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THE ART AND SCIENCE OF PROBLEM SOLVING

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Study the science of art
and the art of science.
- Leonardo da Vinci

1. Introduction

In our educational institutions and in our culture in general, there is a split between art and science. It is believed that these two ways of working and thinking, the artistic attitude and the scientific attitude are two very different worlds, they are like oil and water. Although the link between art and science has historically been very close, exemplified by Leonardo da Vinci, the ideal that Leonardo represents is really not agreed upon by the art and science communities. It is the opinion of the author of this paper that this distinction between and separation of art and science is artificial and increasingly anachronistic. Fortunately things are changing; new fields arise from the synthesis of other fields. For instance, scientists are relaying more and more on visual communication, and artists are working increasingly with computers. There is a common place to transfer information, ideas and knowledge. Visual problems are ultimately the same across disciplines.

The main purpose of this note is to reflect, elaborate and document about how the concept of "the art and science of problem solving" can be used in the real world to deal with important and complex problematic situations in Society. Here, the OR worker is both the artist and scientist supporting a group to deal with a mess. As a scientist, he will be using when needed scientific approaches, experimentation, simulation, mathematical modelling and soft approaches in the problem solving process. As an artist, he will metaphorically speaking be like a painter who combines colours and shapes (the participants in the process) to create an art work (the problem solving process). Or, he is the director of a theatre group performing a piece of art. For the sake of concreteness let us first discuss a real-life case study.

2. Case Study: Planning of High School Examinations in Denmark

This is a real-life and large scale logistic problem where a computer based support system has been developed and implemented. The system has been running at the Danish Ministry of Education since 1992.

2.1 Background

In Denmark, all planning of the official examinations at high school level is centralized at the Danish Ministry of Education. Denmark is the only country where such planning activities are centralised nationally. This cumbersome task had become increasingly difficult and time consuming due to educational reforms in 1998.

The Danish academic school system is divided into primary school (grade 1 through 9/10), high school (grade 10/11 through 12) and university/college, where primary school is the only compulsory school. High school, in the broad sense, has several channels, the academics as opposed to the technical or commercial high schools being the most attended ones. Approximately one half of all primary school graduates continue onto an academic high school.

The academic high school system has two major channels: The Gymnasium which is a 2 or 3 years package, 3 years being the most common, and higher preparatory school (HF), a two years package Through a system of merits, it is also possible to obtain an equivalent qualification through individual study-plans over several years (VUC). Denmark has 77 Gymnasiums, 25 HF-schools, 77 VUC-schools and 69 schools with both Gymnasium and HF curricula. This amounts to approximately 115,000 students and 12,000 teachers.

The students of the Gymnasium and HF are evaluated at the end of each school year. This evaluation includes oral and written examinations in certain courses. The planning of written examinations is much simpler since the days of examination are given before the start of the school year. This is necessary since all students answer the same examination questions and obviously they must do this at the same time. In what follows *examination* means oral examination. A *censor* is an eligible and ministerial appointed person - usually a high school teacher from another school – and an *examiner* is the person who conducts the examination – usually the teacher of the course.

An examination is carried out in the following way: A censor arrives at the school to observe the examination of each student conducted by the examiner for a fixed amount of time. After each student examination, the censor and the examiner agree on a grade for the student and then continue with the next student on the course, if any.

To encourage students to exhibit "good student behaviour", i.e. not miss classes, deliver term papers on time, etc., a bonus is granted in terms of a reduced number of examinations. Almost 95 percent of all students achieve this bonus. While a final year student could be examined in 7 subjects, "good students" will only have to attend 3 or 4 examinations. The decision of which 3 or 4 subjects the student is to be examined in is drawn in private for each student and is not revealed until the last school day. Consequently, the student must prepare himself for all 7 subjects during the regular school year.

The examinations are gathered in a reserved 5 week period at the end of the school year from mid May to mid June. The Gymnasium only uses the last 3 weeks, except for final year students who also use the second week. First year HF-students use the last 4 weeks and VU-students and final year HF-students use all 5 weeks. Except for national holidays (which have a maximum of three whole days), the examination are placed Monday-Friday.

Previously, the examination planning was carried out by examination planners at the Ministry of Education using pencil and, especially eraser. Data was reported from each school on paper and sent by snail mail. In 1990, it was decided at the Ministry to develop an information system containing all relevant school data. The basic system is now an Oracle database with applications developed using Oracle tools and C-programming. Different systems are attached to the database, the examination system being the largest and most complex. A communication system handles the input of new data which is submitted from the schools to the ministry on floppy disks.

2.2 The problem and the approach

Summarizing, we can state that the task is to design and implement a computer based decision support system to plan and schedule the annual oral examinations for secondary education in the whole Denmark. For each student, it has to be decided:

- The number of oral examinations
- The subjects to be examined on
- The day, hour and room number for the examination
- The examinator, and
- The censor.

In practice, there are two main interrelated factors that determine the process of the solution of the above mentioned problem. The *technical approach*, i.e. the suitability of the techniques, methods, software, procedures, and so on, included in the whole decision support system, and the suitability of the *social process* related to the problem solving process itself. In Hansen and Vidal (1995), the technical approach has been described. The second factor demands close interaction and collaboration between the group work, decision makers, experts, consultants and facilitators. In this paper, we will primarily be focusing on the social processes though some aspect of the first factor will be shortly mentioned.

The planning problem described above is a complex and quite difficult combinatorial problem. It contains many decision variables; it has a variety of criteria and many feasible and satisfying solutions. We shall now elaborate on these observations.

Real life planning situations are usually complex. The examination planner has to comply with national laws and customs and must assist schools with their specific problems, making the examination period as smooth as possible. Obviously, a computer system should support him in this task, rather than introduce additional limitations.

The examination timetabling problem is well known for its mathematical difficulty. This is also true for the assignment problems related to our planning problem. Since a student will normally take more than one examination, a school may have as many as 1500 student examinations. Each student examination is to be scheduled on a specific day, which produces very many decision variables. This assignment problem will contain more than 100 million binary decision variables if formulated as a traditional 0-1 optimization problem.

Having multiple criteria is an ingrained feature of real life problems. These criteria involve a good spread of student examinations so as to provide good premises for each student, minimising the costs for the schools, the counties, and the Ministry, and sharing pedagogical benefits equally among the schools, subjects and geographical areas.

After experimenting with prototypes containing preliminary algorithms, it was concluded that finding feasible solutions did not present major difficulties. Finding satisfying solutions was more difficult but was still consider being attainable within reasonable amount of algorithm construction, system implementation effort and computational time. No demands for achieving optimal solutions were given whereas robustness and consistency were considered to be more important. This is in line with the following heuristic principle: Managerial decisions might be improved more by making them more consistent from one time to another than by approaches seeking optimality to explicit cost models; especially for situations where intangibles must otherwise be estimated or assumed. These observations led to the conclusion that the final planning system should provide the examination planner with suitable information and optimising tools based in heuristic methods, which could be used interactively and that could be stopped at the users command yielding satisfying solutions.

To cope with the complexity of the problem at hand, it was decomposed into four interrelated phases, each dealing with separate tasks and having well-defined goals following well-known heuristic principles (Silver et al, 1980). This decomposition approach follows to a certain extent the traditional approach (pencil and eraser) at the Ministry; this makes easier the final implementation process. This traditional approach was very time consuming for two planners with a lot of helpers. These four phases are:

- Subject draft
- Examination Chain
- Examination Scheduling
- Assignment of Censorships.

2.3 The work group and the stakeholders

The decision maker was the chief of the Examination Department at the Ministry. He is responsible that all the processes run smoothly. He played no major role in the development of the decision support system. He gave his full support to the work group. The work group was composed of three planners from the Examination Department at the Ministry. There experiences from many years of work at the Department were extremely useful while testing the different programmes solving each sub-problem. The leader of this group has a central position in the development of the decision support system because as a previous teacher in informatics, he has sufficient background to understand also the technical aspects of the problem and to contribute to its solution. He was at the same the leader, a user and a developer.

Stakeholders were of course the directors and teachers from the different schools that were involved in the discussions about the purpose of the new system, the first tests and the final implementation. The feedbacks from the stakeholders were important during the tuning of the whole system.

The facilitator was my previous student who had developed the technical approach in his MSc thesis; afterwards he was hired as a consultant for the Ministry. He was the facilitator of the whole development and implementation processes. As we will see below other experts were involved. He will seek for the collaboration of the users, the stakeholders, and the experts at the different stages of the development and implementation of the system. Other experts were: One system's designer from a consulting firm and three programmers hired at the Ministry.

2.4 The facilitation process

In this case study the facilitator has two main tasks:

- First, to design, develop and implement a computerized decision support system in close cooperation with the users and other experts. As described above a satisfying system was developed by decomposing the complex problem in a series of interrelated optimization sub-problems each of them being solved using simple, fast, and reliable heuristic methods. Here the facilitator is working as a scientist using rational approaches, mathematical modelling and algorithms to find satisfying solutions and

using the scientific approach to manage the problem solving process.

- Secondly, the facilitation of the work group and the work of the experts in the development and implementation stages of the problem solving process. This was a long process, it started in 1991; the system was used for the first time in 1992, and has being running every year since 1993. The task of the facilitator was to develop an efficient and innovative form of work, a common culture, a positive way of solving conflicts and a creative manner of finding new ideas. Here, the facilitator is working as an artist, he is instructing, directing, and coaching people to be participative, collaborative and creative in the problem solving process. He is like an instructor of a play in a theatre, supporting the different artists to perform their best to create synergetic processes. Or, more metaphorically, he is like a painter were all the participants are his colours to be combined in shapes, shadows and forms to be able to create a master piece.

The technical approaches needed to deal with the above described complex situation are relatively easy to develop. Similar complex logistic problems have been previously solved using mathematical models and heuristics and special dedicated computerized systems.

The real complexity of the problematic situation in question is the social complexity related to the development and implementation of the system by the actors in a participative and collaborative way. It is very complex the management of these social processes. Here the manager, that is the facilitator, is not only a rational and intelligent decision-maker, but also a creative and artistic designer. This managing attitude, managing as designing, is found in architecture, art and design professions.

Of course as with any practical project there have been conflicts, delays, and other problems related to negativity of some of the users or programmers leaving the Ministry; but in the spite of the facilitator's lack of practical experience, he and the leader of the working group believed that it could be done and were highly motivated to do the task. The system has now bee used for 14 years in practice. This has been a great success. For the Ministry, the examination system is the most prestigious system since the examinations have intensive attention from the schools, the public and the politicians; if things go wrong, from the press! Fortunately most people, including many students and teachers, are not aware of the existence of such a decision support system.

3. Art and Science

What is art? The answer to this question is conditioned by the fact that a definition of art has changed due to cultural and historical reasons. The boundaries of art have experienced a radical change over the last century. Previously, art was created in historically validated media and presented in a limited set of contexts for a limited set of objectives, such as search of beauty, religious glorification, or the depiction of persons and places. However, this century has produced new ways of experimentation, breaking and testing of boundaries. Artists have introduced new media, new contexts, new materials and new purposes. This expansion in art activities causes a difficulty in achieving consensus on definitions of art. The following very general definition can be easily accepted:

Making art may be depicted as the process of responding to perceptions, feelings, ideas, dreams, and other experiences by creating innovative works of art through the skilful, thoughtful, and imaginative application of tools and techniques to various media and materials. The "objects" of art that result of encounters between artists and their intentions, their interventions, their concepts and attitudes, their cultural and social realities, and the materials or media in which they choose to work.

Modern artists use unorthodox materials, tools, techniques and ideas inspired by the worlds of science, technology, humanities, economics, psychology, sociology, anthropology, etc. Some are present in non-art contexts, such as factories, laboratories, trade shows, the Internet, schools, and the street. Social interventions are manifold. The process of creating art is filled up of problems related to design and decision-making. The design attitude is related to the creative and innovative process in problem solving, while the decision attitude is related to the scientific approach to problem solving. In this sense, science can support art both providing materials and the media, and rational approaches to problem solving.

What is Science? Researchers and philosophers on science suggest several defining elements. This set of core ideas, *the scientific approach*, includes the following:

- An essay to understand how and why phenomena occur

- Focus on the real (natural, social, human) world
- Focus on empirical information
- Seeking objectivity
- Use of a rational or logical approach
- Knowledge codify into laws and principles, and
- The continuous testing and refinement of hypotheses.

The crucial assumptions of the scientific approach are that the observed world is essentially orderly, and objectivity can be achieved through self-discipline and the reliance on methods such as the calibration of instruments, repeatability and multi-observed verification. There are of course variations in emphasis. That is, empiricists focus primarily on the role of observations, while rationalists emphasizes on the logical processes of theory construction and derivation. Some enhance induction built from observation; others focus on deduction drawn from theory.

Critical scientists see science as a modern delusion, challenging mainly the possibility of objectivity, noting the decisive influences of gender, social position, culture and history. Critical science is focusing in issues such as the interactions of the observer and the observed phenomena; the role of socially constructed frameworks at all stages; and the social forces and meta-narratives that form the questions and paradigms used in the research process.

Several researchers have contributed to the critique of science. One describes the way dominant paradigms shape the questions that get acceptance and support. Another critiques assumptions of scientific rationality, remarking that nature gives different answers when approached differently. Others analyze the metaphoric language of science, its authoritative voice, and its unacknowledged patriarchal under-life.

In social sciences and the humanities, this kind of critique predominates. Scientists and technological innovators, however, believe in the ability to discover universal truths and assert that reform can overcome those places where scientific process falls short of its aspirations to universality and objectivity. As validity, it is usually referred to the accomplishments of the rational approach in building robust theoretical structures, and in predicting and controlling the material, organic and social world.

There are some differences and similarities in the practice of Art and Science. In Table 1 the differences are presented while in Table 2 the similarities are enhanced.

Differences:

Art	Science
• Aesthetic, reflective	• Know, understand
• Emotion, intuition	• Reason, logic
• Idiosyncratic, personal	• Normative, principles
• Visual, sonic	• Narrative, textual
• Evocative, subjective	• Explanatory, objective
• Radical change	• Improve, optimise

Table 1. Art vs. Science: Differences

Art vs. Science: similarities

- Observation, experimentation, sensual
- Creativity
- Change, innovation, improvement
- Models, symbols, abstraction
- Universality

Table 2. Art vs. Science: Similarities

4. The Art and Science of Facilitation

The success of the problem solving process is determined by the effectiveness and creativity of the work group. Since the participants are invited or appointed, it is recommended to use some selection criteria. Some of these criteria could be: Representability, goal compatibility, process compatibility, deliberation abilities, positivism, communication abilities, and focus abilities. Obviously, the quality of performance or the piece of art created depends of the raw material you are using. It is clear that selecting the participants is a very important task, which has to be solved seriously in order to develop effective work group and high quality results. A person, with knowledge and experience with working collaboratively with people, from the organisations involved should undertake this task.

In connection with the work group, there are two social processes to be managed by the facilitator: the problem solving process and the group process. The problem solving process is the way the group act

to solve the task supported by the facilitators and some experts. This is the rational and logical process. The group process is related to the manner in which the individuals in the group work together, how they learn, how they communicate, their social and power relationships, and how they deal with conflicts. This is the intuitive and creative process. Obviously, these two processes interact in various degrees. In ideal group work, these two processes support each other. We talk about **group dynamics**, when energy and synergetic effects are created in the group as a result of well-balanced processes where the task is just as important as the group trust and identity.

In addition, there is a third social process: the facilitation process. The facilitators are the managers of the social process and their main mission is to inspire, create, direct, and support group dynamics. By focusing and guiding group members' communication and decision-making processes in a creative and structured form, the facilitators can reduce the chances of engaging in faulty processes and harness the strengths of the group. The facilitator is both an artist, being the director of an artistic performance to be performed by the group, and a scientist, supporting a scientific approach to problem solving. This situation can be achieved using the following guidelines:

- Use approaches, for example creative techniques, and scientific methods;
- Specify a set of objective ground rules for the group work;
- Build on the strengths of the group and protect the group against its weakness;
- Balance members participation;
- Support the group with technological know-how;
- Support the group while dealing with conflicts;
- Plan time to close the different social processes;
- Make the group reflect and evaluate the group dynamics; and
- Empower the group.

The facilitators are constantly thinking (reflection) and listening to the deliberations in the group so they can make suitable interventions (decision making). An intervention means communicating with the group, giving information and knowledge, and encouraging the participants to think about important topics.

Let us elaborate now more theoretically about the essence of the facilitation process as opposed to its existence or its accidental qualities or, in other words, the attributes by means of which facilitation as management can be qualified or identified. As we have seen, facilitation is a purposeful process carried out by one or several persons that goes forward between two interacting processes. First, the logical/rational/legal process carried out by a purposeful group (the problem solving group) that wants to achieve some goals. This process has been called the problem solving process, and is the scene of objectivity. Secondly, the non-logical/irrational/illegal process that refers to the chaotic social process provoked by each single participant, by the participants' relations to each other, or by the participants' relations to the facilitator of the purposeful group, these bring into the participants own subjectivity, intuition, fantasy and feelings. This process can be called the problem destruction process and is the scene of subjectivity.

The facilitation process will move in the grey zone between the scene of objectivity and the scene of subjectivity. The rational and the irrational processes are fighting one another; the one wants to impose over the other. They are in conflict with each other, but they need each other because while the problem solving process seeks to achieve realistic solutions, the irrational process will be the basis for the production of new ideas. Rationality needs chaos, and chaos needs rationality. Due to this contradiction, rationality vs. chaos, we can stipulate that facilitation is a **dialectical** process.

Let us also emphasise that facilitation is a purposeful intervention in a social process, a designed process. Facilitation is not a necessity for the evolution of the problem solving process but it is designed to support the problem solving process. The facilitation evolves very dynamically in a grey zone trying to construct a bridge between the traditional/conservative problem solving (business as usual) and the new/revolutionary power to change. The purpose of facilitation is to seek that the two above-mentioned processes do not destroy each other, but on the contrary support each other.

The facilitation process can be instructed and directed in different manners, as there are several management styles. The facilitators are the managers of this process. Note that if the group can manage itself, there is no need for a facilitator. That is, the group can learn to facilitate itself. As in any management process, it is a good idea to develop a strategy and design an action plan for the facilitation process. Managing by designing is a fundamental principle in any facilitation process (Boland and Collopy, 2004), therefore all the social processes have to be designed.

Management also involves three other central factors: Power, communication and learning. These aspects are always present in any facilitation process and should be reflected and articulated before, during and after the process. Facilitation becomes **an art** when a synergistic effect is achieved due to the constructive interaction between the rational and the irrational processes. The facilitator then becomes the director of a performance, where each participant plays a central role. By the end of the performance if synergy has been created all the participants will explode in a rush of happiness and pleasure, the pleasure of working creatively and collectively to achieve some goals. It is the same feeling that football players experience after a match where the victory has been the result of a combination of individual creativity, collective hard work and suitable facilitation (the coaching).

Summarising, we can state that the purpose of facilitation as management is not only to solve the task, but other additional goals could be:

- Each participant is a potential facilitator, therefore the importance of the learning dimension;
- Empowerment, the participants learn to be more self-confident and learn to work creatively in a group (creativity is an act of liberation from the jail of our own routines!); and
- Praxis, the facilitators should be able to learn from the experience therefore the importance of the evaluation of the intervention and the systematisation of praxis, in addition learning from failure is a good principle for any facilitator.

5. Conclusions

Everything can de approached scientifically and everything can become art. Our main message is that in what concerns problem solving in complex situations, it is advisable to use both the scientific and the artistic attitudes. More satisfying results will be achieved, the risk of failures will be minimized, all the participants will be empowered, and everybody will learn from the experience, even the facilitator.

In the case of the planning problem, the Ministry could have ordered the decision support system from a firm instead of in-house development. But in such situation the consequences of failure were too serious and could easily become a political issue. In Denmark, there are too many bad experiences with implemented computerized decision support systems that were extremely expensive to develop and implement and that did not solve the problem, on the contrary caused more problematic situations.

In the case study related to the planning of the examinations the facilitator was educated as an engineer, but in the social process he was managing he was an artist although he was not aware of that. He used his intuition to solve conflicts, supervised the experts and used time to dialogue with the users. He was able to create a common language, a common culture and motivate all participants. He was managing by designing.

This note is based in an extended paper published in Vidal (2005). Further discussions and other applications can be consulted in the e-book Vidal (2006) that can be downloaded free-of-charge.

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