ELICITING GROUP KNOWLEDGE IN A COMPUTER-BASED LEARNING ENVIRONMENT

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ABSTRACT

A key issue in building computer models for decision support with client groups is the elicitation of knowledge from the mental models of participants. The system dynamics model-building process is quite complex and consists of several stages each demanding different types of knowledge to be elicited from the client group. In this paper we discuss a structured approach, employing various techniques, for the elicitation of knowledge in formulating and analysing a system dynamics model of the Dutch Health Care System.

THE PROBLEM

Model-building with client groups involves eliciting the relevant knowledge from the mental models of participants in the system. System dynamicists typically rely on interviews with key persons and usually work with freely interacting groups in an informal consulting approach to elicit the necessary knowledge to build the computer model (cf. Randers, 1977; Stenberg, 1980; Weil, 1980; Richmond, 1987; Senge, 1988; Weil and Veit, 1989). However, the construction of a system dynamics model is a complex process and involves a wide variety of tasks to be supported by the client group. Richardson et al. (1989) point out that psychologists studying cognitive processes generally distinguish between three different types of tasks: generating information, exploring courses of action (i.e. problem solving) and evaluating situations. Each stage in a system dynamics model-building process contains one or more of the above mentioned cognitive tasks. For instance in conceptualization one might distinguish between brainstorming relevant variables (generating information) and deciding on which variables to include in the model (evaluation). In model formulation one might distinguish between choosing alternative structural formulations (evaluation) and specifying a correct rate formulation (exploring courses of action). Research seems to indicate that generating information is best done by individuals working alone or in nominal groups, while the other two tasks can best be performed by interacting groups (cf. Lamm and Trommsdorf, 1973).
In addition, Richardson et al. (1989) have shown that apart from interviews and freely interacting groups there exist a variety of sources of knowledge and techniques to extract that knowledge. These range from content analysis of written documents to interviews with key participants to structured workshops. Different cognitive tasks and activities occurring in various stages in the model-building process demand different approaches and techniques to elicit relevant knowledge. Hence, the process of knowledge elicitation has to be designed carefully in advance of the model-building process.
Recently, a number of system dynamics modelers have begun to experiment with variations on the informal consulting approach. Richmond (1987) uses a carefully designed procedure including a number of exercises that have to be carried out by the client group. Richardson and

Senge (1989) report on the use of techniques like multi-attribute utility (Edwards and Newman, 1982) to support the knowledge elicitation process in evaluating model output. Moreover, these authors have also been succesfully experimenting with a separation between the role of model-builder and group facilitator in working with client groups. Finally, Morecroft et al. (1989) highlight a number of important features to improve the process of capturing knowledge from management teams. Important novel features presented by the authors include the application of user friendly algebra, special emphasis on mapping techniques and qualitative modeling methods and selecting model concepts which are close to the way managers normally think about their corporation.

In this paper we will add to these developments by introducing a procedure for eliciting relevant knowledge in a computer-based learning environment for policy making. A computer-based learning environment (Senge, 1989; Kim, 1989; Morecroft, 1988; Graham et al., 1989) puts a group of policy makers in a position to jointly explore a policy problem using a computer model to communicate, sharpen and possibly integrate their mental models of the problem (cf. Morecroft, 1988). The computer model is used as a tool in the process of joint learning about the problem, rather than as a device to convince policy makers (Senge, 1989). Hence, eliciting relevant knowledge from the mental models of participants is an important and integral part of such a computer-based learning environment.

In a previous paper we have discussed the knowledge elicitation process to arrive at a conceptual model of the Dutch Health Care system (cf. Vennix et al., 1988). Here we will focus on knowledge elicitation in the stages of model formulation and analysis. We will discuss the design of a computer-based learning environment for policy making in Dutch Health Care in which various techniques are employed to elicit the relevant knowledge from the mental models of participants. As was the case in the previous paper we will employ the preliminary model approach to start the knowledge elicitation process. Before focussing on the design of the computer-based learning environment we will first briefly introduce the research questions and the computer model.

RESEARCH QUESTIONS OF THE MODEL-BUILDING STUDY

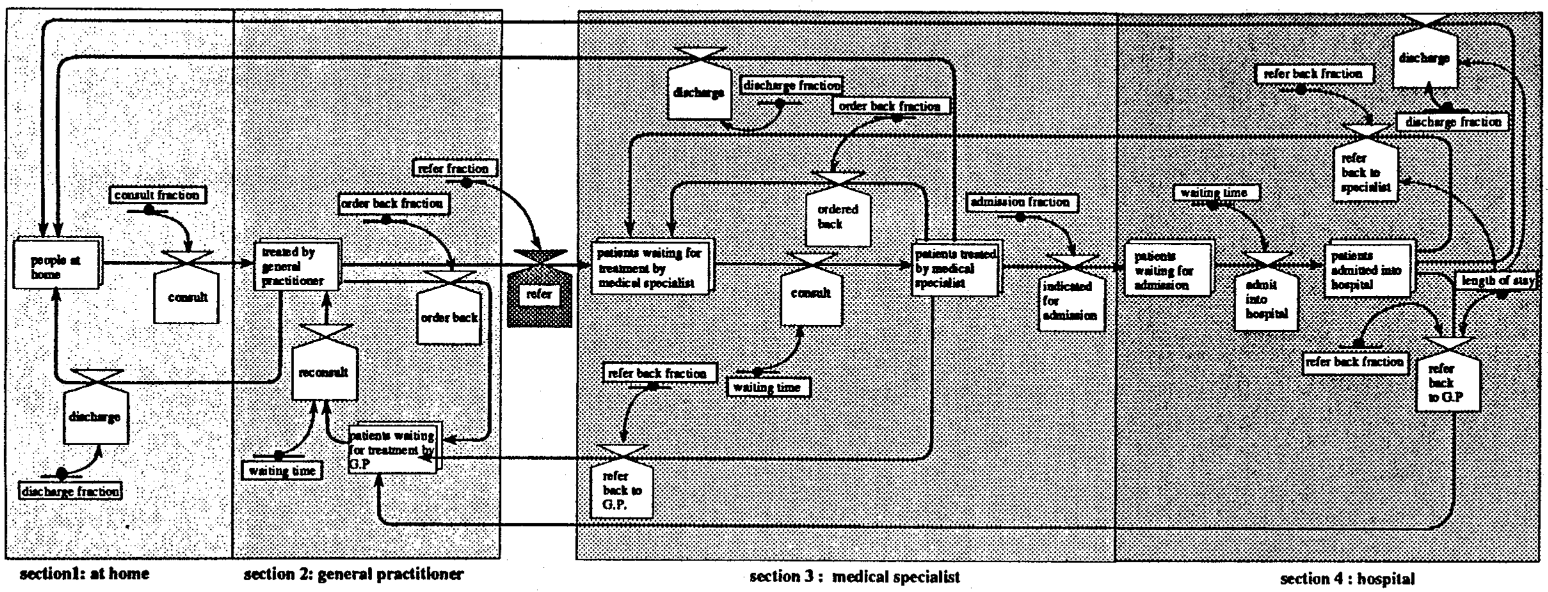
The model-building process of Dutch Health Care is conducted for the Zwolle Regional Health Care Insurance Organization (HCIO). Its purpose is to provide more insight into the factors that have been responsible for the increase in health care costs and the potential effects of several policy options to reduce these costs.

In the first stage a preliminary conceptual model of the regional health care system was designed by a project group, consisting of two persons of the client organization and two model-builders. Next a group of experts from the health care field was consulted to criticize and improve this preliminary conceptual model. For this the project group used a policy-delphi approach and structured workshops (cf. Vennix et al., 1988). Part of this conceptual model was next formalized and quantified by the project group in order to have an operational model with which client groups from the health care region can conduct policy experiments and discuss policy scenarios aimed at reducing health care costs. As was the case in building the conceptual model, this formal model is preliminary, i.e. persons working with the computer-based learning environment will be put in a position to actually challenge and change the model's structure and study the effects of different ways of formulating the structure of the system. Before discussing the computer-based learning environment in more detail we will first briefly present the computer model which is used in the learning environment. For a more in depth discussion of the model and its characteristics we refer to Verburgh et al. (1990)

THE COMPUTER MODEL

The general structure of the System Dynamics model of the Dutch health care consists of three blocks: patients-flows, feedbackloops concerning the workload and the costs generated by the system.

Figure 1 patients flow in the health care system



As far as the patients-flows are concerned, the main variables, linkages and feedback loops are depicted in figure 1 and discussed briefly below. The figure illustrates that the Dutch health care system can be divided into the 4 sections: 'people at home', 'general practitioner', 'medical specialist' and 'hospital'.

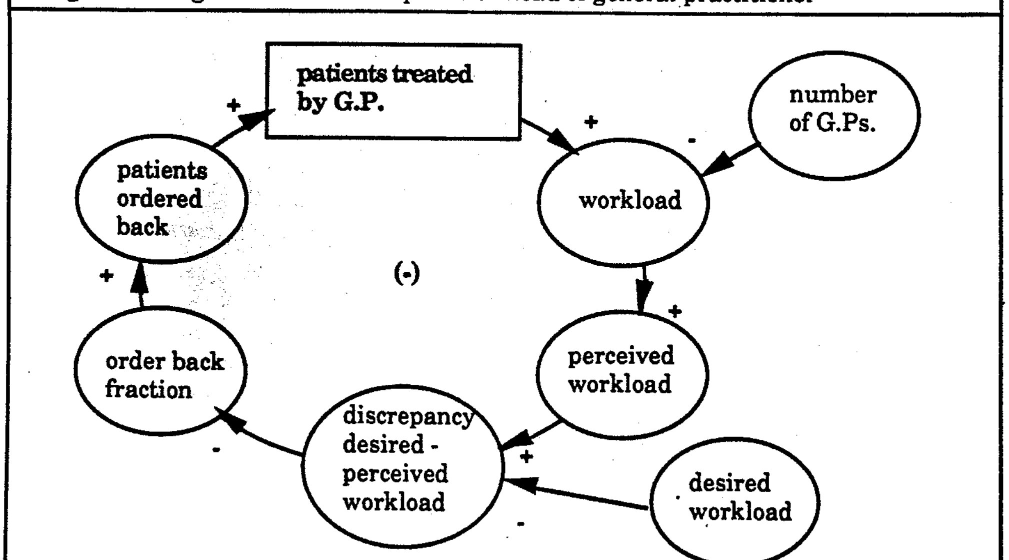
The first section represents the people who have nothing to do with the health care system but can become a part of it by consulting their general practitioner. It is called 'people at home'. Note that people with health complaints in the Netherlands initially consult their general practitioner. They are treated by a g.p., who then has to decide whether to refer them to a medical specialist, to discharge them, or to request them to return (order back). Patients requested to return for another treatment (the outflow called 'ordered back') flow into a level called 'patients waiting for repeated treatment'. After 4 weeks (on the average) they flow back into the level 'patients treated by g.p.' to have another treatment. Patients who are referred to the medical specialist enter the third section. Since medical treatment is more expensive in this section than it was in the section of the g.p., policy makers hold the opinion that by reducing the number of patients referred to the medical specialist, a reduction in the costs of public health care can be accomplished. This idea coincides with a health care issue according to which the g.p. has to become a gatekeeper: the g.p. has to prevent too many patients from flowing into the costly medical specialist and hospital sections.

Patients who are treated by a medical specialist can be ordered back, discharged, referred back to their g.p., or sent to the next section, i.e. hospital. However, because the Dutch have waiting lists for a number of specialisms, patients do have to wait in a level called 'patients waiting for admission into hospital' prior to their actual admission.

Having been admitted into hospital, there are three ways of leaving the hospital: patients are either referred back to the medical specialist or to their g.p. or are discharged, as a result of which they return to the section 'people at home'.

Regarding the influencing factors, figure 2 shows how the levels and flows that are part of the section of the g.p. are affected by a negative feedback loop which is based on the difference between perceived and desired workload. Note that the same kind of negative feedback loop exists for the section of the medical specialist and the section of the hospital as well. In all three

Figure 2 Negative feedback loop on workload of general practitioner

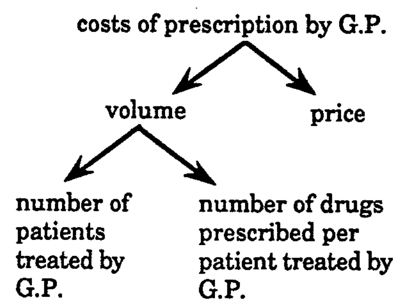


cases, perturbations in workload are corrected by adjustment of fractions whose flows affect the workload. In our example regarding the g.p. section, it is clear that, for instance, an

increase in the number of patients treated by the g.p. leads to an increase in workload. After some time (a delay exists between actual and perceived workload) general practitioners decide to lower their order back fraction in order to reduce their workload.
With respect to the costs generated by the health care system, it suffices to explain that they all have been regarded as a multiplication of volume, i.e. the number of products offered or 'sold', and price. In other words, all the costs have been modelled according to the formula: costs = volume * price. Volumes are derived from the patients flow part of the model. For instance, the number of patients referred to the medical specialist (the flow of 'referred patients') is a measure of the volume belonging to 'costs of referred patients'. Prices, by contrast, are considered as exogenous variables. Figure 3 serves to show which costs have been included in the model and the way in which they have been conceptualized.

Figure 3 Costs included in the model and their conceptualization

1. prescription by G.P.
2. prescription by specialist
3. treatment by G.P.
4. treatment by specialist
5. admission into hospital
6. medical transaction by specialist



In sum, the Dutch health care system consists of four sections. The more patients go to the right hand side of the model, the more expensive their treatment becomes. As a consequence, the number of patients referred to the medical specialist are considered as crucial in the attempt to reduce the costs of health care.

THE DESIGN OF THE COMPUTER-BASED LEARNING ENVIRONMENT

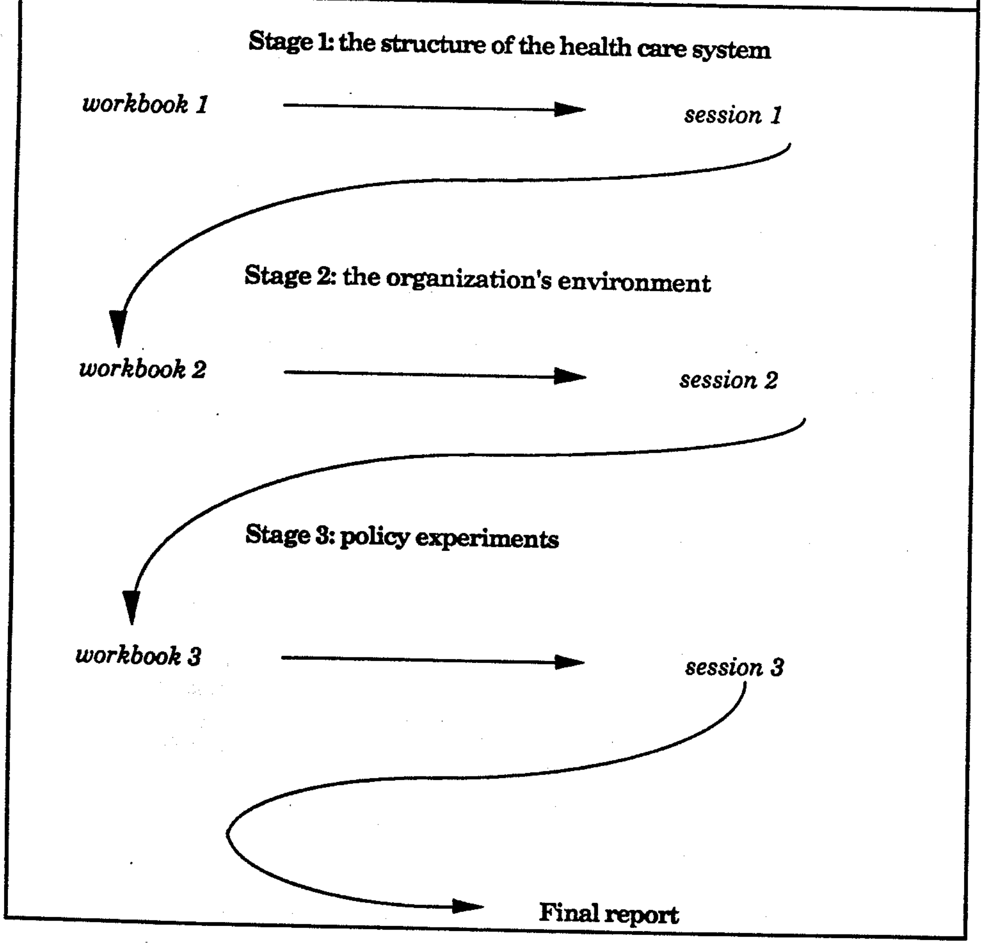
As stated we aim at the design of a computer-based learning environment in which persons can conduct experiments with the computer model themselves. These persons will be selected from the client's organization as well as other health care insurance organizations in the Netherlands.
In close cooperation with the client organization we identified three important stages in having people work with this computer-based learning environment. The first stage aims at making participants acquainted with the preliminary computer model and elicit their mental model on the structure of the health care system. This stage will build the group's trust in the model by putting them in a position to carefully study and challenge and change the model's structure and thereby increase their confidence in the model and their feeling of ownership. The second stage consists of a series of experiments with the model aimed at elements of strategic decision-making. In this stage we elicit knowledge with regard to relevant processes and events in the organization's environment. With the aid of the computer model participants explore developments in the organization's environment and try to determine the impact of these developments on health care cost and other aspects of the organization of health care in the future. The third stage, which builds on the results of the second, aims at conducting a number of policy experiments to provide insight in the effects of future policies for reducing health care costs.
Each of these stages consists of two steps: preparatory work at home for the individual participant through a workbook and a three hour structured workshop in which a group of nine

persons work together on one of the above stages. The design of the computer-based learning environment can be visualized as in figure 4. As can be seen from this figure, the workbooks serve as a basis for the sessions. The results of the first and the second session are in turn reported back to participants in the workbooks of the second and third sessions. The results of all three sessions and accompanying workbooks are fed back to participants in a final report. In the next sections we will describe each of these stages in more detail.

Stage 1: challenging and changing the model's structure

Modeling with client groups aims at communicating and sharing mental models of organization's members (Morecroft, 1988; Senge, 1989). Hence, this first stage aims at eliciting participants' mental models of the structure of the health care system.

Figure 4 Overall design of the computer-based learning environment



This stage starts with a workbook in which we explain the purpose and the procedure of the computer-based learning environment. Next, we introduce the formal model in a stepwise manner, starting with the patients flow model and gradually adding several factors and feedback loops affecting this flow process. Finally, we add variables relating to health care costs. We use diagrams to explain the structure of the model. Having discussed the basic structure of the model we present its standard run. In order to encourage the participant to be critical of the model we present an example of a structural change in the model and discuss its effects on the model's behavior. For this we select a part of the model which is ill-understood and on which there is much debate among health care professionals.

The workbook contains three types of questions. The first is geared towards eliciting knowledge about the system's structure as contained in the mental model of the participant. We ask participants to indicate with which parts of the model they disagree and how these parts should be adapted in their view. In other words participants are invited to draw in the structural changes in the diagrams in the workbook. The second type of questions aims at finding out why persons propose the specified changes in the model, i.e. what arguments they have to propose changes to the model's structure. The third type of questions aims at sharpening the participant's mental model by asking him to provide a prediction of the effects of the proposed changes on the behavior of the model (cf. Richardson and Senge, 1989; Richmond, 1987).

The completed workbooks are sent to the project group one week before the session on the model's structure. The project group categorizes the proposed changes, the argumentations underlying these changes and their predicted effects. On the basis of this categorization the session is prepared and structured.

During the session on the model's structure we first present the general results of the workbooks, i.e. the proposed changes and the argumentations. Next, participants can ask questions and discuss these matters in general terms for about half an hour. The group is then divided into three subgroups each of which can conduct a number of experiments with the model's structure on a computer. Before actually implementing any of the structural changes the group is asked to fill out a form containing the three questions discussed above, i.e. what change is proposed in the model's structure, why it is proposed and what its expected effects on model behavior are. In other words for each of the computer runs a subgroup has to fill out one form with these three questions. Having carried out the model run participants are asked to compare their predictions with the model's outcome and explain any discrepancies between these two in terms of the model's structure. These explanations also have to be recorded on the form.

The subgroups have about 2 hours to conduct these runs. Finally there is a one hour plenary session in which the various subgroups can present the results of their activities by using the filled out forms as a basis for this presentation. One element that these plenary discussions focus upon is potential discrepancies between the model's behavior and the reference mode of behavior which has to be simulated.

The filled out forms, containing elicited knowledge from the subgroups, are left behind by the participants when they leave the room at the end of the session. The project group uses these forms and the results of the plenary discussions to make a preliminary report on the results of this session. This report forms the first part of the workbook for the second session on exploring the organization's environment.

Stage 2: the organization's environment and its implications for policy making.

An important prerequisite for an organization's survival is its adaptation to changes in the uncertain environment. Organizations scan their environment, collect and interpret data on developments in the environment and adapt their behavior to changes in the environment (cf. Cyert and March, 1963; Daft and Weick, 1984). Hence, an important element of a computer-based learning environment is the systematic evaluation of future developments in the organization's environment and their potential effects on the organization. This is meant to reduce the uncertainty with regard to the organization's environment. Milliken (1990) distinguishes between three different kinds of uncertainty with regard to the environment. *State uncertainty* refers to uncertainty about the importance of major trends or events in the environment. *Effect uncertainty* relates to the potential impact developments in the environment might have on the functioning of the organization. Finally, *response uncertainty* relates to the question how to respond to environmental change, either because it is unknown what options are available or because the organization is unsure about the effectiveness of certain options. In the computer-based learning environment all three kinds of uncertainty are addressed systematically. State and effect uncertainty are focussed upon in stage two and response uncertainty in the third stage.

The first step is thus to reduce state uncertainty. This implies that potential environmental changes have to be generated and their importance assessed. Potential important developments in the HCIO environment are for instance the budget provided by the federal government, law regulations prescribing the number of general practitioners who can settle in a certain area and developments in medical technology. For the Zwolle HCIO these are important factors which have to be taken into account in designing specific policies aimed at cost reduction. The next step is to generate knowledge to reduce effect uncertainty by trying to find out (with the aid of the computer model) how these environmental changes will affect the organization.

As was the case in the first stage participants have to read and fill out a workbook. As stated in the previous section, the first part of this workbook summarizes the results of the first session. Next we present a number of potentially important environmental variables. The participant is invited to complete our list of variables and to try to indicate which variables he considers important in the next decade concerning the developments in health care costs. Given the diagram of the model, the participant is then invited to indicate where these important environmental variables fit into the model and what their actual expected developments will be in the coming decade. Finally, based on these quantified statements, participants are asked to predict the potential effects on the model's behavior. The completed workbooks are again used by the project group to prepare and structure the subsequent session.

During the session the project group first presents the results of the workbooks and a short plenary discussion is held. Next the group is divided in subgroups and they can conduct model experiments with the exogenous variables and study the effects on the model's behavior through computer runs with the model. Each group again has to fill out a form for each run containing questions on why this particular variable was selected, how it is expected to behave and what the expected results of the model run will be. The actual model results have to be compared with the predicted results and explanations have to be provided for discrepancies. Again there is a plenary session and participants leave the forms in the room at the end of the session. These are in turn used by the project group to summarize the results of the session and report these back in the workbook for the final session.

Stage 3: designing policy plans and conducting policy experiments

As stated the third kind of uncertainty distinguished by Milliken (1990) is response uncertainty. This refers to both lack of knowledge with respect to available policy options and lack of knowledge with regard to potential effectiveness of these options. Hence, policy making in complex organizations often is a trial and error process. As Mason and Mitroff point out:

> "The policy maker cannot insist on full 'clarification' or 'definition' of a problem before taking action on it. Often, it is only through taking action that a problem becomes clarified. If anything, the trick is to choose the appropriate set of actions that will add significantly to the clarification of a problem. Action and clarification, in other words, are not two separate things but rather two aspects of the same thing -successful problem management." (Mason and Mitroff, 1981, 18)

In other words by taking action and observing results of these actions the policy problem becomes clarified. In reality this process might take years, in which several 'solutions' are implemented and repeatedly adapted. Through a computer-based learning environment this learning process about complex, often ill-understood, problems and the potential effectiveness

of policy strategies might be accelerated significantly. Conducting policy experiments with the computer model aims at clarifying the system's responses to policy interventions.
Based on the results of the two previous stages, the workbook for the third session makes participants concentrate on the design of a consistent and effective policy plan. This includes generating policy options, evaluating these and making a preliminary selection from the list of options.
The first step in the workbook is thus to present a number of policy options and to invite the participant to complete this list. Next the various options have to be evaluated systematically on a number of criteria. Policy options are not only evaluated on their effectiveness with regard to reducing costs. There are a number of other criteria that can be employed to evaluate policy options, which are not incorporated in the model. In order to structure the process of evaluation of policy options we will employ a multi-criteria approach (cf. Edwards and Newman, 1982; Richardson and Senge, 1989; Vennix and Geurts, 1987). The second step in the workbook thus focusses on eliciting the criteria that are used to evaluate policy options. We present a number of these criteria and ask the participant to add criteria to this list. Next participants are asked to indicate the relative importance of each of these criteria by rank ordering these.
This is done in a more or less qualitative way, because some of the criteria are quite broad and fuzzy. For instance criteria like quality of health care is one of these broad and difficult to quantify criteria. Although this does not allow to calculate weighted sum scores for each of the options it is still useful to apply this multi-criteria approach. As Erikson (1981) points out it can be quite useful to use the multi-criteria approach even if this is done at a nominal or ordinal level of measurement. For instance by giving verbal descriptions and comments for each of the options on the various criteria. This at least insures that each option is systematically evaluated at every criterion.
Based on these evaluations of the options participants are asked to design a preliminary policy plan, indicate how it has to be implemented and simulated in the computer model and assess its effectiveness with regard to the policy problem.
During the session the project group again presents the results of the workbooks and invites participants to comment on it. After that participants again work in subgroups. The first step is to agree on a number of criteria to evaluate the policy options. Next the groups are asked to develop a policy plan and to implement this plan into the computer model. Before implementing the policy plan on the computer the group is invited to predict its effects. Again we used prestructured forms which have to be filled out by the groups. The forms contain questions on the selected policy options and, more important, on the argumentations underlying the selection of these options. Moreover, there are questions regarding the effectiveness of policy options as they are evaluated with the aid of the computer model. By means of these forms the participant group is in fact asked to write a brief summary of each policy experiment conducted with the computer model indicating:

- the policy option selected;
- the arguments for this selection;
- predicted effects and actual model outcome with explanations of discrepancies between these; and
- evaluation of the policy experiment on the selected criteria.

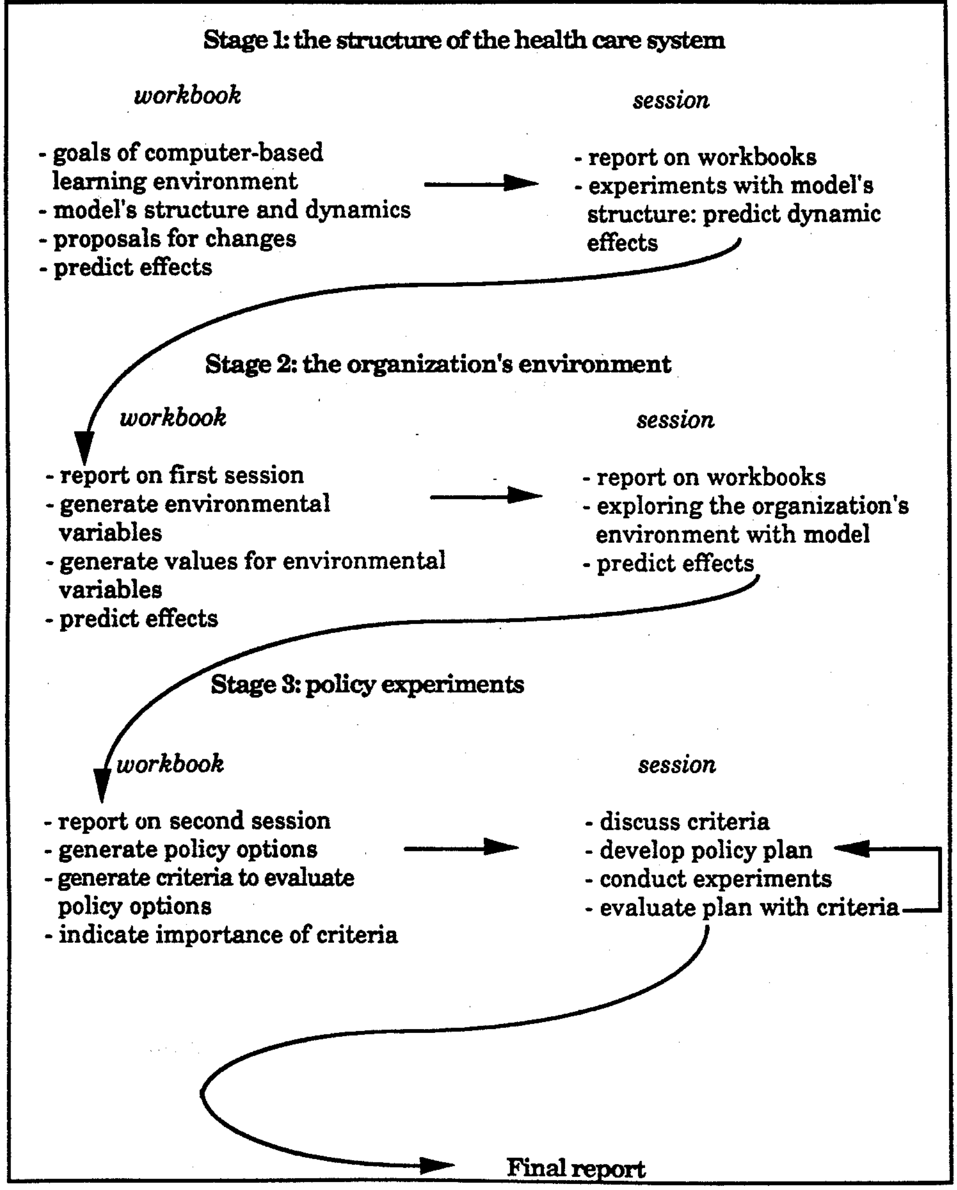
The forms filled out by the subgroups serve as a basis for their plenary presentation and are again left behind after the session. The project group uses these forms to draft a preliminary scenario report (cf. Richmond, 1987) consisting of the following elements:

- description of the policy problem
- options aimed at alleviating the problem
- criteria to evaluate the options
- a number of policy experiments conducted by the subgroups and the results of these model runs as described and discussed by the subgroups on the forms

This preliminary report is sent to the participants one month after the final session. Next, we conduct a session in which the participants are invited to comment on this report. Based on these comments the project group drafts a second version which is sent to all participants.

Figure 5 summarizes the stages in the computer-based learning environment and the main topics dealt with in these stages.

Figure 5 Detailed design of the computer-based learning environment



SUMMARY AND CONCLUSIONS

Eliciting relevant knowledge from client groups in building a system dynamics model is a key issue in supporting decision making in organizations. In this paper we have discussed the process of knowledge elicitation in the stages of formulating and analyzing a system dynamics computer model of the Dutch Health Care System. For this we use a computer-based learning environment, in which participants are invited to criticize this model and conduct a

number of model experiments. A number of different techniques are used to elicit relevant knowledge. First, there is a clear distinction between individual and group work: the workbooks and the sessions. Employing workbooks has not only the advantage of systematically eliciting knowledge. It also creates commitment from the part of the participant to attend the subsequent sessions and it prepares him for this session.
A second characteristic of this approach is that there is a clear distinction between challenging the model's assumptions, exploring developments in the uncertain environment and conducting policy experiments. Third, during the sessions participants work in subgroups in order to create maximum involvement for all participants. Finally, we do not only use workbooks, but also have participants fill out forms. On the one hand these forms are tangible results of knowledge elicited from the subgroups, on the other hand they are used to feed back the results of the sessions to the participants.
Naturally, the procedure is designed to be used repeatedly with different groups. It does not seem useful to design an elaborate procedure for one time use only. Currently we are approaching various health care insurance organizations in the Netherlands to create interest for participation in this computer-based learning environment. In this respect one important element in this computer-based learning environment is the fact that the model can easily be adapted to different regions. Basically the structure of the health care system is the same in most regions, they only differ with regard to the actual initial values of the model, such as the number of general practitioners, the number of hospital beds etc.

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