Innovative Glass-Box Approach: A Better Way to Enhance Learning of Complex Dynamic Systems

Aasia Riasat[1], Syed S. Rizvi[2], and Faraz Arain[3]
[1]Department of Computer Science, Institute of Business Management, Karachi, Pakistan
[2, 3]Computer Science and Engineering Department, University of Bridgeport, Bridgeport, CT
aasia.riasat@iobm.edu.pk[1] , {srizvi[2], farain[3]}@bridgeport.edu

Abstract

Due to increasing demand for simulation and modeling, efforts are needed to build up more powerful simulation and modeling methodologies that can help to facilitate *learning* complex dynamic systems. By learning we mean the acquisition of knowledge, skills and experience for better and faster learning of the various types of complex dynamic systems. System dynamics is one of the successful well formulated methodologies that provides a perfect framework for building highly interactive learning environments where learners involve in reasoning about the relationships between the structure and the dynamics of a complex system. In this paper, we address two recent well known approaches (*Black-Box and Glass-Box*) that enhance learning capabilities in a typical complex dynamic system and demonstrate the overall learning effectiveness by using their own methodologies. Furthermore, we present a critical comparison of traditional black-box approach and the innovative glass-box approach. In addition, we also present two experiments that are associated with the black-box approach.

1. Introduction

System dynamics provides a way to represent and model human expectations, and these are typically linked to policy making decisions. In its simplest form, system dynamics mainly focuses on the flow of information transmitted and returned (feedback) through the system's components. It is an approach for analyzing complex systems to include all the relevant cause-effect relationships. In addition, system dynamics analyzes the impact of time delays and feedback loops in those systems that exhibit unexpected behavior. System dynamics based systems provide a frame work for understanding the dynamic interrelationship between system elements [4] [3]. This implies that the system dynamics goes beyond the strict decision support metaphor, and should be applied as a toll conductive to support thinking, group discussion, and most importantly modeling of complex dynamic systems and interaction with learning effectiveness. Recently, some researchers [1] [2] presented two different approaches: *black-box* and *glass-box,* respectively. Different kinds of complexities are adequately handled by a static structure analysis [6]. System dynamics provides this capability and supports conceptually linking explanations about complex behavior to underlying structure. This allows a learner or decision maker or planner to use a system dynamics simulation as a way to test a hypothesis about how a system will behave in particular circumstances. Furthermore, we can also use system dynamics to show how changes in the structure of a system will lead to changes in its behavior [3].

More recently, learning environments starts using system dynamics that not only useful for modeling the complex dynamic systems but also helpful for providing a methodology that ensures consistent success in the effectiveness of system dynamics based learning environments. For example, the black-box approach for such a learning environment can be best illustrated with the popular learning environments called *SimCity*™ which provides a learner with the scenario about a city that could place him in a situation of ruling the city and making decisions about housing, services, taxes, etc. with the goal of general and sustained city growth and prosperity. The underlying model is never directly revealed to the learner however, he may view the behavior of the system and make different decisions based upon his observations. Since the underlying model is never shown to the learner, his/her inferences about it for the observed behavior might be difficult to make and validate. Some other popular examples of such environments include *People Express*® and *Beefeater*® which are usually regarded as a two-premier management simulator. These two simulators help adults to learn about factors influencing the growth of a particular business [1]. In addition, system dynamics modeling tolls such as *Stella* and *Powersim* and programs like *StarLogo* and *Agensheets* enable users to experiment with complex systems and develop better intuitions about the mechanisms that govern dynamic interactions [7]. These types of interactive tools allow significant learning with both the models and the modeling techniques.

2. System dynamics based learning environments

The goal of black-box approach [1] is to develop a methodology that can be used to not only ensure consistent success in the effectiveness of system dynamics based learning environments but also establish reliable measures of effectiveness for it. They claimed that there is no well established methodology available that can be used to determine which design approach most likely leads to the desired outcome for a certain problem domain and its learning effectiveness. Therefore, they have been particularly involved in developing a 'causal loop mapping tool' and shaping the ways through which it could be more efficiently used to construct a better learning environment and to demonstrate the impacts of system dynamics learning on dynamic problem understanding. The concepts maps of initial learners and experts are constructed by first creating the causal lop diagrams for a targeted problem domain. It has been shown that [1] with a simpler problem domain; experts exhibit similarities in their thinking and reasoning when we compare their concept maps with that of the initial learners. But as the problem domain becomes complex and dynamic, we may find some obvious differences in their initial causal loop diagrams. However, the main problem associated with the black-box approach is that the learner is entirely unaware with the underlying structure of the system [2]. In other words, black-box approach supports peer to peer communication and collaboration that plays a vital role in network-learning environments, but unfortunately an initial learner does not have any experience with the actual complexities of the problem domain. Consequently, due to the incomplete identification of all concepts, the initial learners are unable to draw good causal loop diagrams which lead to the conclusion that a better learning environment, based on system dynamics, requires a comprehensive understanding of the complex dynamic problem domains.

Understanding complex system behaviors involve the ability to provide causal and structural explanations [2] as well as the ability to anticipate and explain changes in underlying causes and structures. Thus this implies that the underlying structure of the system should be made more and more accessible to learners for the purpose of explanation and manipulation as the learner becomes more experienced with the complexities of the domain. The black-box approach is an evaluation methodology that involves both quantitative and qualitative methods [5].The main aim of glass-box approach is to help learners manage complexity in ways that contribute to improved learning and deep understanding of the complex dynamic problem domain. The glass-box approach accomplishes this task by integrating learning theory, system dynamics, and collaborative tele-learning. This approach is also known as Model Facilitated Learning (MFL). The glass-box approach consists of the following three stages: problem orientation, inquiry exploration, and policy development. Of particular interest in the glass-box approach to system dynamics based learning environments is the notion of double-loop learning [7]. In the first loop of learning in the complex systems, learner begins to interpret a system dynamics model of a complex domain. This activity is itself challenging. One might characterize such an activity as using an external model to facilitate the creation of internal mental models. The external model is shared and provides a group of learners or decision makers with a common representation which is required for meaningful discussion.

A second step, however, is required to move learners from familiarity with a complex model to a profound understating of that model. Learners play various roles in simulation based learning environments such as they interact with the environment, make changes in various parameters and then observe the outcomes, and in some cases they can even make their own models. This implies that the second step of this approach brings the learner where he has an influential control over the learning environment. In other words, when learners are asked to make changes in the underlying structure, the realization that structure creates behavior is forced upon them. This is one of the most important features of the glass-box approach that provides a better learning environment for the learners than the black-box approach where the learners do not have such access and in-depth recursive information about the underlying structure of a complex problem domain. On the other hand, when learners see themselves as part of the underlying structure, they are more likely to search for a wide range of solutions to problem behavior.

3. Experiments with black-box approach and critical analysis

The concept of a flight simulator tool was pioneered in the system dynamics community [8], and that architecture for system dynamics based learning environments has become the predominant architecture. This experiment consists of the following three steps. In order to get new and elementary questions, they use computer based tutors which do not depend on system dynamics. The second step is the use of mental modeling or concept mapping techniques to build up models of experts thinking and reasoning in complex domains. Finally, in the third step, we use the same techniques in advance stages to determine the overall effectiveness of the simulator. On the other hand, the Pilot experiment was conducted using three cases of the following dynamic problems: (1) Spread of an infection; (2) Yeast production; and (3) Deer population. In each domain, initially two experts were asked to produce causal loop diagrams on paper. The suggested test tool includes a dynamic description of a problem and a questionnaire. These questionnaires were distributed randomly among students that had no prior experience with system dynamics and system thinking. On a very first day, they were asked to answer relatively simple problems. After the first day, students attended an introductory lecture where they were learned the concepts of feedback, causal relationship, and causal loop diagramming etc. At the end of the second day, students were asked to fill in the questionnaires again, only they were asked to pick up a different problem than they had on the previous day. The data collected from the questionnaire was used to identify that (a) how subjects understand dynamic problems description, (b) how they understand what they were asked to do, (c) what concepts they perceive as important, and (d) how they relate them each other. The three problems that have been considered as a test tools can be graded according to the level of dynamic complexity that they include. For learning more about this experiment, please see [1].

In the first experiment, the first dynamic problem (Spread of an infection) was comparatively easy to understand. According to the results [1], most of the people correctly identified most of the concepts related to the population. However, not all people were able to identify the effects of density and connectivity on the infection rate. It is possible that some people might have confused by the description of the rate of infection and the rate of contacts. According to the results, in some cases, people did not notice that the total population is not changing and also how the density of a certain fraction of population is defined. None of the subjects indicated such parameters as the probability of infection [1]. Similarly, in the second dynamic problem (yeast production problem), most of the people identified most of the concepts and some of them were even able to identify the relationships and effects. However, they also tended to introduce the concepts which are not included in the suggested solution. Finally, in the third dynamic problem (deer population), most of the people identified only the concepts related to the deer population, but very few did mentioned concept related to the predator population.

In the second experiment, flight simulator takes into account the importance for small group collaborations and it situates the learning in realistic settings. In other words, one can make a conclusion that it is useful in the early stages of learning development to challenge learners to identify what they believe to be the most influential factor, perturb the system with a slight change and then predict the outcome. However, what is not provided in such flight simulator is support to help learners reason from observed system behavior to underlying structural causes or to alter the underlying structure and reason forward to predict outcomes. With regard to complex systems, if the underlying model that is causally linked to the behavior of the system is kept hidden, then either learners take long time to infer the cause or most fail to find the cause [9]. Both simulation models that have presented in the last section run in cycles. After each cycle, a group of learners are asked to indicate the current state of the system. The learners have opportunity to possibly change a few key factors and then predict what the state of the system would be at the end of the next cycle. In general, almost all black-box based learning environments have the following characteristics: small group collaborations that spread throughout the learning experience, opportunities to formulate policies that help in decision making, and opportunities to analyze results and reflect upon the decision making process.

4. Conclusion

We present two approaches that greatly involve in system dynamics based learning environments. We argue that the black-box approach has certain advantages but it is only appropriate as long as we have a simple problem domain. As learners become more proficient in using the simulation, they need to access the underlying simulation model in order to improve their understanding. The bottom line is, if the learners do not have access to the underlying simulation model (a black-box approach), learners are unable to develop deep causal understating of a complex system. Consequently, learners are unable to identify correct concepts related to the complex problem domains and unable to draw perfect causal loop diagrams. This implies a glass-box approach is not only provides an access and insight to underlying simulation model but also offers an adequate standard qualitative measure to evaluate the overall effectiveness of the system dynamics based learning environments.

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Author biographies

SYED S. RIZVI is a Ph.D. student of Computer Engineering at University of Bridgeport. He received a B.S. in Computer Engineering from Sir Syed University of Engineering and Technology and an M.S. in Computer

Engineering from Old Dominion University in 2001 and 2005 respectively. In the past, he has done research on bioinformatics projects where he investigated the use of Linux based cluster search engines for finding the desired proteins in input and outputs sequences from multiple databases. For last one year, his research focused primarily on the modeling and simulation of wide range parallel/distributed systems and the web based training applications. Syed Rizvi is the author of 15 scholarly publications in various areas. His current research focuses on the design, implementation and comparisons of algorithms in the areas of multiuser communications, multipath signals detection, multi-access interference estimation, computational complexity and combinatorial optimization of multiuser receivers, peer-to-peer networking, and reconfigurable coprocessor and FPGA based architectures.

AASIA RIASAT is an Associate Professor of Computer Science at Collage of Business Management (CBM) since May 2006. She received an M.S.C. in Computer Science from the University of Sindh, and an M.S in Computer Science from Old Dominion University in 2005. For last one year, she is working as one of the active members of the wireless and mobile communications (WMC) lab research group of University of Bridgeport, Bridgeport CT. In WMC research group, she is mainly responsible for simulation design for all the research work. Aasia Riasat is the author or co-author of 10 scholarly publications in various areas. Her research interests include modeling and simulation, web-based visualization, virtual reality, data compression, and algorithms optimization.

FARAZ ARAIN is a M.S. student of Computer Engineering at the University of Bridgeport. His research interest includes modeling and simulation of complex dynamic systems, multicluster systems and grids computing, scheduling problem and load balancing in cluster.