *Creative Environments* indicate also big challenges for future developments.

7.9 Concluding Comments

The basic conclusions concerning computerized *Creative Environments* are consistent with the experiences from applying computerized decision support: such environments cannot be developed in the abstract, but must involve future users in a careful and deep debate of their essential needs and requirements. The functionality of such environments must be specified with the help of and after consultation with the group of knowledge workers who will actually use the creativity support system. This should not be, however, a one-way communication: before specifying the functionality, the future users must be well informed about the possibilities of this new type of software systems.

Thus, we tried to outline here the possibilities of the development of *Creative Environments* going beyond the already rapid development of computer graphics for artistic or architectural creativity and including diverse activities and processes of knowledge and technology creation, such as knowledge acquisition, debating, experiment design and support, virtual laboratories, roadmapping, brainstorming, gaming, distance learning and teaching.

> A general conclusion is that the research on and the development of *Creative Environments* is a major challenge; this challenge, however, is also an obligation, must be addressed as the knowledge civilization develops.

In order to respond to this challenge and obligation, we intend to write a separate book on *Creative Environments.*