Mental Models and Dynamic Decision Making: An Experimental Approach for Testing System Methodologies

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Abstract
The effect systems thinking and system dynamics on a person's dynamic decision-making abilities is yet not fully known. To explore this relationship, a controlled experimental study was conducted. Results of the study show that most participants initially had poor understanding of basic dynamic situations. However, the completeness and accuracy of their mental models improved considerably with system interventions. Specifically participants' ability to discern between stocks and flows, identify causal relationships and feedback improved by around 27% after systems thinking intervention. These abilities further increased by around 4% after participants underwent a system dynamics intervention. Interestingly, in complex tasks, systems thinking hardly made any positive effect on participants' decision-making. However, for the same tasks, participants' mental models improved significantly after system dynamics intervention. This study contributes to the long-standing debate on the links between system methodologies and dynamic decision-making: particularly the relative contribution of systems thinking and system dynamics to decision-making.

Keywords: dynamic decision-making, intervention, psychology, experimental, systems thinking, system dynamics

Introduction

Systems thinking and system dynamics are widely used methodologies for studying and managing complex systems. Their focus is to study the relationships between components in the system, especially feedback loops and the patterns of behaviour generated by them.
Though both these system methodologies are widely accepted as aids for making decisions in complex systems, surprisingly the relationship between these and dynamic decision-making is yet to be fully explored (Cavaleri and Sterman (1997), Huz et. al. (1996) and Doyle (1997)). There have been some studies conducted in the past to explore participants understanding of dynamic tasks like those by Sweeny and Sterman (2000) and Kainz and Ossimitz (2002). Other studies which address similar issues include those by Maani and Maharaj (2004) and Gary and Wood (2005). However, there isn't any literature on the relative contribution of systems thinking and system dynamics on understanding dynamic situations.

This study seeks to explore the relationship between decision making in dynamic tasks and systems methodologies in a pre-test/post-test design. The aim of this experiment is to test participants' ability to perform in dynamic situations with a variety of skills.

(i) With systems thinking skills alone
(ii) With a combination of systems thinking and system dynamics skills

With this aim the following hypotheses are proposed:

1. The understanding (completeness and accuracy of mental model) of a complex system is enhanced when participants use systems thinking as a decision aid as compared to a control group not using any decision-aid.
2. The understanding (completeness and accuracy of mental model) of a complex system is enhanced when participants use a combination of systems thinking and system dynamics as a decision aid as compared to those who use mere systems thinking and controls.

The paper consists of five sections including this introduction. The second section discusses the method that was followed to conduct the experiment. The subsequent section is devoted to results and discussion. The paper concludes with the major finding of this research, its limitations and avenues for further research.

Method

Subjects

Thirty-one graduate students enrolled in the School of Business at the University of Sydney, participated in the study. All students were either in their penultimate or final semester at the University and some had prior work experience. Students had to undergo the study in order to fulfill course requirements and were graded. Five out of the thirty-one students failed to satisfy the criteria of the experiment as they missed either one of the lectures or one of the tests. These were excluded from the data set.

Design

The experiment is structured around a scenario of a firm that provides consulting and IT services. The scenario describes in sufficient detail the operations of the firm. It then describes a problem of periodic oscillations in revenue over time, the measures taken by the top management and other parties involved as well as includes the response of the employees towards those corrective policies. The task for the participants was to analyse the situation and assess the cause of the periodic oscillations.

All participants were administered three tests (one pre-test and two post-tests termed post-test 1 and post-test 2). Students were distributed the case study a week prior to the pre-test and had ample time to read and re-read the scenario. In the following week they were administered the pre-test. In between pre-test and post-test1, the participants were taught systems thinking. Participants were taught system dynamics modelling between post-test1 and post-test2.

The tests on all three occasions were similar. However, the questions were not provided to the participants after the any test, nor were the students aware that similar questions would be repeated in subsequent tests. Many questions were re-phrased and the data and context was changed for quantitative questions. Keeping in mind that there is a possibility of learning of questions from one test to the other, future experiments have been designed to address this issue.

Procedure

The experiment was spread over 5 weeks and took place either in a lecture hall or a computer lab. All tests were individual and participants were seated at sufficient distance from each other.

While conducting the experiment, eight goals, as specified by Doyle et.al. (1998) were adhered to a large extent.

The detailed schedule of the experiment is given below:

Week 1: Participants were provided with the case study at the end of the lecture. They were asked to read the case during the week and they were also told that they would be quizzed on the scenario in the next week’s lecture.

Week 2: All participants underwent the pre-test in the first hour. After the test, students underwent a short course of systems thinking.

Week 3: The systems thinking lecture continued from the previous week and concepts were revised. After a short break, all participants underwent the post-test1 in the first hour. For the remaining period they were introduced to the concept of system dynamics modeling. Participants were asked to familiarize themselves with the software during the week.

Week 4: The lecture on system dynamics modeling was continued from the previous week. All participants devoted significant time to model in Powersim, analyze the outputs and conduct sensitivity tests. At the end of the session, participants were given questions to practice at home.

Week 5: The first two hours was a revision class where all the concepts from week 2 to 4 were reinforced. During the last hour, participants were administered the post test 2.

The total time spent by students on systems thinking was 10 hours and that on system dynamics was 13 hours. This included time spent in the class as well as time taken to complete related tasks at home. The lectures, related handouts and exercises were drawn from standard systems thinking/system dynamics texts and covered majority of the concepts of these two methodologies.

Data Analysis

The data collected from participants was both qualitative and quantitative. The method of their analysis is described below.

Quantitative Analysis

Quantitative data included participants' response to questions relating to discerning between stocks and flows, calculating the values of certain variables (based on the data provided) and measuring the change in confidence after and before the intervention. Part of this analysis was based on the framework utilized by Kainz and Ossimitz (2002).

Qualitative Analysis

Most of the data collected from participants was in the form of narratives. Analyzing these narratives to measure change in participants' mental models required a coding criteria. The criteria utilized in this study are based on two previous studies (Doyle et.al. (1998) and Maani and Maharaj (2004)). An expert model of the problem was constructed before hand. Each answer of the participant was then matched to this model and the percentage of correctness was calculated by identifying correct causal relationships. This helped in measuring the completeness of the participants' mental model pre and post intervention. Additionally the completeness of the mental models was also measured by measuring the type and number of relationships identified by participants.

Results and Discussion

This study attempted to explore the links between two system interventions (systems thinking and system dynamics) and dynamic decision making. Figure 1 below presents the results of this study.

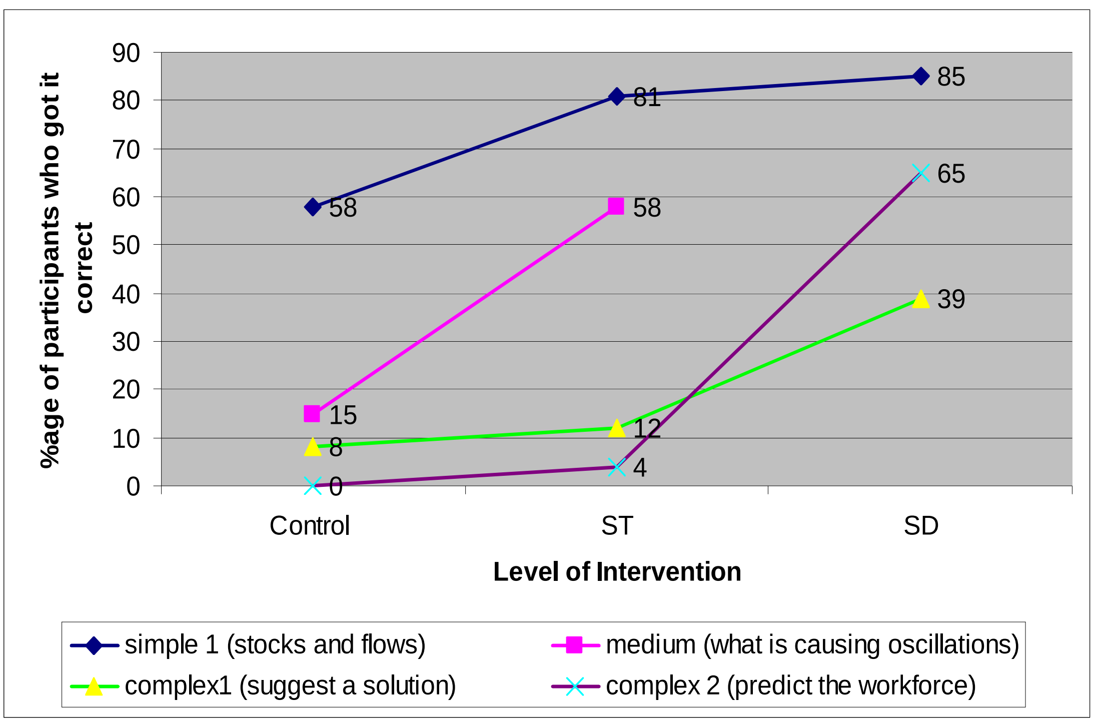

Figure 1: Results

During the course of analysis of the results, various things came up. First and foremost, as found by previous studies (Sweeny and Sterman (2000), Kainz and Ossimitz (2002)) the dynamic decision-making abilities of participants were surprisingly low. The authors were surprised to see such poor results from graduate students, all of whom had a mathematical background. More than 40% of the participants could not find the maximum value of a stock, given the in and outflows. Our results were very similar to those conducted by Kainz and Ossimitz (2002). However, results improved to a great extent by a short course on systems thinking and explanation of stocks and flows. Results further improved (though not as much as before) once participants were given further exposure to stock and flow modeling

The results of the question “what in your view is causing the periodic oscillations in revenue?” were then analysed. Without any systems intervention, more than 50% of the participants could only identify one-to-one relationships. Most of these were quite clearly mentioned in the case study. Furthermore participants were provided a week’s time to read the scenario. Participant responses were mostly superficial and lacked any in-depth analysis of the relationship between key variables. Few recognised the “big picture” by identifying the relationship between the decision, its short-term effect and the long-term unintended consequences. One participant wrote that “I think the most important thing which causes these periodic oscillations is the problem of hiring process. They shouldn’t hire new employees only when they have [got] not enough people and fire them when have not [got] too many projects”. Another simply stated that “an ineffective management on human resources aspect”. Some merely copied parts of text from the case study showing their inability to analyse the problem. However, post-intervention most participants improved in their ability to recognize the key relationship. They could trace relationships as well. Many did an in-depth analysis of the problem and some even attempted to compare the situation correctly with well-known system archetypes. One participant wrote “from the short-period, more project in hand, more new employees hired, and relieve the work pressure, make revenue increase. However, from long-period, this lead to increase in quit-rate, experienced employee decreased, that makes the project fail, this make the revenue fall down. This is a repeatable situation”. This participant not only identified most relationships, but traces variables with their effects on each other, identifies the short-term versus long-term effects and also that this is a cyclic process. Another participant wrote “since employee pressure increase, company will try to increase hiring rate to decrease employee pressure, but there is delay in their process, and other unintended consequences happen faster than this delay, so employee pressure is accumulated, which cause performance to slow down = revenue slow down”. The intervention, made a significant impact on the ability of participants to think causally, focus on the delays of the system and analyse the situation by tracing causal links. Many students were able to identify the feedback loop that was the cause of the oscillations.

The third question “advise a long-term solution to the problem” required participants to utilize the knowledge that they had gained from their analysis of the problem and suggest measures that would help in alleviating the problem. Without any intervention, most (58%) participants focussed their suggestions on ‘planning’ for the project before hand. An equal number of participants (27%) suggested that the current retrenchment of employees be stopped and recruitment should commence. Some (15.38%) participants suggested that the delay in hiring be reduced. Most participants provided more than one suggestion. After undergoing the systems thinking intervention, unlike previous questions, response hardly improved. Participants who thought reducing the delay would be helpful, increased by 19%. However there was no change whatsoever in the number of participants who suggested retrenchment to reduce. Surprisingly there was a reduction in the number of participants who indicated that recruitment be increased (by 4%) and that there was a need for planning of the project (by 12%). After participants underwent a system dynamics modelling session, they modelled the entire scenario in Powersim. The suggestions that they provided subsequently told a different story. A huge amount of participants (50% more when compared to the after the systems thinking intervention) suggested that recruitment should increase as long-term solution. 8% more participants thought that reducing the delay was one of the strategies to alleviate the problem and 15% more thought that impeding retrenchment was a good strategy. 7.7% more participants thought that an improved planning was required. Most participants were able to model the scenario correctly and perform sensitivity tests on it. The improved perception of the underlying cause of the systemic problem might be expected since participants interacted much more with a formal model and simulated it. This indicates that though systems thinking alone does help in understanding the relationship between key variables and delays and to discern between stocks and flows, it is not very useful in situations where the scenario is very complex. In this case, computer modelling, simulation and sensitivity tests give a much deeper insight on the existing problem.

Conclusion

This study was conducted to explore the links between system interventions and dynamic decision making. The findings suggest that both systems thinking and system dynamics are useful methodologies in understanding complex systems. Specifically, participants' ability to take decisions in simple tasks such as discerning between stocks and flows, identify causal relationships and feedback improved by around 27% after a systems thinking intervention was introduced. These abilities further increased by around 4% after participants underwent a system dynamics modeling intervention. Interestingly, in a more complex task that involved numerical data to be processed, required an in-depth analysis and subsequently involved suggesting a solution to alleviate a systemic problem, systems thinking hardly had any positive effect on the participant's decision-making. However, for the same situation, participants' mental models improved significantly after system dynamics modeling intervention. The results of this study confirm the results of some of the previous studies done in this area (Sweeny and Sterman (2000), Kainz and Ossimitz (2002), Gary and Wood (2005)) and give a deeper insight on the impact of system interventions on dynamic decision-making. The study has its own limitations. Given that the study was conducted in a University setting and not with real-world practitioners, these results cannot be generalized to a great extent. Also, the interventions provided to the participants were short in duration due to the structure of the course. The authors are involved in further experiments to explore these relationships in a more rigorous experimental setting.

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