Experts Facing Complexity

An Investigation into the System Dynamics Method[1]

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Abstract:

With the rapid growth in human knowledge, the world has been revealing its greater complexity to us. The faith is put in experts as those possessing knowledge necessary to solve complex problems. But who should be considered experts and what is the nature of the knowledge sufficient to tackle the encountered problems? In this paper, a broader philosophical and cognitive science perspective for considering expert complex problem solving is suggested. Three requirements for a method that would successfully facilitate solving of complex problems are defined as: (1) support a multilateral collaboration between various experts, (2) assist in the investigation of dynamic characteristics of a problem, and (3) allow for the evaluation and development of expert knowledge. In the context of these requirements a potential of system dynamics as a method for complex problem solving is examined.

Keywords: complex systems, problem solving, expertise, interdisciplinary collaboration, hermeneutics

1 Introduction

With the rapid development of human knowledge, the world has been revealing its greater and greater complexity to us. Problems considered as relatively simple yesterday are recognized as more complicated today, and newly emerged problems are most often of a complex nature. The faith has been put in various experts to solve the problems identified within our social, economical or ecological systems.

However, solutions provided to complex problems often have been far from satisfactory, while considerable amount of complex issues remains unsolved. One possible origin of such situation is that experts lack sufficient knowledge about the problems they attempt to solve. The other possible source of the sub-optimal or erroneous solutions may be that experts apply inappropriate solution techniques. In one of his essays analyzing the challenges faced in the modern world, Skirbekk marks the necessity of implementing a new approach when confronted with complex problems:

> "[W]e are *forced* to recognize the rational need for *expanding* the range of required expertise, from one or a few technological and natural scientific disciplines to a broader range of such disciplines. This is needed if we want to be

> rational in our attempt at understanding the case [i.e. the complex problem that needs to be solved] with its far-reaching consequences, and therefore also if we want to act rationally.
> Since the very point of the use of scientific expertise is to create the optimal basis for the decision makers (…), it is furthermore required that the various scientific contributions are adequately *mediated* to the decision makers: a hermeneutic mediation between the different disciplines, with their different conceptual and methodological presuppositions, is required.” (Skirbekk 1992, p.9)

In this paper the Skirbekk’s argument is taken as a point of departure to suggest a broader perspective for considering ways in which experts tackle complex problems. First, different concepts of expert knowledge found in cognitive science and philosophy are presented, and these most plausible for problem solving in complex systems identified. On these bases, the requirements for a method that would efficiently support expert complex problem solving are postulated. In their context, the system dynamics method is examined. A potential of main types of system dynamics interventions to assist in exercising and developing expert knowledge so as to provide valuable support in complex problem solving is discussed.

2 Expert Solving of Complex Problems

2.1 Emergence of Expertise in Complex Systems

Existence of experts in various domains is tightly related to the fact that the human knowledge is fragmented. As people have learned more about the world, human knowledge has become fragmented among many individuals. In medieval and early modern Europe, knowledge of an individual was recognized as an intrinsic part of the greater whole encompassing all knowledge. With the Scientific Revolution, individual’s knowledge has become gradually more specialized. Independent fields of scientific enquiry emerged and the human knowledge has grown at the ever-faster rate.

Simultaneously, with the rapid development of all branches of science and technology the world has been revealing its greater and greater complexity to us. The profound relationship between the complexity of systems we live in and the human knowledge fragmentation is indicated by Forrester:

> “Complex social systems bring together many factors which, by quirks of history, have been compartmentalized into isolated intellectual fields. The barriers between disciplines must melt away if we are successfully to cope with complex systems.” (Forrester 1969, p.109)

Complexity of a problem may be considered along three dimensions: enumerative, relational and temporal. The enumerative characteristic defines how many elements are involved in the particular problem. The more elements, the more complex is the problem.[2] The relational characteristic defines interrelationships that may be found between identified elements. The more interrelationships, the more complex is the problem. The temporal characteristic of the problem reveals itself through a behavior pattern generated over time and depends on the nature of the interrelationships between the system’s elements. The relational dimension bridges the static ’snap-shot’ view of the problem where one may see elements and their interrelationships and the dynamic view of the problem situation unfolding over time.

If elements of these three dimensions were easily identifiable, the complexity of a problem could be dealt with by the application of some procedural approach. However, complexity is characterized by ambiguity, which disturbs our perception of the real nature of a complex problem (Sterman 2000, p.25). The perception of the problem's complexity is dependent on the observer's needs and knowledge:

> "[A]s one deals with the situation, more and more parameters may be discovered, needing a continuing cognition, understanding and action (…) Under these conditions, the observer would like to set a boundary for the complex system suitable to his needs and variety." (Murthy 2000, p.75)

Setting the boundary is necessary and unavoidable due to (1) an incompleteness of any individual's knowledge and (2) various limitations of human cognitive capacity.[3] Any kind of bounding leads to a reduction in the degree to which the problem complexity is perceived accurately. The more bounded our perception of the problem is, the more endangered is arriving at the correct problem solution. Therefore, it is crucial that no additional, unnecessary bounding is introduced. Yet, with the development of different knowledge domains a dangerous 'specialization mentality' has been growing. This mentality has been founded on the belief in a power and supremacy of deeply specialized scientific knowledge and led people to define problems within the narrow frames of particular disciplines. While such an approach has increased efficiency of tackling relatively simple tasks and problems, it has impeded successful solving of more complex problems by bounding them within the narrow frames of the particular discipline. Skribekk points out dangers of such position:

> "One of the problems involved is that of the nature of technology. It can be stated briefly in this way: for one thing there is still a widespread optimistic belief in the possibility of solving all problems by means of some 'technical fix', some new techniques correctly used by some experts. Thereby all issues are turned into expertise questions in a narrow sense. Hence complex problems with sociological and ecological characteristics, tend to be described in technical and economical terms and to be defined as technological problems which can be solved by finding the appropriate technical and instrumental means." (Skirbekk 1992, p.2)

The 'technical fix'-like approach bounds the problem within the limits of technical and (or) economical domains. This introduces an additional and unnecessary bounding which threatens a successful solution of any complex problem, for: the more deformed the problem becomes, the less likely it will be successfully solved. It should be in the interest of experts to avoid the consequences of the 'technical fix'. By removing any type of problem fixation (technical, economical or of other nature) experts are able to see the problem better and clearer. This increases their chances for delivering a successful solution. And the more successful the experts are in their practice, the more of an expert their communities consider them to be. And the more of an expert they are considered, the more challenging tasks they are assigned to tackle, and thus the better possibilities they have to develop their expertise. Importance of the relationship between experts and their constituency is emphasized by Stein:

> "An expert is more than the sum of his or her cognitive abilities and skills – he or she is also co-defined by context" (Stein 1997, p.192).

The psycho-sociological perspective while not dismissing the necessary cognitive capacities and knowledge experts must possess, highlights the important role of communities in the expert 'appointment' process (Strenberg and Frensch 1992). Because of their critical role, it is important that the communities have a good understanding of what kind of knowledge and practice is required to tackle successfully the problems encountered in complex systems, and that they apply a correct set of criteria when 'appointing' experts. Below different conceptions of the expert knowledge are discussed. To identify a correct understanding of expertise necessary for complex problem solving, one needs to understand the interdependence between the nature of expert knowledge and expert practice.

2.2 Expert Knowledge

In large human systems, such as communities or organizations, a number of people are involved in any complex problem solving process. Different groups play different roles at particular stages of the process. In that context, two different types of experts may be considered. First, there are experts who are responsible for identifying a problem and designing its solution. These experts will be referred to as 'domain experts' to contrast them with 'operational experts' – the other type of experts involved in the complex problem solving process. The operational experts are those who are responsible for actual implementation of designed solutions. Although the distinction between the two types of experts is crucial for the way in which expert knowledge should be understood, it has been rarely made.

Based on the classification proposed by Rolf (1998), three main stances on expert knowledge can be indicated:

- SCIENTIFICALLY GROUNDED EXPERTISE: here expert knowledge is governed exclusively by rules based on scientifically proven laws
- INTUITIVE EXPERTISE: here expert knowledge is denied to be based on and governed by any rules
- EXHAUSTIVE EXPERTISE: here expert knowledge is governed by scientifically grounded rules as well as rules derived from ethical and value system an expert adheres to

Taking one of these perspectives implies a certain interpretation of expertise, i.e. a distinct understanding of 'an expert' and 'expert practice'. Below, each of three conceptions of expertise is characterized in turn.

SCIENTIFICALLY GROUNDED EXPERTISE

This perspective relies largely on postulates of the logical positivism that define the scientifically, i.e. experimentally or logically, proven knowledge as the only sound knowledge. Any other statements grounded e.g. on ethics or religion were discarded as meaningless.[4] Therefore, in this perspective expert knowledge must be entirely founded on scientifically proven laws. The scientific knowledge gives experts a privileged position to deal with problems faced by societies. It equips them with techniques that will guarantee a successful solution to problems they tackle. The expert practice in its essence becomes an appropriate application of learned, scientifically grounded techniques.

This view of expert knowledge and practice seemed to be confirmed by initial research on expertise conducted in the field of cognitive psychology (see e.g. Glaser and Chi 1988, Staszewski 1988). Here, expertise was defined as a large and well-organized knowledge base of explicit rules accompanied by cognitive capacities, such as efficient information retrieval mechanisms and effective information chunking, which allowed experts to outperform others (Lasegold 1988, Staszewski 1988, Galotti 1999). The definition of expertise as highly efficient knowledge-base provided a convenient ground for considering expert knowledge as similar to a computer information system. Here, similarly information was stored in an organized way and retrieved with effective search procedures in response to queries posed. The human mind/computer metaphor founded a hope that expert knowledge may be successfully transferred into a computer application. This initiated research in artificial intelligence and the development of computerized expert systems. Simultaneously, opponents of the information-processing view of expertise argued the impossibility of replacing human expertise with artificial expert systems. Hubert L. Dreyfus and Stuart E. Dreyfus were two of the most famous opponents of the rule-based view of expert knowledge.

INTUITIVE EXPERTISE

Dreyfus and Dreyfus (1986), in *Mind over Machine*, developed a five-step schema describing acquisition of expertise. In this schema, rules and procedures are only the basis for actions of *novices* or *advanced beginners*. As a person proceeds to the next stage of *competence*, one does not follow rules any longer. The focus shifts to plan formulation and consideration of "what occurs thereafter" (Ibid., p.26). Entering the fourth stage of *proficiency*, a person ceases to make conscious choices and begins to rely on '*intuition*.' However, at this stage a person,

> "(…) while intuitively organizing and understanding his task, will still find himself thinking analytically about what to do. Elements that present themselves as important, thanks to the performer's experience, will be assessed and combined by rule to produce decisions about how best to manipulate the environment." (Ibid., p.29)

Reaching the fifth stage, the *expert* stage, means that a person simply "knows what to do" (Ibid., p.30). The rules followed during the initial stages of expertise acquisition are now so deeply internalized, that they are used unconsciously: experts "usually don't make conscious deliberative decisions" (Ibid.); experts "do what normally works" (Ibid., p.31) drawing on their knowledge acquired from cumulative experience.

A stream of cognitive research conducted in the 1980s supported this view on expertise (see e.g. Glaser and Chi 1988, Sternberg and Frensch 1992). Expert knowledge was seen as a collection of solution schemas (compact packets of knowledge about the solution suitable for a particular case) to different problems rather than a collection of rules that may be applied under a particular set of circumstances. This schema-based knowledge was enriched with one's experience and allowed experts to 'automatically' provide correct answers to problems that novices spent time on and still answered incorrectly.

Dreyfus and Dreyfus advocate such 'automatic' and 'unconscious' action as an ideal of expert practice:

> "What should stand out is the progression *from* the analytic behavior of a detached subject, consciously decomposing his environment into recognizable elements, and following abstract rules, *to* involved skilled behavior based on an accumulation of concrete experience and the unconscious recognition of new situations as similar to whole remembered ones." (Dreyfus and Dreyfus 1986, p.35)

With this very statement, Dreyfus brothers point to a specific kind of expert knowledge underling 'skilled behavior.' This type of knowledge is crucial for operational experts. The 'skilled behavior'-type expert performance is highly beneficial at the operational stage of complex problem solving, when actual solutions are to be implemented. However, at the stage when the problem solution is searched for, this approach could be extremely harmful.

Recent advances in cognitive science (discussed in more a detail in the following section) indicate that once the non-reflective practice has been established, the inclination for any deliberation before acting reduces at an ever-increasing rate. The power of an automatically identified solution becomes too great to resist, and developing a deeper understanding of the problem becomes virtually impossible. Therefore, experts in the INTUITIVE EXPERTISE sense will usually perform poorly as domain experts who identify solutions for complex problems.

EXHAUSTIVE EXPERTISE

The expert knowledge in the EXHAUSTIVE EXPERTISE perspective, similar to SCIENTIFICALLY GROUNDED EXPERTISE, is based on rules. However, it is not claimed that all rules used by experts should be scientifically grounded. On the contrary, it is emphasized, in an Aristotelian spirit, that expert knowledge has a dual character which requires *techne* (technological know-how) to be applied in parallel with *phronesis* ('ethical know-how'). *Techne* supports a skillful and proficient application of theory (*episteme*), while *phronesis* refers to wisdom and judgment.

Expert practice relying solely on *techne* would be similar to this in the sense of SCIENTIFICALLY GROUNDED EXPERTISE. By applying *phronesis* one allows for a problem to be seen in a broader scope of rights, values, and moral and ethical systems. Without an appropriate assessment and judgment, any investigation of the problem would be limited to a pure consideration of factors that determine feasibility of a particular technology, or procedure application, and as such would lead to the superfluous bounding of a problem and to 'technical fix'-like solutions.

Understanding expertise in the EXHAUSTIVE EXPERTISE sense requires one to acknowledge that solutions to complex problems should be identified in the context of their particularity. The necessity of the unique treatment of each problem does not imply that literally novel solutions are developed for each problem encountered. The need for expert awareness of each situation's uniqueness is emphasized to avoid routine and blind application of known procedures, and not to hinder the employment of suitable and established practices (see

Schön 1991, e.g. pp. 138-139). Such approach seems indeed appropriate, since complex problems although similar are unique.

Experts failing to analyze a particular problem situation in its uniqueness often misperceive its complexity, potentially ignoring some important features that may indicate an appropriate solution. Feltovich et al. (1997) point to such misperception of complexity as one of the main reasons for poor expert performance in the solving of highly complex problems. These cognitive scientists identify 'cognitive flexibility' as an ability to perceive accurately the complexity of the real world. It is hypothesized that different aspects of practice cause an increase or reduction of one's cognitive flexibility. Drawing on their research, Feltovich et al. (1997) claim that experts do not develop and even gradually loose their cognitive flexibility, when resorting to the schema-based, non-reflective practice. These experts gradually perceive the world in a more simplified way, developing primitive and unrealistic mental models of their environment. Acting upon these models, they fail to successfully solve problems encountered. In these cases, experience, so vital to learning and developing one's knowledge, begins to play a destructive role in expertise development.

The research on cognitive flexibility indicates that EXHAUSTIVE EXPERTISE offers the most accurate understanding of expertise especially when referring to domain experts: To increase chances for identification of successful solutions to complex problems, domain experts should study them in its 'full' complexity.

Additionally, a careful selection and constant verification of applied rules are crucial for domain experts' practice:

> "The distinguishing mark of professional knowledge is that reflection is directed towards improving or defending existing practice." (Rolf 1998, p.8)

In the EXHAUSTIVE EXPERTISE perspective, an expert's place in the knowledge creation process is fully recognized. The positivistic distinction between scientists, who are the only legitimate knowledge creators, and experts, who merely apply the findings of science, becomes blurred. Due to the unavoidable specifics of each situation and the variability and instability of the world, the supremacy of the scientific knowledge is denied in the EXHAUSTIVE EXPERTISE perspective. Yet, its utility as a source of the on-going improvements to the existing practices is fully recognized.

Expert in the EXHAUSTIVE EXPERTISE sense applies technical and theoretical know-how (*techne*), but also considers a problem in a broader scope of ethical norms, values and rights (*phronesis*). Bernstein emphasizes the importance of applying such broader perspective in problem solving:

> "(…) *praxis* requires choice, deliberation, and decision about what is to be done in concrete situations. Informed action requires us to try to understand and explain the salient characteristics of the situations we confront." (Bernstein 1985, p.160)

Phronesis is necessary to take into an account and understand the salient characteristics of more complex situations. This knowledge allows for a more adequate treatment of the unique situations we are confronted with.

2.3 Discussion

Much of the recent cognitive science research reports that a striking majority of experts fail to provide successful solutions to highly complex problems.[5] The poor expert performance is primarily attributed to difficulties people have with certain characteristics of complex problems, such as feedback structures, non-linearity of relationships, or delays and their temporal interpretation.[6] Feltovich et al. (1997) point out misperception of the complexity as the second reason for the unsuccessful expert performance. These researchers emphasize that approaching a complex problem in a non-schema-base manner increases substantially chances for finding its appropriate solution. Hence the non-schema based approach may be identified as the most appropriate for the domain experts responsible for defining problems and developing their solutions.

However, defining the problem and finding its appropriate solution, although very important, is not sufficient. The solution needs to be than implemented, and for the implementation to be efficient an application of schema-based rather than non-schema expertise seems to be most advantageous. Hence, the schema-based knowledge may be identified as the most appropriate for operational experts.

Expert knowledge understood as SCIENTIFICALLY GROUNDED or INTUITIVE EXPERTISE is seen as a schema-based knowledge. The solution schemas in the SCIENTIFICALLY GROUNDED view are in the form of scientifically-founded prescriptions, while in the INTUITIVE view they are in a form of scripts that experts internalize in the course of their practice. In the SCIENTIFICALLY GROUNDED EXPERTISE perspective, the applied solution schemas have explicit character while in the sense of INTUITIVE EXPERTISE they remain largely tacit. It has been indicated by various authors both in cognitive and managerial science, that people act to a great degree upon knowledge that is tacit (see e.g. Galotti 1999 and Argyris and Schön 1974, Nonaka 1994). Moreover, it has been reported that those who are successful and adept in their performance, have often difficulties when asked to explicitly formulate the rules upon which they act. Hence, INTUITIVE EXPERTISE is identified as the most plausible understanding of expert knowledge when defining operational expertise.

The ideal performance of operational expert must be "ongoing and non-reflective" (Dreyfus and Dreyfus 1986, p.31) to be effective. However, this performance could hardly be referred to as 'expert' when applied to tasks of domain experts. Here deliberation and thorough understanding are crucial to define a complex problem and design its appropriate solution. Application of the operational expertise would inevitably lead to an unnecessary bounding of the problem and thus its misperception. From the presented review of the research only EXHAUSTIVE EXPERTISE offers a plausible understanding of a domain expert knowledge and practice.

In this perspective, it is emphasized that expert knowledge is not schema-driven. Each solution is designed with a consideration of all aspects of the complex problem. The expert knowledge is dual in its nature encompassing both *techne* and *phronesis*, and the emphasis is laid on the harmonious use of both knowledge elements:

> "*techne* without *phronesis* is blind, while *phronesis* without *techne* is empty." (Bernstein 1985, p.161)

The application of *phronesis* – wisdom and judgment – requires experts to investigate each problem thoroughly. In that way the expert practice is guarded against the 'technical fix' trap. The careful examination additionally allows for identifying problems, which require interdisciplinary treatment, i.e. their appropriate solutions may be designed only when using knowledge from multiple domains. The ability to identify that the particular problem exceeds one's competence is especially important when tackling complex problems. Due to their nature these problems usually are not limited to any particular knowledge domain and do require an interdisciplinary approach.

To deal with complex problems effectively, we should use all expertise available, but it is essential that we use it in a right way.

2.4 Need for a Method to Support Complex Problem Solving

An inappropriate tackling of problems in the complex human system may be especially harmful. Many difficult problems we face today result from inappropriate handling of complex problems in the past. Results of deficient problem solutions not only fell short of expectations, but also often contradict the original intentions. Such unintended consequences are widely accepted as a natural element of our reality. This kind of 'side effects' mentality is well described by Sterman:

> "We frequently talk about side effects as if they were a feature of reality. Not so. In reality, there are no side effects, there are just *effects*. When we take action, there are various effects. The effects we thought of in advance, or were beneficial, we call the main, or intended effects. The effects we didn't anticipate, the effects which fed back to undercut our policy, the effects which harmed the system – these are the ones we claim to be side effects. Side effects are not a feature of reality but a sign that our understanding of the system is narrow and flawed." (Sterman 2000, p.11)

'Side effects' are the effects of policies for which no one wishes to take responsibility. This is often the a case when policies are put in place without making the effort necessary to investigate a particular problem situation together with potential effects of proposed policies. The 'side effects' of quick 'technical fix'-like solutions often become the foundation of new troubling and complex problems. Since societies and communities entrust experts to deliver successful solutions to these problems, it is crucial that the *right* experts undertake this task in a *proper* way.

Domain experts will rarely be successful if their knowledge is based mainly on intuition or theory. EXHAUSTIVE EXPERTISE is necessary to identify problems in their complexity and design their successful solutions. Operational experts will rarely be successful if their knowledge is based mainly on theory or if they deliberate every time they have to perform a task. INTUITIVE EXPERTISE is necessary to efficiently conduct operational experts' tasks. Moreover, a single expert will rarely be successful if she or he tackles complex problems independently. An integrated and interdisciplinary effort with participation of various domain and operational experts is necessary to appropriately tackle complex problems. There is need for a method that would facilitate this.

The method should support interdisciplinary inquiry into a complex problem situation by both domain and operational experts. Only by utilizing all relevant knowledge we would allow for a thorough problem analysis. Such analysis allows us to reduce a possible misperception of the real nature of the problem. Treating complex problems in a ‘technical-fix-free’ manner is vital to their successful tackling.

Beyond facilitating the collaborative expert inquiry into a complex problem situation, our method should also assist in evaluation of possible problem solutions. An increase in complexity of a problem, i.e. an increase in enumerative, relational and temporal dimensions of the problem, implies that the problem’s structure is likely to contain feedback processes, delays and non-linear relationships, and human mind is not fit to tackle these dynamically complex structures.

Finally, the method should not only support solving a particular problem, but also developing and verifying expert knowledge. Solving complex problems is not only difficult, it is also important. These problems relate to a variety of aspects of our life and therefore their solutions affect a great number of people. Being responsible for solving complex problems, experts do play a critical role in modern communities.

Based on the hitherto discussion, three main requirements may be identified as crucial for the method facilitating complex problem solving:

1. Support a multilateral collaboration between various experts
2. Assist in the investigation of dynamic characteristics of a problem
3. Allow for the evaluation and development of expert knowledge

Since system dynamics is designed to help people solve complex problems, in the next section the method is examined to assess a degree to which it fulfills the above requirements.

3 Rational Complex Problem Solving with the System Dynamics Method

In the context of the requirements identified in the previous section, system dynamics potential as a method for complex problem solving will be examined from a broad philosophical and cognitive science perspective. This examination will be an initial attempt to assess the method’s potential. It is important to emphasize that a further, more thorough study of the method principles and practice is necessary for the results to be truly conclusive.

Since the system dynamics method is practiced in a variety of ways, particular types of system dynamics interventions will be considered, rather than the method in general.

Wolstenholme (1990) distinguishes between qualitative system dynamics and quantitative system dynamics. Qualitative system dynamics focuses on development of a conceptual model of a problem situation, while quantitative system dynamics refers to developing a formal, computer-based simulation model. This taxonomy is applied e.g. by Vennix (1996) to distinguish between interventions that deliver only a conceptual description of the problem situation, and these that extend the analysis to deliver also a simulation model. Thus with regard to the process scope, two general types of interventions may be distinguished:

1. Interventions during which only **qualitative analysis** of the problem is conducted and a conceptual model is developed
2. Interventions during which both **qualitative and quantitative analyses** of the problem are conducted and both conceptual and formal, simulation models are developed

Different system dynamics interventions vary also in the extent to and the way in which problem owners are involved in the modeling and problem solving process. With regard to the degree and way in which problem owners are involved, three general types of interventions may be distinguished:

1. **Modeler-driven interventions**, where individual problem owners are contacted independently by the modeler and are not involved directly in the model building process
2. **Group model-building interventions**, where problem owners participate directly in the model building process
3. **Interactive learning environment based interventions**, where problem owners learn how to tackle some complex issue.

Both modeler-driven and group model-building interventions are the types of interventions that take place when some presently faced complex problem needs to be tackled. The interactive learning environment based interventions are conducted for people to learn how to address some complex problems, but do not aim at solving any particular problem. The last type of intervention is applied in slightly different contexts; for the sake of clarity, this type of system dynamics practice will be therefore excluded from the following discussion.

Requirement # 1: Support a Multilateral Collaboration Between Various Experts

Complex problems are often tackled inappropriately by experts. In systems such as economic markets, ecosystems, companies, nations or communities, experts specializing in different areas, e.g. marketing or manufacturing, typically develop their solutions to complex problems independently. Frequently, domain experts propose unfeasible solutions due to their unawareness of actual constrains, or operational experts propose deficient solutions due to their narrowed specialization.

Any system dynamics intervention starts with problem identification (Forrester 1991, p.5). Focusing on the problem to be solved, system dynamicists try to avoid its dangerous classification within the limits of any particular knowledge domain or specialization. Experts from all relevant fields are involved to investigate the problem. Domain experts identify the problem and design its overall solution, while operational experts verify the actual feasibility of a particular solution and eventually implement it. The nature of experts' participation differs depending on the way in which system dynamics intervention is conducted. In the case of a modeler-driven intervention, experts are interviewed independently by the modeler, while in the case of group model-building they collaborate directly during model-building workshops. However, both modeler-driven and group model-building interventions foster the integrated approach which allows experts from all relevant knowledge domains to participate in the investigation of a particular complex problem. Different opinions are taken into account and no particular point of view is favored. Such pluralistic treatment of various knowledge domains is not common when tackling complex problems.

> "Democratic participation is discretely left in the background, in favor of a narrow selection of experts and in favor of the anonymous forces of market economy. Thereby one also weakens the role of a broader ethical discussion of the problems and their possible solution (…)." (Skirbekk 1992, p.2)

Both modeler-driven and group model-building system dynamics interventions facilitate the democratic problem solving in the sense that they treat contributions from all relevant knowledge domains – management, economical, social, technical or other sciences – equally. However, one may pose two questions: (1) Are these types of system dynamics interventions indeed beneficial to communities, since they – in a way – 'favor' experts, ignoring other members of a particular community? (2) Is the discussion between various parties involved in the process facilitated equally well by both modeler-driven and group model-building interventions?

Why Only Experts?

Communities recognize domain experts as having superior knowledge and operational experts as having superior skills in a particular filed, and appoint them to tackle difficult problems. By empowering experts to solve important problems, communities express their belief that delivered solutions will be satisfactory. In this sense domain experts can be seen as holding a unified knowledge: The knowledge consistent with the knowledge and beliefs of other members of their community. This knowledge should allow domain experts to develop policies yielding the system behavior desired by all community members. Similarly, abilities and skills of operational experts must be consistent with practices considered as plausible by their communities. Therefore experts may be seen as those representing knowledge, skills and abilities recognized by their communities.

Experts' understanding of a system is enhanced during any system dynamics intervention. This understanding will allow experts to improve their practice and this should be beneficial to their communities.

Is an interdisciplinary discussion properly facilitated?

A process employing expertise from various domains should ensure that all parties involved understand each other well. For this understanding to be feasible an appropriate, hermeneutic mediation is necessary:

> "(…) [The] need for *interdisciplinary pluralism* implies a need for interdisciplinary *mediation*, since the different experts reports should preferably be presented for the political agents as an intelligible whole. A hermeneutic mediation and methodological reflection on different disciplinary presuppositions and limits should therefore be undertaken. When, finally, the agents are the educated participants of a democracy, this need for critical interdisciplinary mediation between the various scientific contributions becomes even more essential. Without such a reflective mediation these agents would understand the issue less well. This need is therefore a rational one (…) leading from monological

> single sciences to a dialogical and reflective mediation theory to a free and open discussion." (Skirbekk 1992, p.11)

A hermeneutic mediation is based on a hermeneutical cycle process. The process involves a deeper understanding of some external phenomena: we interpret the phenomena, e.g. text, to understand it and make it meaningful to us.[7] During the hermeneutical cycle process an iterative movement between one's internal knowledge and an external object takes place. A description of coming to understanding of studied texts given by Kuhn illustrates the process:

> "When reading the works of an important thinker, look first for the apparent absurdities in the text and ask yourself how a sensible person could have written them. When you find an answer, I continue, when those passages make sense, than you may find that more central passages, ones you previously thought you understood, have changed meaning." (Kuhn 1977, p.xii; quoted after Bernstein 1985, p.132)

A parallel may be drawn between the hermeneutical cycle process and system dynamics group model-building intervention. During this intervention mental models, expressing experts' understanding of the reality, are elicited in a group environment. Often experts' mental models of the same situation vary substantially and this discrepancy is not only a cause of problem situation, but also a barrier preventing a dialogue (Ford and Sterman 1989). Participants interpret their different mental models to understand various positions taken. The process of coming to the mutual understanding is based on the hermeneutical cycle process. Once the understanding is reached, a dialogue in search for most accurate understanding of the reality is enabled. A model, based on the reached consensus, expresses a shared understanding of reality and is adopted by experts as a foundation for their own mental models. Such dialogical process of coming to a shared understanding requires direct contact between experts. Therefore it may only take place during a group model-building intervention.

Modeler-driven interventions, though not facilitating a direct dialog between parties involved, also facilitate a hermeneutic mediation, though of a different type – the so-called 'double hermeneutic process.' This process refers to a situation when a change in one's understanding of a system results from an inquiry into the system conducted by a third party. The change in understanding requires one to interpret the novel explanation of the system delivered by other person as a result of her/his inquiry into and interpretation of the system (Giddens 1976). During a model-driven intervention a similar two levels of interpretation take place. First, modelers elicit mental models of various experts. Then, they interpret this information to understand the problem encountered within a system. They express their understanding of the system in a form of a model. The model in turn must be accepted as valid by experts. This requires that experts interpret the model and accommodate it within their own (possibly re-constructed) understanding of the system. The validated model is eventually adopted by experts as a foundation for their mental models.

Requirement # 2: Assist in the Investigation of Dynamic Characteristics of a Problem

A choice between different policies requires a comparison of the potential effects of these policies. Policy analysis involves 'simulating' a system after each policy implementation. Real-life systems are usually complex and characterized by a high number of feedback processes, non-linear relationships and various delays. Due to their cognitive limitations, people cannot reliably analyze behavior of such systems. Computer-based models, such as system dynamics simulations, may support effectively the analysis.

Therefore only system dynamics interventions that deliver a simulation model fulfill the 2nd requirement.

System dynamics simulation models are much more than mere control and forecasting tools, for they not only allow simulation of different scenarios delivering accurate 'predictions,' but also provide an explicit description of the system structure (Meadows 1980). Only by analyzing the system structure in the context of the generated behavior one may comprehend and reliably identify causes of this behavior. The analysis often delivers counter-intuitive results: for example, experts often identify some variables as main causes of a certain system behavior. Yet, results of various simulation runs may demonstrate that these variables actually have little or no impact. The 'surprise behavior' discoveries can substantially improve the experts' understanding of the system's nature (Forrester 1991).

The inconsistencies between simulation results and experts' expectations are not always due to the supreme simulation capacities of the computer-based models; they may also result from an erroneous structure of the model. This in turn indicates a flaw in experts' understanding of the system, in their mental models: A model behavior is governed by its structure (Forrester 1961, Davidsen 1991). If the model structure differs form the actual system structure, such model will not simulate the system's behavior (or will, but only by chance). When experts expect a model to generate the actual behavior of a system, they must consider the model structure as a valid representation of the real system structure (Forrester and Senge 1980, Barlas 1996). A valid model generating results that differ from the actual data indicates a flaw in experts' mental models. In this way the accuracy and correctness of expert knowledge can be assessed.

Requirement # 3: Allow for the Evaluation and Development of Expert Knowledge

The expert knowledge is evaluated when experts' mental models are challenged and verified, and is developed when experts learn.

Experts' mental models may be challenged and verified by others and by simulation results. Group model-building interventions provide a forum where different opinions may be discussed. In this way the interventions support an examination of experts' knowledge by other experts. The reliability of any assessment of expert knowledge is enhanced when supported by simulation results. Therefore group model-building interventions, employing both qualitative and quantitative analyses of a problem, support the evaluation of expert knowledge in a more comprehensive way than group model-building interventions involving only qualitative analysis. Modeler-driven interventions, as opposed to group model-building interventions, do not provide good environment for experts' knowledge evaluation by others. However, they still can challenge and verify experts' knowledge sufficiently when employing both qualitative and quantitative analyses of a problem.

Experts learn when: (1) their understanding of the way in which the system works is enhanced, and when (2) their knowledge about the system is expanded beyond the scope of their specialization.

Experts' understanding of a system is improved by challenging and verifying their current understanding. The more their current mental models are challenged and verified, the more chances are that any flaws are identified and corrected, i.e. learning occurs. Group model-building interventions during which both qualitative and quantitative analyses of the problem are conducted seem to support in a most comprehensive way this expert knowledge development.

Experts' knowledge about a system may be expanded beyond the scope of their specialization to the greatest degree when they have an opportunity to discuss their understanding of the system with experts of other specializations. In that context, group model-building interventions seem to offer the greatest potential for the interdisciplinary forum allowing for learning about different aspects of the system.

The development of experts' knowledge is consistent with the primary system dynamics goal of improving people's structural understanding of the system, i.e. improving their mental models (see e.g. Richardson and Pugh 1981, Forrester 1991, Vennix 1996, Lyneis 1999). However, this goal may seem at first contradictory to one of the most fundamental system dynamics premises that a system behavior is governed by the system structure. In this context, a change of people's mental models may seem to be of little importance with regard to the system behavior change, since the behavior is to be driven by the system structure, not by a human agent. Therefore:

Why do we care for accuracy and development of experts' knowledge?

In his recent articles, David C. Lane addresses the human agent/structure controversy (Lane 2000a, 2000b). He points out that

> "system dynamics is frequently mis-judged as (…) [taking] an extremist dehumanising view of the extent of structural control on human agency." (Lane 2000a, p.11)

Addressing this criticism, Lane indicates that one could come to such a mechanistic view of system dynamics, for example based on Forrester's statement that

> "decisions are not entirely 'free will' but are strongly conditioned by the environment." (Forrester 1961, p.17, as quoted by Lane 2000a, p.13)

Lane argues:

> "In discussing the policies represented in a model (…) [Forrester] does say that, 'the people's reactions are a consequence of the changes of the system within which they are embedded.' Crucially, he then offers an extended quotation which supports the notion of that the environment that controls human decision making is <u>itself</u> made by human decisions." (Lane 2000a, p.13, quoting Forrester 1961, p.16)

Forrester in his work indeed illustrates control of the environment over human decision-making. However, Lane's indication that Forrester implies that the environment is "made by human decisions" (Ibid.) is somewhat mistaken. Based on Forrester's work what forms the environment are policies and not decisions:

> "By policy I mean the criteria for decision-making. Policy is the rationale that determines how a stream of decisions will be modulated in response to changing inputs of information." (Forrester 1980, p.8)

To change a policy means to change a system's structure. System dynamics models are used "to alter policies for the purpose of changing the environment that *induces* decisions." (Forrester 1980, p.17 (italics added))

Making a clear distinction between decisions and policies is a key to identifying the system dynamics position in the human agent/structure debate. It is also important to realize that without a good, structural understanding of the system, an effective change in policies, i.e. in the system's structure, is not possible.

That people act upon their understanding of the reality is consistent with Gadamer's hermeneutics. He argues for the interrelationship of three elements essential in hermeneutics: understanding, interpretation and application.

> "[According to Gadamer a]ll authentic understanding (…) is not detached from the interpreter but becomes constitutive of his or her *praxis*." (Berstein 1985, pp.145-146)

As mentioned earlier, system dynamics process resembles the hermeneutical cycle process and yields understanding that is ultimately interrelated with human actions:

> "The type of knowledge and truth that hermeneutics yields is practical knowledge and truth that shapes our *praxis*." (Ibid., p.150)

People's actions are always guided by some policies that are based on their current understanding of a system, i.e. their current mental model of the system. To follow different policies that would modify the structure of the system in such a way so it yields a better behavior, people need to reformulate appropriately their mental models.

Policies describe the intimate link between human actions and system: the link that empowers people to change the system behavior. For this change to be possible, indeed a change in mental models of experts, as those who design and implement policies in our systems, is necessary.

4 Concluding Remarks

Among studies conducted to assess effectiveness of system dynamics interventions, most refer to group model-building interventions and evaluate their effectiveness and impact based on (often qualitative) empirical data.[8] The examination presented in this paper is an initial attempt to assess the system dynamics method's potential in a broader philosophical and cognitive science perspective.

A point of departure was a general analysis of what it requires to be an expert who successfully tackles complex problems. Three main requirements for a method that would facilitate effective expert complex problem solving were defined as: (1) support a multilateral collaboration between various experts, (2) assist in the investigation of dynamic characteristics of a problem, and (3) allow for the evaluation and development of expert knowledge.

In the context of these requirements, system dynamics was examined by discussing a degree to which each requirement is fulfilled by a particular type of system dynamics intervention. To summarize these discussions, an initial evaluation of how well each requirement is met by the particular intervention type is presented in Table 1.

Table 1 The degree to which various types of system dynamics practice fulfill the three requirements defined as crucial to meet for a method supporting complex problem solving

		Requirements and their fulfillment		
Type of system dynamics intervention		Support a multilateral collaboration between various experts	Assist in the investigation of dynamic characteristics of a problem	Allow for the evaluation and development of expert knowledge
Modeler-driven modeling	Qualitative	Limited	Poor	Limited
	Qualitative & Quantitative	Limited	Very Good	Good
Group model-building	Qualitative	Good	Poor	Good
	Qualitative & Quantitative	Good	Very Good	Very Good

Based on this preliminary analysis, it may be concluded that all types of system dynamics interventions meet the defined requirements. However, group model-building employing both qualitative and quantitative modeling seems to fulfill the requirements to the greatest extent.

The broader philosophical and cognitive science perspective suggested in this paper can guide both assessment and improvement of various types of system dynamics interventions. Developing and applying such framework may be a valuable asset in the ongoing search for most effective ways to practice system dynamics.

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Notes

[1] This paper is based on a research paper in philosophy of science submitted in partial fulfillment of the requirements for the Ph.D. degree in system dynamics to the University of Bergen, Norway in January 2001.

[2] The enumerative dimension of complexity is referred to as 'detailed complexity' by Sterman (2000) and 'enumerative complexity' by Murthy (2000).

[3] A number of cognitive science studies document various human mind limitations (for an overview see e.g. Galotti 1999), with a landmark study of George Miller (1956) indicating that processing capacity for most of adults is limited to seven, plus or minus two information chunks.

[4] Other core philosophers of the positivistic thought, such as Auguste Comte and John Stuart Mill, also discarded the non-scientific sources of knowledge though they argued knowledge obtained from such sources is false rather than meaningless.

[5] When given complex problems to solve, experts often perform no better than novices, and often their solutions are worse than those given by a simple linear model approximating optimal decisions. The scope of this paper does not allow for detailed analysis of these findings, but only their brief review. For additional discussion of expert performance see e.g. Dörner 1989, Sterman 1989, Ericson and Smith 1991, Hoffman 1992, Dörner and Wearing 1995, Feltovich et al. 1997.

[6] People perform poorly when they try to infer the behavior of complex systems containing feedback processes, delays and non-linear relationships. The vast body of research in this domain has been conducted in Germany dating back to 1970s (see e.g. Dörner 1989, Funke 1991). In the system dynamics community, people's problems with inferring behavior of complex systems were pointed out by Forrester (1961), and a number of experimental work in this domain has been conducted (see e.g. Kleinmuntz and Thomas 1987, Sterman 1989, Moxnes 1998, Sweeney and Sterman 2000).

[7] Hermeneutics initially was a method for interpretation and understanding of religious texts. Later the method was applied for analysis of other written texts, as well as speech and actions.

[8] See e.g. Vennix et al. 1996, Cavaleri and Sterman 1997, Huz et al. 1997, and Vennix and Rouwette 2000 and Vennix et al. 1993 for comprehensive surveys of group model-building interventions.

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