

ACT Water Management: A System Dynamics Based Learning Intervention

Sondoss El Sawah, Alan Mclucas

s.elsawah@studnet.adfa.edu.au, a.mclucas@adfa.edu.au

University of New South Wales, Australia

Abstract

Since the inception of System Dynamics (SD) modelling and simulation around 50 years ago, researchers and practitioners have sought to foster in-depth understandings of complex, dynamic problem situations with the aim of improving individual and group strategy-development and decision-making performance. Whilst considered by many to be a mature discipline, SD still falls short of being universally accepted by managers and strategists as a tool used to inform decision making. Arguably wider acceptance is inhibited by the following key issues; how decision makers think about complex problems, and challenges in demonstrating the validity of the very models developed during SD interventions to represent a problem situation, and hence building confidence in those models and strategies developed from them. Evaluative research is now considered necessary to further investigate the ways decision makers think about complex problems and the utility of SD as a learning, strategy-development and decision-support tool.

This research designs a SD intervention to address a complex real-world problem. From the outset the conduct of the research and the findings will be subjected to critical evaluation. It uses a two-phase methodology to test, at both holistic and feature levels, an **SD-Based Interactive Learning Environment (SDBILE)** developed for the purpose of investigating how decision-makers, both managers and consumers, think, decide and make actions which impact upon the limited water resources of a confined geographical territory. At the holistic level changes to patterns of water consumption arising from re-framing of the thinking of consumers and managers will be investigated. At the feature level, an experimental study will test the impact of model transparency on understanding the problem structure and dynamics. A Theory-Based Evaluation (TBE) approach will be used to examine those factors that might make participation in a series of SDBILE simulations a valuable learning experience.

An argument often found in the SD literature is that decision-makers' understanding of structure of a given problem situation leads to superior results in strategy development. The essence of this argument is that understandings of the structure of cause-and-effect mechanisms, often involving feedback (circular causality) and delay mechanisms, limit variety and thereby act to constitute order. As a result, decision-makers heighten their awareness and become capable of developing superior remedial strategies.

It is becoming increasingly evident that the water shortage problem described in this paper is inherently complex, involves circular causal feedback mechanisms and delays, and exhibits counter-intuitive responses to management strategies. The problem exhibits those characteristics which make it a good candidate for ST/SD research.

The TBE methodology is followed to ensure the veracity of two related tests. Firstly, empirical evidence will be gathered to test the *transparency assumption* or *designer logic*. Here the extent to which making those feedback structures underpinning a

problem situation explicit, that is overtly transparent, affects the performance of the decision-maker. Second, the veracity of a set of simulation models is tested insofar as they facilitate the investigation of the water resource management problem and enable the development of strategies for managers and users respectively.

This research will capture and examine the mental models initially held by water users and resource managers. A series of 'micro-world' simulations will be designed to test the development of mental models held by users and managers evolve during the intervention. Whether it is possible to significantly influence individual interpretations of the structural mechanisms that underpin the dynamics of the water resource management problem will be investigated. How this might then influence both individual behaviour and broader social actions will be investigated. This paper is the first on a series which will report on the research as it progresses.

Keywords: System Dynamics based Interactive Learning Environment, Learning, Evaluation studies, and water management.

I. Introduction

System Dynamics (SD) is one particular form of methodological and practical application of systems thinking (ST) philosophy and theory. Arguably, after fifty years of development, SD is now established as a discipline. Whilst the philosophy and theory of SD have been well documented for decades, SD methodology and practice are less well established and continue to evolve. It is the last of these, the practice of SD, is still in a relative state of flux.

Midgley (2000) makes a compelling argument that in developing sound systemic intervention we cannot separate the philosophy, theory, methodology and practice: indeed, each must inform the other. Whilst SD approaches maturity, refinements in methodology and practice are still needed. This suggests there is still a need for research into methodology and practice which necessarily calls for further testing the assumptions that underpin previously published SD studies.

SD focuses on the underlying causes of dynamic complexity. Somewhat paradoxically it is the nature of the complexity itself that makes it difficult to establish the veracity of claims of success in SD-based interventions. This may explain the controversy about some SD studies.

Investigations in the realm of physical sciences seek to satisfy the 'repeatability' criterion. That is, experimental results replicated under exacting conditions by different investigators at different times and in different places returning the same result are accepted as demonstrably repeatable. This is necessary for the results to be accepted as being true. In contrast, investigations into complex socio-technical and socio-economic problems which characteristically involve 'hard' and 'soft' variables, complex feedback mechanisms and delays are rarely, if ever, precisely repeatable.

At best, research investigations or interventions based on ST and SD can be shown to be 'recoverable'. The 'recoverability' criterion is necessarily less strong than the 'repeatability' criterion but is stronger than 'plausibility'. For 'recoverability' to be achieved, the whole research activity or intervention, including the methodology to be employed must be made explicit [and, therefore, unambiguous amongst stakeholders] from the outset, so that in **(Checkland & Poulter 2006)(Checkland & Holwell 1998)**.

Lane (2001) observes:

“the theoretic assumptions of the field are seldom explicit but rather are implicit in its practice”.

This suggests that SD researchers and practitioners need to continuously externalize, that is, make explicit the philosophies and theories that underpin their understanding of SD methodology and how their interpretations are translated into practice. This would require them submitting their own mental models to processes of scrutiny and evaluation.

Several (unproven) hypotheses appearing frequently in the SD literature suggest there is a need for further research which investigates SD practice, tracing back through methodology to theoretical and philosophical roots:

- The relationship between mental model's accuracy and decision-makers' poor performance in dynamic tasks (**Gary & Wood 2005**)
- The efficacy of ST/SD in improving the quality of mental models (**Huz et al. 1997**) (**Cavaleri & Sterman 1997**), and managing dynamic systemic problems (**Ozge & Vennix 2005**).
- Whether systems archetypes (**Senge 1990**) limit or expand decision-makers' capabilities to reason in settings where circular feedback causality arise (**Richardson et al. 1994**) (**Richardson 1996**),
- The efficacy of Group Model Building processes (**Vennix 1996**) (**Andersen et al. 1997**) in promoting learning and the possibility of learning transfer from the individual to the organizational level (**Schaffernicht 2006**) (**Rouwette et al. 2002**),
- Whether learning about systemic structure improves decision making in situations where dynamic complexity exist (**Kim 1993**) (**Grossler 2000**) (**Spector & Davidsen 2000**).
- The efficacy of computer-based SD interventions in promoting learning, improving decision making and fostering behavioural changes (**Maier & Grossler 2000**) (**Doyle et al. 2007**).

Bringing the spotlight back to these theoretical hypotheses, sometimes taken in contemporary SD literature to be sacred premises, does not seek to challenge the success claimed for previous SD intervention projects. Rather, it seeks to build additional strength into the SD field thereby enhancing opportunities for broader acceptance.

Richardson (1996) and Rouwette and Vennix (2003) argue that well-documented research and practice findings, in which confidence is high, accumulate eventually thereby creating an empirically based theoretical foundation for decision making and learning in dynamic systems. Rigorously controlled studies which result in defensible evidence being well presented will serve to convince sceptics about the scientific efficacy of SD interventions (**Doyle 1997**). This research seeks to strengthen SD as a reputable research field (**Andersen et al. 1997**).

Adding to the corpus of evaluative research, this paper presents an exposé of an ongoing research project in which a computer-based SD learning intervention is designed and evaluated. Since statements about the efficacy of a learning intervention should be context dependent (**Grossler et al. 1999**) (**Klabbers 2006**), the project focuses on assessing the impact of learning of users and managers about the increasingly serious water-shortage problem in the Australian Capital Territory (ACT), which is described in more detail later.

This context stimulates research interests for a couple of reasons. The problem is similar to shortages experience in dry regions around the world. It represents a significantly complex and challenging domain, one where environmental, social and psychological variables interact and are in a state of flux. This presents particular challenges for designing effective learning environments (**Exter & Alison**

2003)(Stave 2003) (Pahl-Wostl 2007). From a social perspective, as hot winds of drought and prospects of permanent water shortages appear on the horizon, it is now critically important to arm ourselves with investigative and learning tools which promise to improve both our ability to understand and our long-term ability to manage scarce water resources. As residents of the ACT we also seek to find ways to improve the prosperity of our community.

The paper is organized as follows:

- Section I presents the research background and relevant learning evaluative research literature.
- Section II contextualizes the research study in terms of the ACT water resource management problem. It spots light on relevant types of interventions in an attempt to appropriately position the proposed intervention in the Environmentally Significant Behaviour literature.
- Sections III and IV outline the research roadmap and formulate the proposed assessment framework.
- Finally, the paper reflects on the motivation for the study, expected contributions and challenges to its successful completion.

I. Research background/Literature Review

Learning Assessment in SD Literature

In a reflection on his long career as a pre-eminent as a systems scientist, Jay Forrester (1985) distinguished two learning paths in SD:

- learning by interacting with simulators or computer-based SD learning intervention (Doyle et al. 1996) (Hirscha,Gary & Immediato 1999)(Fischer & Barnabè 2007), and
- learning by interacting with the modelling process.

Zagonel (2002) crafted the term “modelling dichotomy” to differentiate two specific roles allocated to models. A SD model may enable research by being a “micro-world” or a “boundary object”:

- “Micro-worlds” are designed to both enable investigation of a problem situation and engage decision-makers in developing or testing various candidate strategies.
- A “boundary object” enables investigation of the impacts of changing the boundary of a problem situation.

It is important to note that in ST/SD studies a boundary is convenient device for limiting the scope of a study. It is arbitrarily draw around a problem space. The consequences of where, or how, we draw any boundary can be profound. Drawing boundaries in different ways can lead us to different problem formulations with potentially different strategies for addressing a problem situation.

Midgley (2000) argues that defining the boundary in a systemic intervention also involves moral judgements because we, the modellers or researchers, make a series of

choices about which of the stakeholders should be included or excluded. This will impact upon the possible mental models developed to explain to problem, to form the basis for studying it, for taking some form of remedial action, and acceptability by stakeholders of likely remedial actions.

In general, the SD methodology is viewed as a feedback process in which knowledge from mental models is elicited and used to develop a formal model, which in turn creates new opportunities for learning that improve the accuracy, coherence, and complexity of mental models (Doyle et al. 2007). Doyle and Ford (1998) expressed this belief as:

“Mental models are thus the stock in trade of research and practice in system dynamics: they are the “product” that modellers take from students and clients, disassemble, reconfigure, add to, subtract from, and return with value added”

Even though this belief is widely accepted by many ST/SD researchers, the efficacy of these interventions in achieving such goals is still controversial even within the SD society (Zagonel 2004). Based on alternative learning perspectives, it is possible to determine three approaches for learning assessment at the individual level.

Using an iceberg metaphor, the virtual performance-oriented approach represents only the tip of learning, while the behaviour-oriented approaches reside at the deeper, and rarely explored, levels of evaluation. In a virtual performance oriented approach the intervention is conducted over a relatively short period with performance being measured during or at the end of the intervention. The knowledge-oriented approach seeks to measure subjects' knowledge pre and post the intervention. The behaviour-oriented approach seeks to achieve changes in behaviour based on longer-term knowledge development. Figure 1 portrays the timeframe for each approach relative to the timeframe for conducting learning intervention.

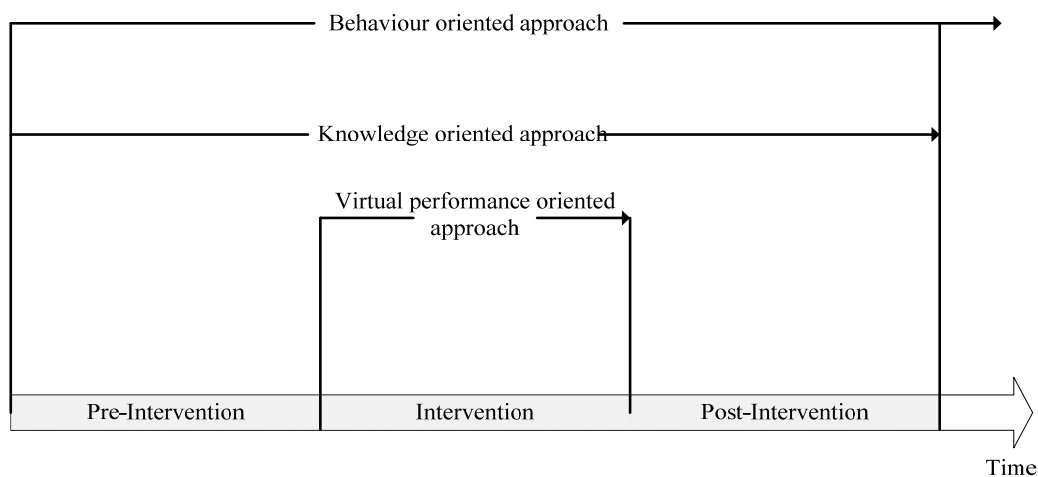


Figure 1 Learning assessment approaches

One objective of defining such an evaluative taxonomy is to help in identifying critical blind spots in literature. It is, therefore, important not to limit discussion to any particular one of these SD learning interventions. Each is examined below.

Virtual performance oriented approach

In a virtual performance oriented approach, learning is measured using a performance score, for example the profits accumulated or the costs incurred at the end of the game session, such as used in the Beer Distribution Game (**Sterman 1989**). Behind this approach is the premise that relative success achieved by players in a simulation is a reasonable indicator of understanding; hence knowledge gained from the virtual environment can be translated into improved decision making and performance (**Bakken 1989**). This is considered the most convenient and, therefore, the most common assessment approach in which outcome and process are loosely coupled (**Woods et al. 1994**). Unfortunately, the nature of the coupling, that is, the mechanisms by which knowledge might be translated into performance and performance might inform the development of knowledge are not made explicit. This approach touches only superficially on the concept of learning.

Moreover, the virtual performance oriented approach emphasises a “video game” mentality, whereby individuals repeat experimentation trials until their scores improve with little reflection on [or in-depth understanding of] why their actions produce a certain outcome (**Kim 1989**) (**Senge 1989**). This reinforces the “gaming control” goal rather than “acquiring knowledge” (**Gruber et al. 1993**) (Grüber et al., 1993). In other words, observed improvements in the participants' performance is attributed to “short term learning to improve performance”, rather than “long term performance improvement” (**Langley & Morecroft 2004**). Results obtained from such studies are not conclusive, as they do not bring any [real] insights into whether the learning objectives were achieved (**Sawicka & Campbell 2001**). In addition, a methodological problem may occur through using the simulator to satisfy two functions that of being both a development and assessment tool (**Grossler et al. 1999**). Further, Funke (1993) asserted the need to distinguish between knowledge acquisition and knowledge application.

Knowledge oriented approach

In the knowledge-oriented approach, learning is viewed using acquisition metaphor (**Sfard 1998**) where (strategic and domain-specific) knowledge development and transmission are the expected outcomes of the process (**Bakken et al. 1994**). SD researchers typically prefer to represent this knowledge gain in terms of the observed changes in the complexity and accuracy of mental models, that is, theories-in-use pre- and post- the intervention (**Vennix 1990**) (**Doyle et al. 1996**) (**Spector 2001**) (**Christensen et al. 2000**) (**Schaffernicht 2006**) (**Gary & Wood 2005**). This approach has roots in behavioural decision making where relevant behaviour is “reasoned” and influencing the cognitive processes underlying behaviour choices will also affect these choices themselves, as stated by Ajzen (1991) .

“At the most basic level of explanation ... behaviour is a function of salient information, of beliefs, relevant to the behaviour ... It is these salient beliefs that are considered to be the prevailing determinants of a person's intention and actions”

However, this approach is criticized because:

- as yet little supportive evidence has been presented (**Klabbers 2000**);
- most work has focused on observing change in cognitive structures, overlooking the endurance of such change (**Dhawan et al. 2007**);

- assessment techniques used are subjective, as they rely heavily on pre- and post- game questionnaires and interviews (**Doyle et al. 1996**) (**Romme 2004**); and
- as Grössler (1999) suggests, what is actually measured is the “perceived effectiveness” or “the learning effect as perceived by learners”, which is not necessarily the actual effect.

“To measure perceived effectiveness, therefore, can only be an additional element (or a first step) of evaluation research”

Behaviour-oriented Approach

In the behaviour-oriented approach, using the participation metaphor, learning is demonstrated when changes in behaviour appear. SD interventions hold out the promise that new thinking and new insight will generate new ways of acting (**Isaacs & Senge 1992**). However, the relationship between mental models and behavioural intent is neither simple nor easily determined. There is no clear evidence that adequate mental models may alter individual actions in a certain way. Alternatively, individuals show skilful ways to sustain their old habits which thwart actual learning (**Argyris & Shon 1974**).

Through a study of public understanding of how thermostats work, Kempton (1986) (**Kempton 1986**) found that people who typically hold correct [operative knowledge] models about the system consume more energy [in heating and cooling their homes, for example] than those who did not have any correct understanding. Since the research is extended beyond the laboratory to the daily practices in the real world, it remains the most challenging, overlooked and time/labour intensive but most promising approach. According to Doyle (1997)

“... assessments of systems thinking interventions should measure both behavioural *and* cognitive changes”

However, SD learning evaluative research is still in its infancy. There appears to be ambiguity about which cognitive processes change and how they are changed, particularly as the intervention stimulates different levels of knowledge acquisition from the basic skill level to the higher abstract (**Bakken et al. 1994**). There is a significant lack of experimental studies and consequently little evidence to give confidence in how the cognitive processes are influenced (**Doyle 1997**) (**Grossler et al. 1999**) (**Romme 2004**). Moreover, research conducted is locked at superficial assessment levels (**Schaffernicht 2006**). Despite appearing to be correct, we argue that all these reasons are merely the problem symptoms, while the central cause appears to be what Davidsen et al. (1999) (**Davidsen et al. 1999**) described as the disturbing gap in the SD community knowledge about learning theories:

“... that these theories are reasonably well established and articulated but have not been embraced by the system dynamics learning community is somewhat disturbing”

SD researchers need to expose themselves to a wider spectrum of learning and program evaluation theories. Since most evaluation studies are done by researchers who are familiar with simulations, we can reasonably assume that simulations perform as intended, and that simulation performance can be, or has been,

comprehensively verified. However, explaining learning by experimentation through simulation requires detailed understanding of the relationship between learning and knowledge (**Hense et al. 2007**).

Understanding this relationship depends upon fundamental consideration of the nature of knowledge, how knowledge is formed and how it is structured, that is the related “ontology”. How knowledge is formed and expressed depends on the experiences through which the knowledge was acquired and even the language, icons and symbols used to both describe and communicate that knowledge.

Ways of thinking, expressed in terms of “epistemology”, can differ markedly from individual to individual. It would be a mistake for either SD researchers or practitioners to assume that all who face a problem situation will think about the problem in the same way. This applies equally to whether it is possible to formulate a solution by applying any particular way of thinking or, indeed, if a solution is possible.

For example, ST is an epistemology, with its own philosophy and theories. This epistemology sets the foundation for both methodology and practice. ST/SD researchers and practitioners cannot assume that all involved in, or affected by, a study will have a shared understanding of the problem faced or have shared belief in any epistemology that might be applied during the study. Midgley (2000) suggests some researchers argue that ontology and epistemology are inseparable, leading to the notion of “onto-epistemology”. We need to consider these additional factors about knowledge generating systems such as how knowledge developed, stored and communicated will be essential if we are to be effective in the conduct of our research. We are duty-bound to conduct this research which challenges our philosophical and theoretical foundations otherwise are at risk and vulnerable to getting entrapped in a “dead node” (**Klabbers 2000**) or “repeating history” (**Grossler 2003**).

System Dynamic Based Interactive Learning Environments

Technology-based learning environments are growing in number and areas of application. However, the debate about their learning effectiveness and their value to the society continues as well. Tansey and Unwin (1969) called for investigating the learning effects of computer based simulations and games:

“There comes a time when hunches must be proven or rejected before they become myths, jargon or commercial folklore. Pertinent questions exist to be answered, and on the answers rests the future of gaming and simulation as techniques”

Computer based simulations lie on a continuum between representing a set of dogmatic beliefs [defined in an authoritarian way without little basis in the real world] and representing reality with high levels of fidelity. This suggests there is a gap between practical experience with interactive learning environments and scientific evidence to support claims of success (**Klabbers 2000**). Based on our research interest, we focus our attention to a particular type of learning environments, those

built using the SD methodology. In order to avoid any confusion caused by using any ambiguous and imprecise terminology commonly used in either gaming or SD literature, for example, Flight Management simulators, Micro-worlds, learning environments)(Maier & Grossler 2000), we prefer to uniformly use the definitive term “System Dynamics Based Interactive Learning Environment” (SDBILE) (Spector & Davidsen 2000). Thus, it becomes clear that participants learn by directly intervening with a SD simulation model (Lane 1995).

As a member computer based learning family, SDBILE inherited the questionable effectiveness history (Lane 1995) (Maier & Grossler 2000) (Doyle et al. 2007) (Paich & Sterman 1993), even in the SD community itself which implicitly, and sometimes explicitly, favour learning by interacting with the modelling process (Davidsen et al. 1999) (Zagonel 2004). It is not our intention to criticize or defend any of them because [their perceived] superiority is problem-sensitive (Zaraza et al. 1998). For instance, in case of large number of target learners, for example, citizens of a city, learning by modelling becomes relatively difficult. Therefore, we will narrow the discussion to the effectiveness of SDBILE in learning about complex systems.

SDBILE may be categorized into black-box and transparent models. SDBILE is tagged transparent/visible if learners can access the structure of the underlying model. In contrast with black-box models, learners are not only able to examine the outcome of their previous decisions, but trace the causal chain of such result (Grossler 2000). Drawing upon the literature of psychological decision making (Balzer et al. 1989), transparent SDBILE advocates share the belief that it is not sufficient to provide only behaviourally oriented feedback about complex systems but providing cognitive feedback in form structural information will further lead to better understanding and improved decision making (Spector & Davidsen 1999). However, research has been limited, with mixed and sometimes contradictory evidence presented.

Richardson et al. (1994) (Richardson et al. 1994) started the discussion about transparency when they differentiated “designer logic” and “operator logic” with respect to simulations. The designer logic hypothesis suggests that when decision makers are exposed to the structural representation of complexity sources, their thinking patterns become correspondingly sophisticated and hence their abilities to predict system responses and manage effectively are increased. The operator logic hypothesis suggests that a more direct route to improving decision making lies in providing managers not with design logic but with improved strategies and tactics for accomplishing their aims. In a later work, they supported their argument experimentally (Andreson et al. 1994).

Under the title “transparency”, research continued by four groups:

- Grössler at Mannheim;
- Spector and Davidsen at Bergen University;
- Machuca in Seville and
- Langley in London.

Using Ashby's law of requisite variety (Ashby 1956), Spector and Davidsen, (2000) (Spector & Davidsen 2000) explain that knowing about the problem structure limits variety and thereby acts to constitute order. Thus, the decision making task becomes

more manageable and cognitively accessibly. They add that this brings understanding not only about a given situation but enables knowledge transfer into other domains and across time.

Davidson (2000) views transparent SDBILE lying on the mid-way between the two learning avenues. He claims that uncovering the model structure carries in depth knowledge to those who do not get the opportunity to participate in the modelling process. In contrast with black-box simulation, Machuca (2000) (**Machuca 2000**) asserted that transparent SDBILE defies trial-and-error learning and enables both self and distant learning.

Langley and Morecroft (2004) illustrated experimentally how an online task structure feedback helped participants to outperform the control group even when the help was removed in later trials. In contrast, Goodman and Wood (2004) argued that increasing the feedback specificity is beneficial for initial performance but discourages exploration and undermines the learning needed for later, more independent performance. The results of their transfer experiment demonstrated that increasing the specificity of feedback positively affected practice performance, but its benefits did not endure over time, or result in modification of the task. While Grössler (1999: 2000) suggested that highlighting the intimate relationship between system structure and behaviour helps in understanding the phenomenon observed, Alessi (2001) disagreed justifying that black-box simulators encourage specific exploration which fosters better understanding. Given this snapshot of the current debate, testing the assumption of transparency effects is a worthwhile exercise to undertake.

III. Research Context: ACT Water Shortage Problem

Australia is referred to as the driest inhabited continent on Earth. Uncertainty characterizes the supply and demand of water across much of the country where water resources are under pressure on several fronts (**Pigram 2006**). The research described in this paper focuses on water available in the Australian Capital Territory (ACT). The ACT was built early in the 20th Century to house the Australian Federal Government and its many Government departments. It is now home to just over 300,000 inhabitants, numerous commercial and industrial enterprises and a smaller number of rural and agricultural activities. The ACT is land-locked territory on the southern highlands located within the state of New South Wales. The ACT has a temperate climate with an average rainfall in the range of 450-600 mm. The ACT covers some 65 kilometers from North to South and 35 kilometers from East to West. It is bordered by, and shares many of its resources with, several smaller towns, villages and rural communities. The ACT is seriously threatened by water shortage due to population growth, increasing usage *per capita*, the aftermath of the 2003 bushfires in the Cotter catchment and long-term climate change.

The current water crisis in Australia is not just a crisis of low rainfall and climate change, but a complex socio-technical [and socio-economic] crisis where technological, environmental, economic, psychological and social dimensions are all in flux (**Sofoulis 2005**). Water shortage, as with most of social problems, is characterized by being: a history dependent untamed problem, where the system may escape external control attempts by adaptation, and human may behave in an unanticipated manner (**Exter & Alison 2003**)(**Stave 2003**) (**Pahl-Wostl 2007**).

Traditional 'pipes, pumps and prices' oriented approaches ignore the complexity added by human behaviour. Whilst the 'people and perception' aspects are critical, because of the inextricable links to human behaviour, they are given little consideration. Recently, water authorities recognized that their core business is no longer limited to providing sufficient supply, but expanding to include the management of water demand; that is, how and why people use water (**Gleick et al. 2003**) (**Shove 2003**).

Environmentally Significant Behaviour (ESB) oriented Interventions

Individuals affect their environment either directly making decisions which harm the environment (e.g. over-consumption of water, using anti-environment products) or indirectly by making decisions in business and organizations which cause harm (**Stern 2000**).

Since all environmental problems, including resources degradation, result from the aggregated outcome of human actions, therefore problems need to be re-conceptualized as a function of the social and psychological factors (**Stern 1992**) (**Mazanov 2007**).

Stern's (**1995**) causal model is a good starting point to explain the socio-psychological factors deriving ESB. The model outlines the role of institutional processes and social values in guiding general belief systems, attitudes, intentions, and behaviour. The model provides a useful theoretical and empirical base to organize and systematically evaluate economic, social, and psychological factors determining EBS behaviour in general. Figure (2) depicts a modified version of the model adopted from Stern (**1995**).

According to the model, higher-level structures are more stable, less susceptible to transient influences, and more resistant to change relative to lower-level structures. Moreover, higher-level structures have a greater influence on lower-level structures than lower-level structures have on them (this is recognized by the bold downwards arrows). This explains why some researchers have overweighted the effectiveness of macro-level focused interventions with respect to changes done at the individual level (**Stern 2000**) (**Brown & Cameron 2000**).

While important, we argue that both types should go hand by hand. Taken to the extreme, an exclusive focus on the macro-level approach may lead to reification of the change process. If a phenomenon is reified, actors come to believe that they have no control over it (**George & Jones 2001**). Micro-level based interventions still represent a high leverage point for cultivating the seeds of organizational change (**Kim 1993**), as that they represent the momentum of social learning. Senge et al. (1997) referred to individuals as the "place of change". It is necessary to recognize that, first and foremost, change is initiated and carried out by individuals. Second, macro-level process of change should be well informed by analysis of change at the individual level. Therefore, modest outcomes of micro-level interventions should not be devalued. When small numbers of people start behaving differently, that behaviour can ripple outward until a critical mass or "tipping point" is reached, changing the world face (**Gladwell 2002**).

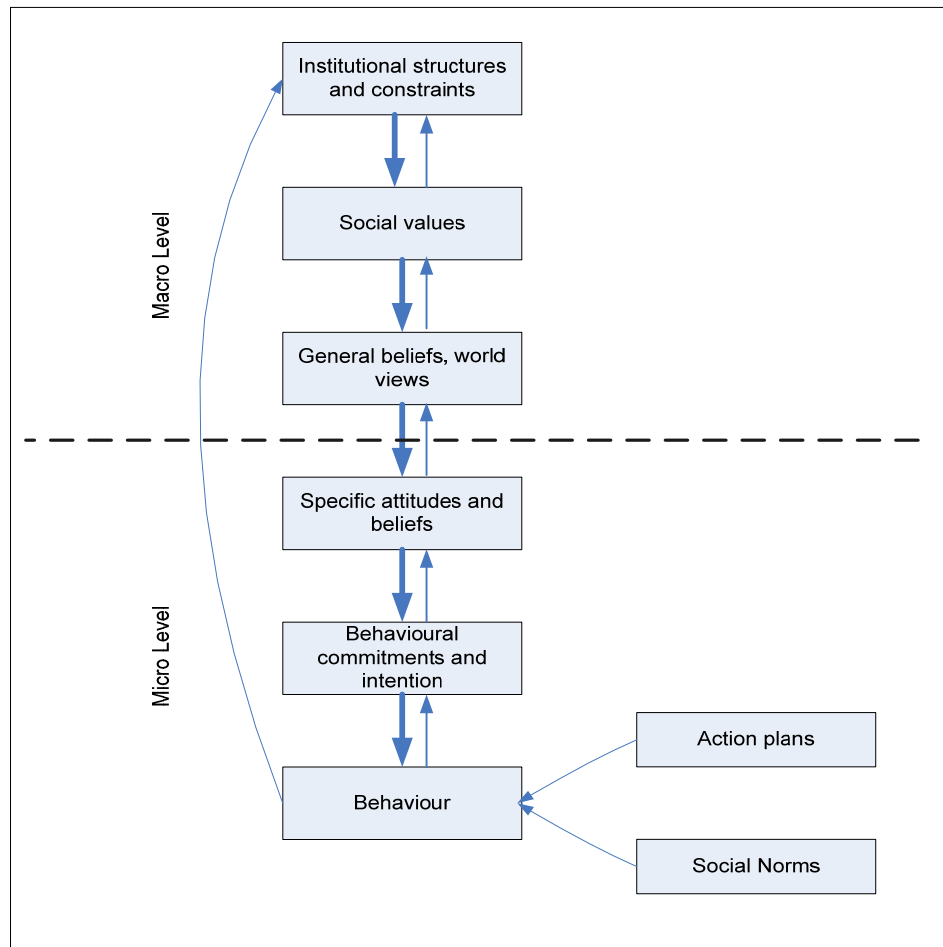


Figure 2: A modified version of Stern's (1995) ESB model

A Micro-level learning Intervention

Facing an overwhelmingly complex situation with limited cognitive capability and knowledge, individuals and organizations as social systems need to effectively learn about the problem expanding their boundaries of understanding to comprehend inherent sources of complexity (**Sterman 2000**) (**McLucas 2003**). Learning provides the leverage for changing the dysfunctional and undesired situation.

For this “double-loop” learning to occur, people need more than merely feedback about the outcome of their decisions. They need to systemically learn about the cause-and-effect relationships which impact upon the water shortage problem as well as the accumulated, long term and irreversible effects of their action. If people do not learn about the systemic economically, socially and environmentally problematic generated consequences of their behaviour, they are not expected to alter it. Users have to be able not only to examine the results of their decisions but also the causes of these results, providing the possibility for reflection.

In SD language, people need to learn about the underlying system structure and the intimate relationship between system structure and behaviour. Feedback heightens understanding of the problem or “awareness of consequences” (e.g. of environmental effects), affecting their attitude, and strengthening their inclination and possibilities to adopt other, less harmful kinds of behaviour (Liebrand & Messick

1996). Our basic assumption, as SD practitioners and researchers] is that learning about the systemic structure heightens the awareness of the long term, delayed, distant and collective consequences of users' actions. Only, when people learn how to “think globally and act locally”, they will comprehend the evolving systemic risk. Kreps explains the feedback based decision process [Kreps, 1990 #271]:

“Individuals make individual choices, and the institutional framework aggregates those actions into an aggregate outcome which then determines constraints that individuals face and outcomes they receive. If individuals take a “trial shot” at an action, after the aggregation is accomplished and the feedback is fed back, they may learn that their actions are incompatible or did not have quite the consequences they foresaw. This leads individuals to change their individual actions, which changes the feedback, and so on”.

However, people find it difficult to estimate the effects of accumulation over time and infer the system structure from externally viewed system behaviour (Dorner 1997) (Sterman 1989). Complexity sources, feedback effects, delays, nonlinearity, have to be cognitively mediated by making use of advances in computer aided modelling. This opens up the opportunity for gaming simulation as a method to support people and organizations in dealing with the sustainable (re)construction of their reality (Kriz 2003).

This suggests that using computer aided system thinking and modelling tools for improving learning in complex decision making (Brehmer 2005) (Sterman 1994). Reaching this point of discussion, we think that the rationale behind the development and evaluation SDBILE for water management has been well materialized for readers supported by evidence from SD and ESB literature. In addition, the link between the research hypothesis and context is established.

IV. Proposed Research Design

Our research projects passes by two major phases: design and evaluation. Figure 2 is an annotated roadmap of the proposed research design. In the design phase, we follow a classical System think/dynamics intervention to build the proposed SDBILE (Sterman 2000). From a traditional point of entry, we identify the client, problem, purpose and the preliminary dynamic hypothesis of the problem.

- Client: ACT community (as the affected social group) and ACTEW (as the problem owner) (Vriens,Dirk & Achterbergh 2006).
- Problem: Water demand management in ACT.
- Purpose: To hone learning of users about the causal structure and dynamics of the ACT water shortage problem.

The oval shapes in Figure 3, starting on the left and read top to bottom then on the right top to bottom list the research activities. Corresponding to these are the design phase and evaluation phase activities, shown in the shaded boxes.

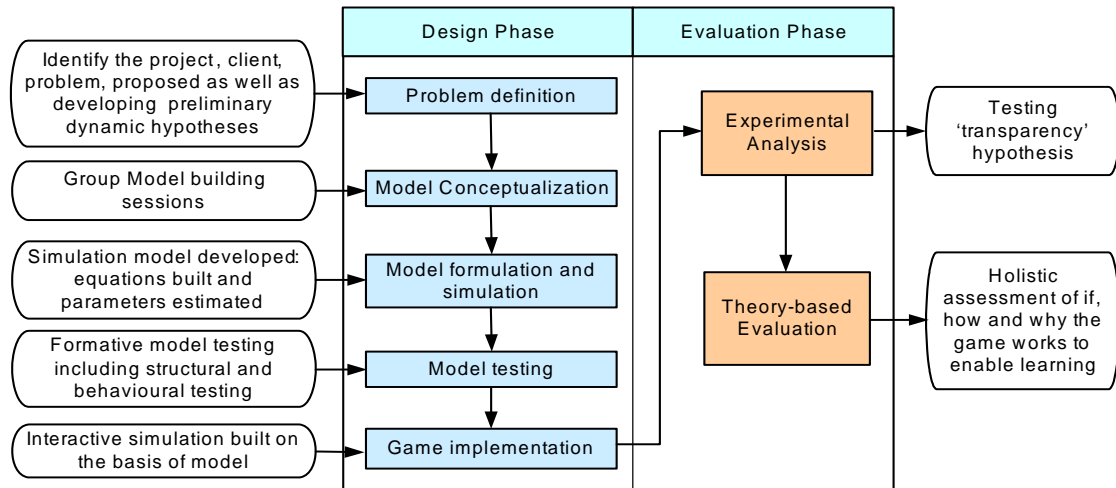


Figure 3: An annotated roadmap of the proposed research design

Preliminary Dynamic Hypothesis

The project is currently in the conceptualization phase. Planning based on a literature review and preliminary engagement with the client has culminated in a set of dynamic hypotheses. A preliminary nested Causal Loop Diagrams (CLD) is sketched using concepts and variables previously tested in literature. The diagram contextualizes the decision process in terms of the complex cross-level interactions among environmental, social, and individual level variables. It investigates the overall influence of water users' decisions on water shortage problem. The preliminary diagram acts as a good starting point for organizing available knowledge and highlighting the key hypothesis for empirical assessment. Figure (4) shows an overview of the nested CLD with the cross level interactions. In order to facilitate communication, we develop a separate, easily digested CLD for the environmental, social and individual level respectively in figure 5, 6 and 7. Each level is connected to the previous level by a relationship denoted by an arrow or a variable.

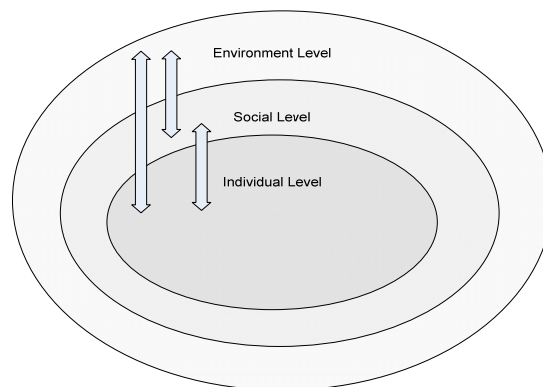


Figure 4: Outline of the nested CLD

Any system consists of physical structure and the decision rules used by people in the system (the behaviour structure). It is usually recommended to start by capturing the physical structure since it is easier to visualize and less controversial (Sterman 2000). Figure (5) depicts the dynamics of environment relevant variables.

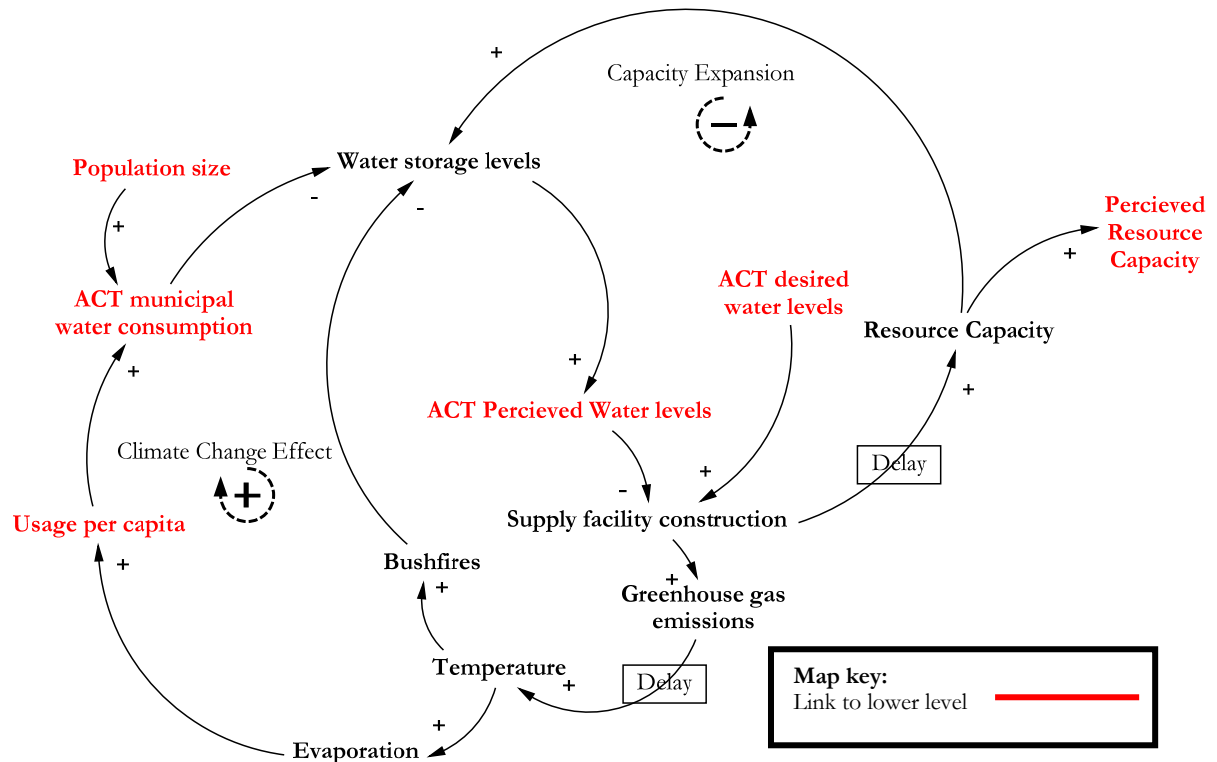


Figure 5: The dynamics of the problem at the environment level

The traditional approach to water management problem has been a new supply facility construction (e.g. a dam, desalination plants). Whenever the perceived water levels decrease, the pressure to increase capacity increases. Although these gigantic energy-hungry projects would supply a small percentage of urban water, they produce greenhouse emissions that add to the global warming, produce drier climates, increase water demand and probability of bushfires at a longer term (Sofoulis 2005)(Gleick et al. 2003).

At a social level, when people perceive an increase in the resource capacity, their perceived water levels increase which leads to the “myth of abundance” or “*big pool illusion*”. They overestimate the resource level and assume that the pool is large enough, by using a large quantity of the resource (Roch & Samuelson 1997) (Gustafsson et al. 1999). Then water consumption becomes a social norm and people become thirstier for water. The “myth of abundance” has a spiralling effect at the individual and collective levels. Water users search for statements and behaviour of others which support their perception. For example, they may falsely interpret the over-consumption of others as an increase in water levels and hence an increased opportunity for consumption (Rapoport et al. 1992). In other words, the attractiveness for consumption increases at the individual level and water consumption becomes a habit.

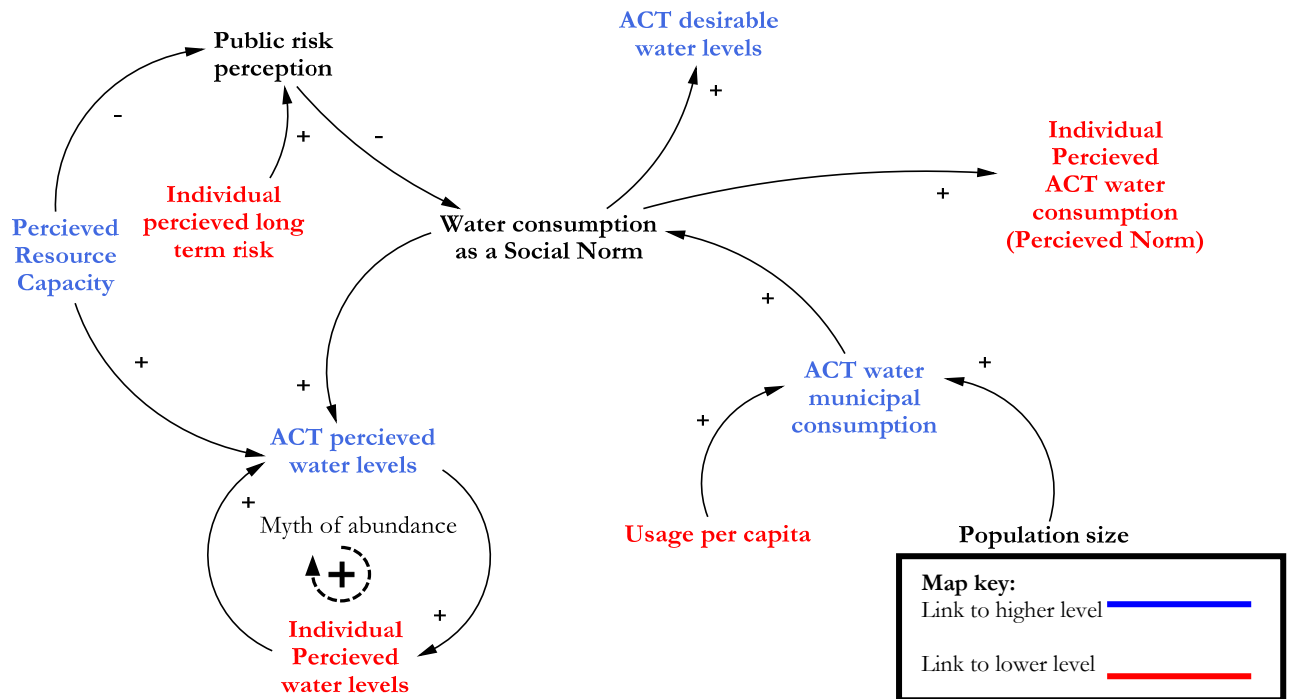


Figure 6: The dynamics of variables at the social level

On making decision regarding their water use, people consider long term risk and efficacy of water saving. Risk perception is a subjective construct significantly influenced by factors such as gender, national culture, age and other collective and individual determinants (**Jens & Peter 2006**). Whenever people are able to perceive risks, they are more willing for cooperative behaviour. Dealing with environmental risks in general and common-pool resources in particular, consequences are delayed, distant, irreversible and systemically generated. As we have closely discussed earlier, human decision-making anomaly centres on outcomes that occur to us, here, now, and for sure. Consequences that deviate in one or more of these aspects are valued less, that is, they tend to be discounted. There is much evidence that humans discount outcomes that are uncertain, temporally delayed, spatially distant, and/or occurring to others. In other words, they are not aware of the real consequences. This may explain why we were riveted to the entrapment of three whales by ice, while unmoved by the extinction of more than 50,000 species every year (**Suzuki 1996**).

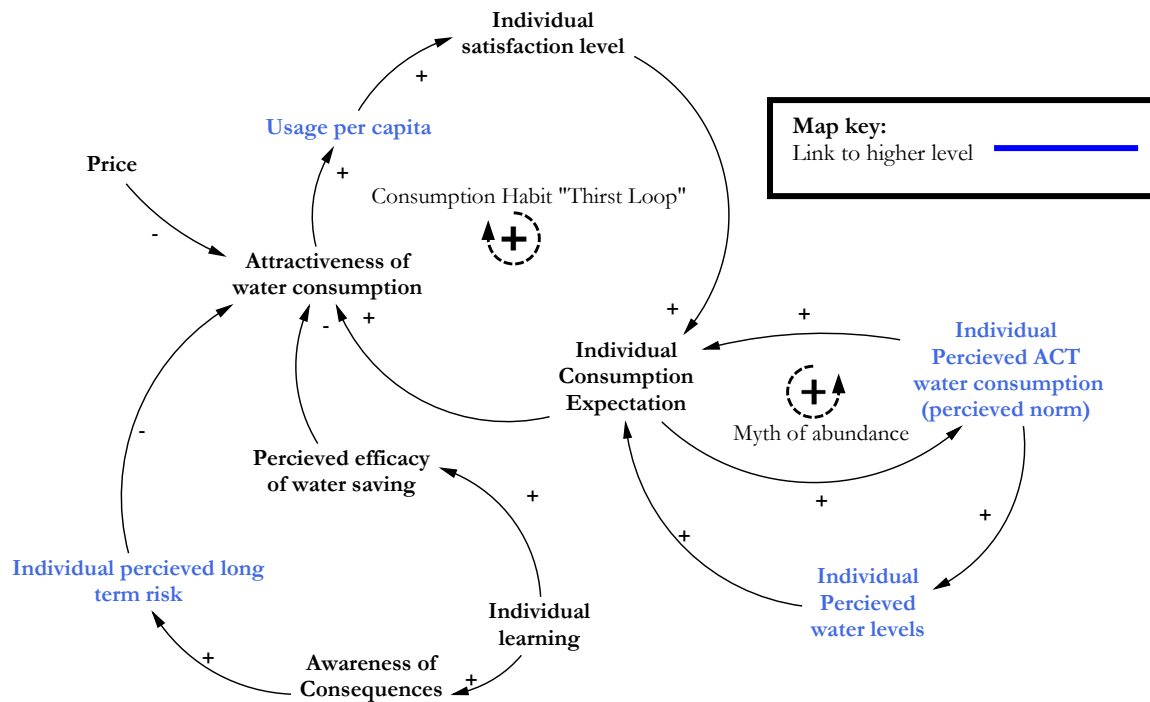


Figure 7: The dynamics of variables at the individual level

Moreover, users usually hold the assumption that “water shortage is too big for individuals to make a difference”. They believe that the resource usage/conservation per person have a minimal effect on the resource depletion. They fail to grasp that individual-level resource management decisions sum, across billions of individuals' actions, to societal-level management in ways that are mysterious, partly irrational, and yet all-important (Vlek & Steg 2002) (Thompson & Stoutemyer 1991). Therefore what seems to be rational at the individual level may be catastrophic at the global scale. Social dilemma research suggests that cooperation varies directly with consumers' perceived efficacy, or the extent to which users believe that their own contributions can actually “make a difference” (Van Lange et al. 1992).

A Theory Based Evaluation Framework

In the evaluation phase, a two-phase learning summative evaluation methodology is used, comprising an experimental study and Theory-Based Evaluation (TBE). The experimental study is conducted to investigate the effect of the systematic treatment of model transparency on learning outcomes. This slowly-but-surely approach is essential for building testing particular theories about particular SDBILE characteristics. As declared by Grössler (1999)

We are not heading towards establishing a theory about the general effectiveness of business simulators, but it is—at least—possible to articulate hypotheses about characteristics of business simulators which cause effectiveness under certain circumstances. These hypotheses can be scrutinized using the evaluation approach of experimenting with business simulators that differ in one characteristic. In conclusion, the search for characteristics of business simulators which are effective for specific groups of users in specific situations can replace the search for the absolute value of simulators.

A TBE is conducted to take the evaluation further beyond testing outcomes with regard to meeting learning goals to explaining those mechanisms that make participation in the game a successful learning experience. There is a frequent critique about the traditional “variance-based” experimental approaches shortcomings which are strictly concerned whether the effect is observed regardless of the underlying process. The debate about the conception of causality from “variance-based” versus “process-based” lens is one of the methodological issues that SD needs to settle in order to penetrate Social Science thoroughly (**Morris 2005**). As Maxwell (2004) asserted:

“...a realist process-oriented approach to explanation ... recognizes the explanatory importance of context of the phenomena studied,...an relies fundamentally on an understanding of the process by which an event or situation occurs, rather than simply a comparison of situations involving the presence or absence of the presumed cause”

TBE is a process-oriented approach, which provides information about the interaction of the causal mechanism and the desired outcome. It is a flexible approach for inferring causality in practical settings (**Reynolds 1998**). The framework of assumptions underlying evaluation is referred to as “program theory”. Logic models are derived from many sources, such as: cognitive learning theories, social science theories, previous research and stakeholders' input. When the theory on which the logic model is built, is fine grained, the evaluation can capture each link in the chain of assumptions. However, discovering that the theory is not quite right or failing to collect data about all mediating variables should not devalue the evaluation efforts. A logic model still helps to: clarify how the learning process is actually working, focus on key factors, provide a framework to structure interpretation of results, and identify areas for improvement in the game design or implementation (**Kriz & Hense 2006**) (**Birckmayer & Weiss 2004**). Each evaluation study is unique to particular settings, and findings can not be generalized.

The program theory should be distinguished from the formal model underlying the simulation model embedded in the SDBILE. To the best of our knowledge, TBE has not been applied to any SDBILE before. The program theory developed for this study is shown in figure (8). At this stage of evaluation, two questions are addressed:

- Does participation in the game have effects on the short-term and long term outcomes?
- Which elements in the input and process contribute substantially to predicting the outcomes of participation?

This two-phase evaluation methodology helps to overcome the tension in literature about role of simulations/gaming in the “science of analysis” and “design science” (**Klabbers 2003:2006**)(**Kriz 2003**). Where academics (opponents of analytical science) rely on experimental design and statistical analysis to test their hypothesis, professionals (opponents of design science) design and assess the usability of specific games with clearly defined context and audience. In order to bypass this gap, knowledge and findings from the experimental study are used as input into the design practice (**Kriz & Hense 2006**).

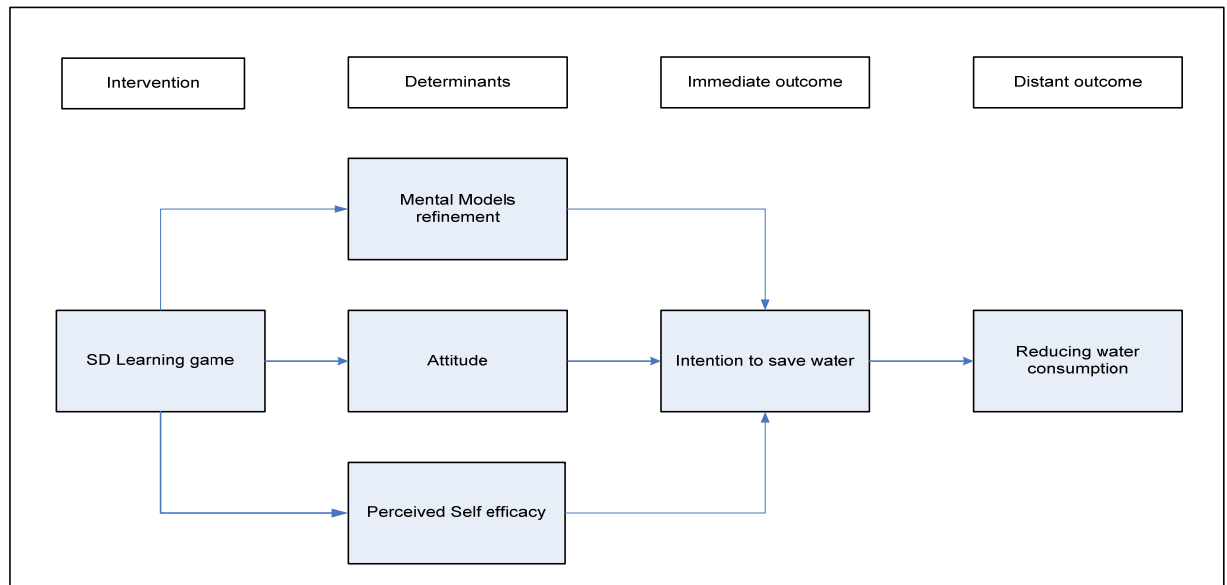


Figure 8: Proposed program theory

V. Conclusion

The research described in this paper is motivated by a desire to avoid the undesirable consequences of potentially erroneous claims of accelerating learning that flow from systems thinking and desire to develop valuable tools that as Sterman (2001) suggests should really help us understand complexity, design better operating policies, and guide effective change.

This research is informed by Klabber's (2003b) design-in-small (DIS) and design-in-large (DIL) metaphors, where games (DIS) are designed, evaluated and used with the intent to change existing dysfunctional situations into preferred ones. It is expected that this research will make two key contributions. Because the work is based on experimentally-driven evaluative it is expected to bring new evidence, evidence that will eventually accumulate to build a theory about learning effects of transparent SDBILE.

In the short term we expect that the experimental findings will inform the design and development of interactive learning-centered risk communication tools to raise the awareness of people about the evolving water shortage problem in ACT. As ACT becomes continuously threatened by water shortage, it is critically important to arm ourselves with these learning tools. At the individual level, they support people to gain new cognition, sensibilities and insights which often lead to new attitudes (DIS). If a large number of ACT residents succeed to change their personal attitudes, this will ultimately act as a catalyst towards a cultural change within the whole society (DIL).

Though the project is only in the conceptualization phase, SD has been valuable in enabling both thinking about a serious and complex problem and provided the basis to communicate potential strategies about addressing the problem.

References:

- Ajzen, I. 1991, 'The theory of planned behavior', *Organizational Behavior and Human Decision Processes*, vol. 50, pp. 179-211.
- Alessi, S. 2001, 'Model transparency in educational System Dynamics', in *International Conference of the System Dynamics Society*.
- Andersen, D., Richardson, G. & Vennix, J. 1997, 'Group model building: adding more science to the craft', *System Dynamics Review*, vol. 13, no. 2, pp. 187-201.
- Andreson, D., Maxwell, T., Richardson, G. & Stewart, T. 1994, 'Mental Models and Dynamic Decision Making in a Simulation Welfare', in *International System Dynamics Conference*, Stirling, Scotland, pp. 11-28.
- Argyris, C. & Shon, D. 1974, *Theory in Practice: Increasing Professional Effectiveness*, ossey-Bass, San Francisco.
- Ashby, W. R. 1956, *An introduction to Cybernetics*, Chapman & Hall Ltd, London.
- Bakken, B. E. 1989, 'Learning in dynamic simulation games: Using performance as a measure', in *Computer-Based Management Of Complex Systems*, eds. P. Milling & E. Zahn, Springer, Berlin, pp. 309-316.
- Bakken, B. E., Gould, J. & Kim, D. 1994, 'Experimentation in Learning Organizations: A Management Flight Simulator Approach', in *Modeling for learning organizations*, eds. J. Morecroft & J. Sterman, Productivity Press, pp. 243-266.
- Balzer, W. K., Doherty & O'Connor, J. 1989, 'Effect of Cognitive Feedback on Performance', *Psychological Bulletin*, vol. 106, no. 3, pp. 410-433.
- Birckmayer, J. & Weiss, C. 2004, 'Theory-based evaluation in practice: What do we learn?', *Evaluation Review*, vol. 24, no. 4, pp. 407-431.
- Brehmer, B. 2005, 'Micro-worlds and the circular relation between people and their environment', *Theoretical Issues in Ergonomics Science*, vol. 6, no. 1, pp. 73-93.
- Brown, P. & Cameron, L. 2000, 'What can be done to reduce overconsumption?', *Ecological Economics*, vol. 32, pp. 27-41.
- Cavaleri, S. & Sterman, J. 1997, 'Towards evaluation of systems thinking interventions: a case study', *System Dynamics Review*, vol. 13, no. 2, pp. 171-186.
- Checkland, P. & Holwell, S. 1998, 'Action Research: Its nature and validity', *Systemic Practice and Action Research*, vol. 11, no. 1, pp. 9-21.

- Checkland, P. & Poulter, J. 2006, *Learning for Action: A Short Definitive Account of Soft Systems Methodology and its use for Practitioners, Teachers and Students*, John Wiley & Sons.
- Christensen, D., Spector, J., Sioutine, A. & McCormack, D. 2000, 'Evaluating the impacts of system dynamics based learning environments: preliminary study', in *18th International System Dynamics Conference*, Bergen, Norway.
- Davidsen, P. 2000, 'Issues in the design and use of system-dynamics-based interactive learning environments', *Simulation & Gaming*, vol. 31, no. 2, pp. 170-177.
- Davidsen, P., Spector, J. & Milrad, M. 1999, 'Learning in and about simple systems', in *International Conference of the System Dynamics Society*, Wellington.
- Dhawan, R., O'Connor, M. & Borman, M. 2007, 'What Our Mental Models Retain and What They Don't: An Experimental Follow-up of System Dynamics Intervention', in *International Conference of the System Dynamics Society*, Boston.
- Dorner, D. 1997, *The Logic of Failure: Recognizing and Avoiding Error in Complex Situations*, Perseus Books Group.
- Doyle, J. 1997, 'The cognitive psychology of systems thinking', *System Dynamics Review*, vol. 13, no. 3, pp. 253-265.
- Doyle, J. & David, N. 1998, 'Mental models concepts for system dynamics research', *System Dynamics Review*, vol. 14, no. 1, pp. 3-29.
- Doyle, J., David, N., Radzicki, M. J. & Trees, S. 2007, 'Mental models of dynamic systems', in *Complex Decision Making*, Springer Berlin, pp. 269-294.
- Doyle, J., Radzicki, M. J. & Trees, S. 1996, 'Measuring the Effect of Systems Thinking Interventions on Mental Models.', in *International System Dynamics Conference*, Boston.
- Exter, K. d. & Alison, S. 2003, 'Assisting Stakeholder Decision Making using System Dynamics Group Model-building', in *Australian Pacific Extension Network Forums*, Hobart.
- Fischer, M. M. & Barnabè, F. 2007, 'Microworld development: Transforming tacit knowledge into action', *Simulation & Gaming*.
- Forrester, J. W. 1985, 'The "model" versus a modeling "process"', *System Dynamics Review*, vol. 1, no. 1, pp. 133-134.
- Funke, J. 1993, 'Microworlds Based on Linear Equation Systems: A New Approach to Complex Problem Solving and Experimental Results', in *The Cognitive Psychology of Knowledge*, eds. G. Strube & K. Wender, Elsevier Science, Amsterdam, pp. 313-330.

- Gary, M. S. & Wood, R. E. 2005, 'Mental Models, Decision Making and Performance in Complex, Dynamic Environments', in *The 23rd International Conference of the System Dynamics Society*, Boston.
- George, J. M. & Jones, G. R. 2001, 'Towards a process model of individual change in organizations', *Human Relations*, vol. 54, no. 4, pp. 419-444.
- Gladwell, M. 2002, *The tipping point: how little things can make a big difference*, Back Bay Books.
- Gleick, P. H., Haasz, D., Henges-Jeck, C., Srinivasan, V., Wolff, G., Kao Cushing, K. & Mann, A. 2003, *Waste Not, Want Not: The potential for urban water conservation in California*, Pacific Institute for Studies in Development, Environment and Security, Oakland, California.
- Goodman, J. S. & Wood, R. E. 2004, 'Feedback Specificity, Exploration, and Learning', *Journal of Applied Psychology*, vol. 89, no. 2, pp. 248-262.
- Grössler, A. 1999, 'Musings about the effectiveness and evaluation of business simulators', in *CUSA Workshop on "Introducing the business plan as a learning tool to support SMEs' growth"*, Palermo, pp. 1-15.
- Grössler, A. 2000, 'Enhancing learning capability by providing transparency in business simulators', *Simulation & Gaming*, vol. 31, no. 2, pp. 257-278.
- Grössler, A. 2003, 'Don't let history repeat itself - methodological issues concerning the use of simulators in teaching and experimentation', *System Dynamics Review*, vol. 20, no. 3, pp. 263-274.
- Grössler, A., Notzon, I. & Shehzad, A. 1999, 'Constructing an Interactive Learning Environment (ILE) to Conduct Evaluation Experiments', in *International System Dynamics Society*, New Zealand.
- Gruber, H., Renkl, A., Mandl, H. & Reiter, W. 1993, 'Exploration strategies in an economics simulation game', in *Simulation-based experiential learning*, Springer-Verlag, Berlin, pp. 225-233.
- Gustafsson, M., Biel, A. & Garling, T. 1999, 'Overharvesting of resources of unknown size', *Acta Psychologica*, vol. 103, p. 47.
- Hense, J., Kriz, W. & Wolfe, J. 2007, 'Putting theory-oriented evaluation into practice: A logic model approach for evaluating SIMGAME', in *forthcoming in Simulation & Gaming*.
- Hirsch, Gary & Immediato, C. S. 1999, 'Microworlds and generic structures as resources for integrating care and improving health', *System Dynamics Review*, vol. 15, no. 3, pp. 315-330.
- Huz, S., Andersen, D. F., Richardson, G. & Boothroyd, R. 1997, 'A framework for evaluating systems thinking interventions: an experimental approach to mental health system change', *System Dynamics Review*, vol. 13, no. 2, pp. 149-169.

- Isaacs, W. & Senge, P. 1992, 'Overcoming limits to learning in computer-based learning environments', *European Journal of Operational Research*, vol. 59, pp. 183-196.
- Jens, O. Z. & Peter, T.-G. 2006, 'Risk as an interdisciplinary research area', in *Risk in Social Science*, ed. O. Z. a. P. Jens, Taylor-Gooby, Oxford University Press, pp. 20-47.
- Kempton, W. 1986, 'Two theories of home heat control', *Cognitive Science*, vol. 10, pp. 75-90.
- Kim, D. 1989, 'Learning laboratories: Designing a reflective learning environment', in *Computer-based Management of Complex Systems*, eds. P. Milling & E. Zahn, Springer-Verlag, Berlin.
- Kim, D. 1993, 'The link between individual and organizational learning', *Sloan Management Review*, vol. 35, no. 1, pp. 37-50.
- Klabbers, J. 2000, 'Learning as acquisition and learning as interaction', *Simulation & Gaming*, vol. 31, no. 3, pp. 380-406.
- Klabbers, J. 2003a, 'Gaming and simulation: Principles of a science of design', *Simulation & Gaming*, vol. 34, no. 2, pp. 569-591.
- Klabbers, J. 2003b, 'Simulation and gaming: Introduction to the art and science of design', *Simulation & Gaming*, vol. 34, no. 4, pp. 488-494.
- Klabbers, J. 2006, 'A framework for artifact assessment and theory testing', *Simulation & Gaming*, vol. 37, no. 2, pp. 155-173.
- Kriz, W. 2003, 'Creating effective learning environments and learning organizations through gaming simulation design', *Simulation & Gaming*, vol. 34, no. 4, pp. 495-511.
- Kriz, W. & Hense, J. 2006, 'Theory-oriented evaluation for the design of and research in gaming and simulation', *Simulation & Gaming*, vol. 37, no. 2, pp. 268-283.
- Lane, D. C. 1995, 'On a resurgence of management simulatons and games', *Journal of the Operational Research Society*, vol. 46, pp. 604-625.
- Lane, D. C. 2001, 'Rerum cognoscere causas Part I—how do the ideas of system dynamics relate to traditional social theories and the voluntarism/determinism debate?', *System Dynamics Review*, vol. 17, no. 2.
- Langley, P. A. & Morecroft, J. 2004, 'Perfomance and learning in a simulation of oil industry', *European Journal of Operational Research*, vol. 155, pp. 715-732.
- Liebrand, W. B. & Messick, D. 1996, 'Social dilemmas: Individual, collective and dynamic prespectives', in *Frontiers in Social Dilemmas Research*, eds. L. W. G. & D. Messick, Springer, pp. 11-38.

- Machuca, J. A. 2000, 'Transparent-business simulators: An aid to manage the complexity of organizations', *Simulation & Gaming*, vol. 31, no. 2, pp. 230-239.
- Maier, F. & Grössler, A. 2000, 'What are we talking about?—A taxonomy of computer simulations to support learning', *System Dynamics Review*, vol. 16, no. 2, pp. 135-148.
- Maxwell, J. 2004, 'Causal Explanation, Qualitative Research, and Scientific Inquiry in Education', *Educational Researcher*, vol. 33, no. 2, pp. 3-11.
- Mazanov, J. 2007, 'Psychology and climate change', *InPsych Bulletin*.
- McLucas, A. C. 2003, *Decision Making: Risk Management, Systems Thinking and Situation Awareness*, Argos Press, Canberra.
- Midgley, G. 2000, *Systemic Intervention - Philosophy, Methodology and Practice*, Springer.
- Morris, D. R. 2005, 'Causal inference in the social sciences: Variance theory, process theory, and system dynamics', in *International Conference of the System Dynamics Society*.
- Ozge, P. & Vennix, J. 2005, 'Effect of system dynamics education on systems thinking inventory task performance', *System Dynamics Review*, vol. 21, no. 2, pp. 147-172.
- Pahl-Wostl, C. 2007, 'The implications of complexity for integrated resources management', *Environmental Modelling and Software*, vol. 22, no. 5, p. 561.
- Paich, M. & Serman, J. 1993, 'Boom, bust, and failures to learn in experimental markets', *Management Science*, vol. 39, no. 12, pp. 1439-1458.
- Pigram, J. 2006, *Australia's water resources: From use to management*, National Library of Australia.
- Rapoport, A., Budescu, V., Suleiman, R. & Weg, E. 1992, 'Social dilemmas with uniformly distributed resources', in *Social dilemmas—Theoretical issues and research findings*, eds. W. Liebrand, D. Messick & H. Wilke, Oxford: Pergamon Press, pp. 43-57.
- Reynolds, A. J. 1998, 'Confirmatory Program Evaluation: A Method for Strengthening Causal Inference', *American Journal of Evaluation*, vol. 19, pp. 203-221.
- Richardson, G. 1996, 'Problems for the future of system dynamics', *System Dynamics Review*, vol. 12, no. 2, pp. 141-157.
- Richardson, G. P., Anderson, D. F., Maxwell, T. A. & Stewart, T. R. 1994, 'Foundations of mental models research', in *International Conference of the System Dynamics Society*, Stirling, Scotland.

- Roch, S. G. & Samuelson, C. D. 1997, 'Effects of Environmental Uncertainty and Social Value Orientation in Resource Dilemmas', *Organizational Behavior and Human Decision Processes*, vol. 70, no. 3, pp. 221-235.
- Romme, A. 2004, 'Perceptions of the value of microworld simulation: Research note', *Simulation & Gaming*, vol. 35, no. 3, pp. 427-436.
- Rouwette, E. & Vennix, J. 2003, 'Process and outcomes of modeling: an attempt at formulating a conceptual framework', in *International Conference of the System Dynamics Society*, New York.
- Rouwette, E., Vennix, J. & Mullekom, T. V. 2002, 'Group model building effectiveness: A review of assessment studies', *System Dynamics Review*, vol. 18, no. 1, pp. 5-45.
- Sawicka, A. & Campbell, D. 2001, 'Facilitating learning in System Dynamics Practice', in *19th International System Dynamics Conference*, Atlanta.
- Schaffernicht, M. 2006, 'Detecting and monitoring change in models', *System Dynamics Review*, vol. 22, no. 1, pp. 73-88.
- Senge, P. 1989, 'Organization Learning: A new challenge for system dynamics', in *Computer-based Management of Complex Systems*, eds. P. Milling & E. Zahn, Springer-Verlag, Berlin.
- Senge, P. 1990, *The Fifth Discipline: The art and practice of the learning organization*, Doubleday Currency.
- Senge, P., Kleiner, A., Roberts, C., Ross, R. & Smith, B. 1997, *The fifth discipline fieldbook*, Currency Doubleday, New York.
- Sfard, A. 1998, 'On Two Metaphors for Learning and the Dangers of Choosing Just One', *Educational Researcher*, vol. 27, no. 2, pp. 4-13.
- Shove, E. 2003, *Comfort, Cleanliness and Convenience*, Library of Congress.
- Sofoulis, Z. 2005, 'Big Water, Everyday Water: A Sociotechnical Perspective', *Continuum*, vol. 19, no. 4, pp. 445-463.
- Spector, J. 2001, 'Models and Simulation for learning in complex domains: using causal loop diagrams for assessment and evolution', *Computers in Human Behavior*, vol. 17, pp. 517-545.
- Spector, J. & Davidsen, P. 1999, 'Transparency and interaction in System Dynamics based learning environments', in *Annual Meeting of the American Educational Research Association*, Quebec, Canada.
- Spector, J. & Davidsen, P. 2000, 'Cognitive complexity in decision making and policy formulation', in *Systems Perspectives on Resources, Capabilities and Management Processes*, pp. 155-171.

- Stave, K. 2003, 'A System Dynamics Model to Facilitate Public Understanding of Water Management Options in Las Vegas, Nevada', *Journal of Environmental Management*, vol. 67, pp. 303-313.
- Sterman, J. 1989, 'Misperceptions of Feedback in Dynamic Decision Making', *Organizational Behavior and Human Decision Processes*, pp. 301-335.
- Sterman, J. 1994, 'Learning in and about complex systems', *System Dynamics Review*, vol. 10, no. 2/3, pp. 291-330.
- Sterman, J. 2000, *Business Dynamics: Systems Thinking and Modeling for a Complex World*, McGraw-Hill/Irwin.
- Sterman, J. 2001, 'System Dynamics Modeling: Tools for Learning in a Complex World', *California Management Review*, vol. 43, no. 4, pp. 8-25.
- Stern, P. 2000, 'Psychology and the science of human-environment interactions', *American Psychologist*, vol. 55, no. 5, pp. 523-530.
- Stern, P., Dietz, T. & Guagnano, G. 1995, 'The new ecological paradigm in socialpsychological context', *Environment Behaviour*, vol. 27, pp. 723-743.
- Stern, P. C. 1992, 'Psychological dimensions of global environmental change', *Annual Review of Psychology*, vol. 43, pp. 269-302.
- Suzuki, D. T. 1996, 'Foreword', in *Learning to Think Environmentally While There Is Still Time: While There Is Still Time*, ed. L. W. Milbrath, State University of New York Press.
- Tansey, P. & Unwin, D. 1969, *Simulation and gaming in education*, Methuen, London.
- Thompson, S. C. & Stoutemyer, K. 1991, 'Water use as a commons dilemma The effects of education that focuses on long-term consequences and individual action', *Environment and Behaviour*, vol. 23, no. 3, pp. 314-333.
- Van Lange, P. A. M., . . ., Messick, D. M. & Wilke, H. A. M. 1992, 'Introduction and literature review', in *Social dilemmas: theoretical issues and research findings*, eds. L. W. G., D. M. Messick & H. A. M. Wilke, Pergamon Press, Oxford, pp. 3-28.
- Vennix, J. 1990, *Mental models and computer models: Design and evaluation of a computer-based learning environment for policy-making*, Unpublished doctoral dissertation, University of Nijmegen.
- Vennix, J. 1996, *Group Model Building: Facilitating Team Learning Using System Dynamics*, Wiley.
- Vlek, C. & Steg, L. 2002, 'The commons dilemma as a practical model for research and policy making about environmental risks', in *Marketing for Sustainability: Towards Transactional Policy-Making*, Ios Press Inc, pp. 285-303.

- Vriens, Dirk & Achterbergh, J. 2006, 'The Social Dimension of System Dynamics-Based Modelling', *Systems Research and Behavioral Science*, vol. 23, pp. 553-563.
- Woods, D. D., Johannesen, e. J., Cook, R. I. & Sarter, N. B. 1994, *Behind Human Error: Cognitive Systems, Computers, and Hindsight*, Crew Systems Ergonomics Information Analysis Center.
- Zagonel, A. 2002, 'Model conceptualization in Group Model Building: A review of the literature exploring the tension between representing reality and negotiating a social order', in *International Conference of the System Dynamics Society*.
- Zagonel, A. 2004, 'Developing an interpretive dialogue for group model building', in *International Conference of the System Dynamics Society*, Oxford.
- Zaraza, R., Joy, T. & Guthrie, S. 1998, 'British Petroleum is not Jackson Middle School: Different best modeling practices for different environments', in *International Conference of the System Dynamics Society*, Bergen, Norway.