Learning Through Collaborative Problem-Solving: A Case in Environmental Decision Making

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Abstract. In this paper we ellaborate on collaborative problem-solving as a way of effective learning targeted to domain experts. We explore decision-making as a typical expert activity that requires group work when dealing with complex problems. We propose a framework that employs (1) a well-defined methodology, (2) well-chosen real-world cases relevant for the participants' area of expertise, and (3) collaborative work involving decision support and domain experts. We illustrate the approach in the area of decision support in the implementation of environmental policy, and describe an experiment in which the participants of a specialised seminar achieved excellent results in terms of the quality, complexity, and relevance of obtained decision models.

1 Introduction

To enable and support exchange of information in the society, where "staying behind" means a serious disadvantage in the competitive business world, educational sector is increasingly offering seminars and workshops that support and promote informatisation. Nevertheless, a closer inspection of this practice (Flach, et al., 2000) shows that some target groups are covered very well, while some others can still be approached more intensively. In the first, well covered group, one may find very different classes of seminars, ranging from non-customized seminars that provide basic computer literacy to highly priced and specific educational programmes for managers. In spite of their diversity, most of these seminars have something in common, namely, many of them directly or indirectly promote a chosen vendor of tools and applications. In the second group, not sufficiently covered yet, are experts in different areas, such as engineering, medicine, ecology, etc., who could substantially improve the efficiency of their work by using advanced methods and techniques, such as data mining and decision support.
Experts are a very demanding target group for educational programmes. They are very busy and can not afford wandering from a seminar to a seminar, looking for some information that might turn out to be useful for them. Also, they know very well what they are looking for: what their problems at work are and what they should learn to solve these problems. Therefore, it is very important to design effective educational programmes that offer them both, general information about the methods, approaches and programmes, as well as demonstrations and illustrations based on cases from their

own or very similar field of work. This enables for seeing the analogies or differences between the presented and their own problems, and constantly keeps them interested.

The cases included in the seminars should be chosen very carefully. The following issues are always important, but become crucial when targeting a group of experts:

- The case should be easy to understand, but difficult to solve.
- The case should be interesting and relevant for the target audience of the seminar.
- The case should allow for generalizations.
- The lecturer should know it sufficiently well to be able to comment different ideas and suggestions given by the audience, and not just present one of the possible solutions.

One of the most effective ways of problem solving is solving them in small groups. Group activities enhance the learning process by giving participants a different perspective on the topic and engaging them in discussions. In addition, interaction with other participants leads to greater learning and stimulates creativity (Draves, 1997).

In this paper we explore the importance of good case choice and group work in specialized educational programs for professionals. We illustrate it in the area of decision support (Mallach, 2000) in the implementation of environmental policy. First, in section 2 we describe the educational setting for collaborative decision making, which has been organised in a form of a seminar about multi-attribute decision modelling for solving environmental problems. Section 3 provides a general description of the decision making problem and highlights the most common problems that occur in real-life applications. Section 4 presents two real-life cases that were used by participants in collaborative problem solving. The description and results of the group work during the seminar are presented in section 5.

2 Educational Setting for Collaborative Decision Making

In the framework of the Sol-Eu-Net project IST-1999-11495 "Data Mining and Decision Support for business competitiveness: A European virtual enterprise" we designed a programme aimed at promoting decision support among professionals in the area of ecology. A one day seminar entitled "Decision Support in the Implementation of Environmental Policy" was for the first time organised in May 2001 by the Center of Knowledge Transfer in Information Technologies at the Institute Jožef Stefan, Ljubljana, and the Nova Gorica Polytechnic. It is planned that this seminar will be offered on a regular basis.

Environmental policy usually emphasizes environmental protection and nature conservation goals. Achieving such goals at full consideration of the economic ones, provided social development and welfare, is not an easy task. Many questions need to be answered and many dilemmas to be resolved during the implementation of such a policy. For this purpose, multi-attribute decision modelling methods (Bohanec, Rajkovič, 1990; Clemen, 1996) are offered as the problem-solving support.

The participants of the seminar were involved into investigation and discussion on the key questions and dilemmas regarding environmental decision making, for example: How to create and implement a policy which is in principle supported by the general society, but may cause strong resistance of different interest groups on the local level when it comes to the implementation? How to make decisions in specific circumstances where the application of general rules does not seem adequate? What is the value system behind preferences? How to resolve conflicts? How to take into account the affordability of certain goals and different types of uncertainty, like variability in parameter values on one hand, and changes in value systems on the other?

Two real-life case studies from Slovenia were carefully chosen to demonstrate multi-attribute decision modelling and engage participants in practical collaborative work. These were: "Evaluation of thermal burden on the Sava river due to Nuclear Power Plant (NPP) Krško" which served as a learning example, and "Siting of low and intermediate level radioactive waste repository in Slovenia" as a training case study (section 4). After an introduction into multi-attribute decision modelling, and multi-attribute modelling tools DEX and DEXi (Bohanec, Rajkovič, 1990), the participants exercised the following components of the multi-attribute decision modelling:

- elicitation of decision parameters and criteria,
- structuring of a decision model (developing a hierarchy of attributes),
- development of decision rules,
- evaluation, analysis and interpretation of results.

In terms of methodology, the seminar has been designed at an introductory level. However, background and experience in environmental issues has been treated as advantage. In the seminar held in May 2001, out of 37 participants, 19 reported that they had already had some professional experience with decision making in ecology related issues. Eight of these were regularly involved in this kind of activities. The list of positions they hold at their institutions shows that approximately half of them have special responsibilities as directors, advisors, project leaders or heads of departments. The others are mainly researchers and postgraduate students in different fields.

3 Decision Support for Solving Real-Life Problems

In theory, decision making is defined as a process concerned with choice (Simon, 1977): given a set of options (or alternatives), which typically represent some options or actions, the goal is either:

- to choose an option that best satisfies the aims or goals of a decision maker, or
- to rank the options from the best to the worst one.

In addition, it is often required that a final choice is carefully analyzed, justified, explained, and documented.

In practice, however, this seemingly simple task is faced with many obstacles. Severe problems may appear with any element of the decision making process, turning it into a complex and difficult task. The problems that occur most often are related to:

- *Goals*: In practice, it is almost impossible to specify goals clearly and in their entirety. There are always some unspecified, unknown or even conflicting goals. This is especially true in group decision making, where each group may have their own goals.
- *Options*: In theory, the options are given in advance. In practice, they often need to be identified during the decision making process. Even when the options are known in advance, they need a careful investigation to obtain and understand their properties. Still after that, it is likely that some properties remain loosely defined or unknown.
- *Parameters and criteria*: Parameters that influence the decision originate in goals, but they have to be identified and quantified in the decision making process, which turns out to be one of the most difficult tasks. The questions should be answered such as: Which are the relevant parameters? How do they influence each other and the final outcome? Are they well defined? Are they complete and do they properly describe the problem? Is it possible to measure them? Also, the complexity of the process increases dramatically with the increasing number of parameters; for example, twenty parameters may be already quite difficult to handle, but really complex decision problems usually require up to hundred or more parameters.
- *Resources*: Resources are always limited.. In decision making, most common issues are the lack of time, non-availability of personnel, and scarcity of knowledge, especially regarding the decision making process and its possible consequences.

To cope with these (and other) problems, a multitude of theories, methods and techniques have been developed to support people in making complex decisions. To name just a few: game theory, utility theory, theory of choice, pencil and paper, optimization, operations research, decision analysis, decision support systems, expert systems, data warehouses and on-line analytical processing, data analysis and data mining.

Among these, there is an important class of methods based on modelling. They provide a systematic framework for analysing real-life decision problems by:

- structuring and breaking them down into more manageable parts,
- explicitly considering the alternatives, available information, involved uncertainties, and relevant preferences;
- combining these to arrive at optimal or “sufficiently good” decisions.

The decision process usually proceeds by building models and using them to perform various analyses and simulations, such as “what-if” and sensitivity analysis, and Monte Carlo simulation. Typical modelling techniques include decision trees, influence diagrams, and multi-attribute utility models.

4 Cases for Collaborative Decision Making

Decision modelling techniques are particularly suitable for seminars. On one hand, they require a careful and systematic approach, and model developers must be well aware of problems that might occur in the decision making process. Model development motivates the search for relevant information and stimulates discussion, which is particularly suitable for working in groups. On the other hand, modelling techniques are relatively easy to understand, at least at a basic level, and most types of modelling are well supported by suitable computer programs. For seminars, this allows to attack fairly complex decision problems and develop quite sophisticated prototype models relatively quickly – maybe in a session or two of group work, supported by a skilled moderator.

In our seminar about environmental decision making, we employed a technique of qualitative multi-attribute modelling, which is supported by a computer program DEXi, a recent successor of DEX (Bohanec, Rajkovič, 1990). So far, DEX has been used in more than fifty real-life decision problems in various areas (Urbančič, et al., 1998), including site selection (Bohanec, Rajkovič, 1999).

In the following, we describe two real-life cases that were used in the May's seminar to engage the participants in collaborative problem solving.

4.1 Case 1: Thermal Burden on the Sava River due to NPP Krško

The aim of the first example is to *get the participants familiar with the modelling method*. The task which the participants need to solve is relatively easy. They are requested to develop two small components of the model: a small subtree and corresponding decision rules.

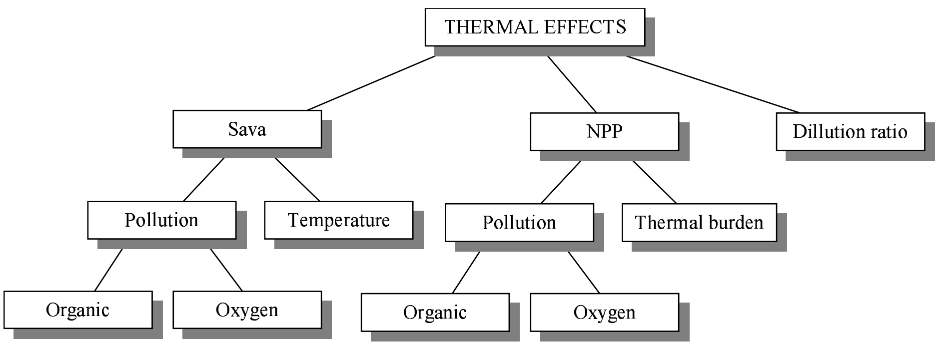

Fig. 1. Structure of the multi-attribute model for the evaluation of thermal effects to the Sava river due to the NPP Krško. See Box 1 for the description of attributes.

The case study is about assessing thermal effects to the Sava river for the purpose of adjusting operating conditions, namely the power, of the NPP Krško (Kontić, Zagorc-Končan, 1992). A brief description of the problem is provided in Box 1. After a fairly detailed description of the case and discussion/clarification of certain questions regarding operating modes of the plant, the participants were provided by a multi-attribute model (Fig. 1). Based on this, they were asked to:

- think about additional parameters that can be used in this case (some hints were given for that),

- extend the structure of the model with a small subtree consisting of these additional parameters, and
- define the corresponding decision rules.

Box 1. Description of Case 1 with the brief explanation of the selected attributes

The consequences of discharging cooling waters from thermal power plants into the rivers are multiple: damage of the biocenosis, decrease in the dissolved oxygen concentration, higher rate of degradation and other processes, etc.. Therefore, limitations for discharging cooling waters into the river bodies is a common policy. For the NPP Krško this limitation is attached to the quality of the Sava river and is expressed in terms of degradable organic pollution and dissolved oxygen concentration. If the conditions in the Sava river are such that its quality may suffer due to discharge of cooling water from the NPP Krško, the plant is obliged to decrease power. Evaluation of thermal burden of the Sava river is therefore a multi-attribute problem.
The meaning of selected attributes as presented in Fig. 1 is as follows:

- "Pollution" means degradable organic pollution expressed in BOD or COD (Biochemical Oxygen Demand, Chemical Oxygen Demand)
- "Oxygen" means dissolved oxygen concentration expressed in mg/l
- "Dillution ratio" means a ratio between the Sava river waterflow and the cooling water flow, taking into account their temperatures.

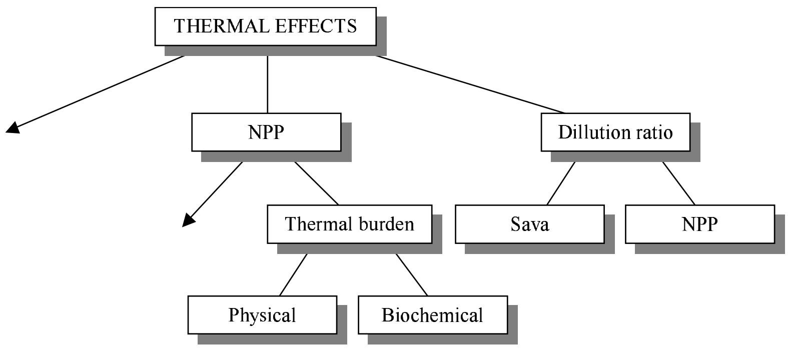

Fig. 2. Two possible extensions of the model from Fig. 1

Table 1. Decision rules for Dillution ratio

	Sava	**NPP**	**Dillution ratio**
1	max	low	high
2	max	medium	high
3	max	high	medium
4	medium	low	high
5	medium	medium	medium
6	medium	high	low
7	min	low	medium
8	min	medium	low
9	min	high	low

In other words, the participants were expected to extend the model in a way similar to Fig. 2, which shows two possible extensions. One is to further refine the NPP's thermal burden by explicitly considering its physical and biochemical components. Another possible refinement is to decompose the dillution ratio and define it by means of the quantities, i.e., waterflows, of the Sava river and the cooling water from the NPP. For each of these, the participants were expected to define a set of qualitative values for the new attributes, and for each subtree to specify decision rules, such as shown in Table 1.

4.2 Case 2: Siting of a Low and Intermediate Level Radioactive Waste Repository in Slovenia;

The purpose of this case study is to lead the participants through the whole process, *from problem definition to modelling* The second case is considerably more complex, as it requires the participants to attack a problem from the beginning and perform the activities that are usually one of the most difficult tasks in decision making. In terms of the exercise's framework, they are expected to:

- understand the decision problem, including the involved dilemmas and uncertainties; the decision problem is identification of the most suitable site for the repository among three alternatives,
- understand the available alternatives.

Specifically, the participants are given a four-page text describing the problem of radioactive waste disposal. Three possible locations are described in the provided text. The participants are then asked to:

- carefully read the text,
- identify the most relevant parameters for the evaluation of alternative sites,
- discuss these in a group (which is occasionally promoted and advised by a skilled moderator),
- jointly propose the structure of a multi-attribute model, and
- present their result to other groups.

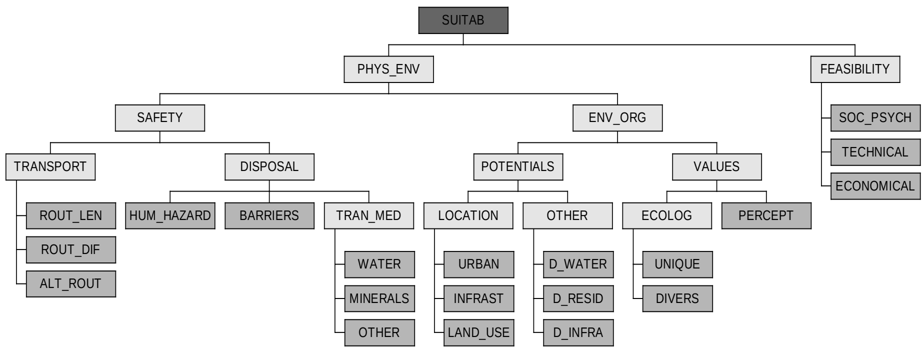

Fig. 3. Sample model structure for the evaluation of locations for radioactive waste disposal. See Box 2 for the description of attributes.

An example of the model structure that is expected from such an exercise is shown in Fig. 3; a brief description of attributes is given in Box 2.

Box 2. Description of the model attributes as shown in Fig. 3

- Suitability of a site (SUITAB)
- Physical components of a site, i.e. environment, relevant for the evaluation of its suitability for a repository (PHYS_ENV)
- Environmental attributes which are relevant for the safety of a repository (SAFETY)
- Vulnerability of the environment for siting a repository in terms of its potentials for other uses, values, and organisation (ENV_ORG)
- Attributes which describe feasibility of a repository apart from environmental issues (FEASIBILITY)
- Length of the transportation route (ROUT_LEN)
- Difficulty of the transportation route-roads (ROUT_DIF)
- Alternative transportation routes and modes of transportation (ALT_ROUT)
- Hazard to human health (HUM_HAZARD)
- Environmental characteristics which contribute to the prevention of the leakage and migration of radionuclides from the repository (BARRIERS)
- Possible media for transport of the radionuclides from the repository (TRAN_MED)
- Potentials for urbanisation of the site (URBAN)
- Potentials for infrastructure at the site (INFRAST)
- Distance to residental areas (D_RESID)
- Distance to water resources (D_WATER)
- Distance to infrastructure corridors (D_INFRA)
- Unique ecological values at the site (UNIQUE)
- Ecological biodiversity at the site (DIVERS)
- Perception of the ecological values (PERCEPT)
- Social-psychological acceptability of a repository at a particular site (SOC_PSYCH)
- Technical feasibility of a repository at a particular site – construction and transportation issues (TECHNICAL)
- Economical feasibility of a repository at a particular site – direct and indirect cost (ECONOMICAL)

5 Description and Results of the Group Work

Six groups of participants have been formed, each consisting of 4 to 6 members. The majority of participants did not know each other, therefore the formation of groups was more or less spontaneous. Consequently, the groups were heterogeneous, involving participants with different background and level of expertise. This introduced some similarity with real-life situations, where different standpoints, priorities, and interests greatly influence the decision-making process.

After only two hours of methodological introduction and two hours of collaborative work, all the groups succeeded to develop a meaningful structure of a model. These models were surprisingly complex, containing from 26 to as much as 49 attributes. According to the expert's assessment of the results, they all provided a suitable starting point for further refinement of the models. The expert also expressed his opinion that the participants, if left alone with the problem, could not reach the same level of performance. Furthermore, a considerable proportion of them would probably not come up with a feasible model structure, at least not in the available time.

At the end of the seminar, the participants were asked to give a more detailed feedback by filling in a questionnaire. 26 questionnaires were returned. The results relevant for the topic of this paper are presented in Table 2. The answers clearly show that:

- the participants assessed the cases as sufficiently general and complex,
- the group work has helped to shape the views on the discussed issues,
- the experience gained through the collaborative problem-solving will help them in their professional work.

Table 2. Evaluation of the group work

Questions	Answers	
	Yes	No
Were the cases sufficiently general to serve as an illustration of the decision method and the tool?	21	3
Was the task sufficiently complex from the environmental point of view?	22	1
Was there enough data available to solve the problem?	19	5
Do you have enough knowledge to actively participate in the group work in solving this task?	15	8
Did the group work help you in shaping your view on the discussed issues?	21	3
Were you in a position to contribute to the group your own ideas and views?	22	2
Do you believe that the experience with this exercise will help you in your professional work?	21	1
Are you interested in the continuation of a seminar?	17	5
Are you interested in a specialized workshop where you could elaborate a problem from your working environment, working with your own data?	17	4

The participants were also invited to express their wishes regarding the contents of the continuation of the seminar and/or specialized workshops. More than 10 suggestions were given, some of them related to the method (dealing with qualitative and quantitative information, criteria selection, and dealing with uncertainty), some to the practical experience with the tool (hands-on experience with DEXi or other tools), and some to the area of application (site selection, environmental impact assessment for the use of pesticides, biological impact assessment, disposal of ash and other waste from thermal power plants, ranking of alternatives). The desired length of the workshop ranges from 4 hours to 3 days.

6 Conclusion

The experience with the educational programme described in this paper confirms the benefit of collaborative work as a problem-solving method in cases where experts with different backgrounds and interests have to develop a decision-making model. To ensure the effectiveness of such collaborative work, a well-defined methodology is needed. The experts who participate in this process should be informed with this methodology in advance in order to be able to concentrate on the problem itself when the actual decision-making takes place. To this end, we propose a form of continuing education programme customised to special needs of these experts. We ellaborate on collaborative problem-solving whose crucial components are the following:

- well-defined methodology using supporting tools, such as DEX and DEXi, proven in practice;
- well-chosen real-world cases relevant for the participants' area of expertise;
- group work providing the collaboration of decision support and domain experts.

In our experiment with this approach in the area of implementing environmental policy, the participants achieved excellent results. The models they developed during a two hour session of guided collaborative work in solving a difficult real-life problem, exhibit high complexity and relevance that could hardly be achieved otherwise.

In the future we plan to investigate the interest for decision making among experts working on environmental issues and ecology, and their reasoning in such situations. For this purpose real, actual cases from Slovenia will be used. The cases will be such that they are widely recognised as relevant, and for which decisions have not been made yet. We find this exploration relevant and interesting because of almost even distribution of the answers which we received to the following multiple-choice question: Who should, by your opinion, decide about environmental issues? Possible answers were: politicians, experts, the public. If we confirm such answers also after this investigation, we believe that there is a much wider potential for the multi-attribute decision modelling than we thought so far. It will give us additional orientation and ideas for future work on both research and application level.

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