European Journal of Operational Research 235 (2014) 195–205

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Decision Support

Learning from discrete-event simulation: Exploring the high involvement hypothesis

Thomas Monks [a,*], Stewart Robinson [b], Kathy Kotiadis [c]

[a] University of Exeter Medical School, University of Exeter, Exeter EX1 2LU, UK
[b] School of Business and Economics, Loughborough University, Loughborough, Leicestershire LE11 3TU, UK
[c] Warwick Business School, University of Warwick, Coventry CV4 7AL, UK

A R T I C L E   I N F O

Article history:
Received 18 October 2012
Accepted 2 October 2013
Available online 10 October 2013

Keywords:
Psychology of decision
Learning
Model building
Model reuse
Generic models
Simulation

A B S T R A C T

Discussion of learning from discrete-event simulation often takes the form of a hypothesis stating that involving clients in model building provides much of the learning necessary to aid their decisions. Whilst practitioners of simulation may intuitively agree with this hypothesis they are simultaneously motivated to reduce the model building effort through model reuse. As simulation projects are typically limited by time, model reuse offers an alternative learning route for clients as the time saved can be used to conduct more experimentation. We detail a laboratory experiment to test the high involvement hypothesis empirically, identify mechanisms that explain how involvement in model building or model reuse affect learning and explore the factors that inhibit learning from models. Measurement of learning focuses on the management of resource utilisation in a case study of a hospital emergency department and through the choice of scenarios during experimentation. Participants who reused a model benefitted from the increased experimentation time available when learning about resource utilisation. However, participants who were involved in model building simulated a greater variety of scenarios including more validation type scenarios early on. These results suggest that there may be a learning trade-off between model reuse and model building when simulation projects have a fixed budget of time. Further work evaluating client learning in practice should track the origin and choice of variables used in experimentation; studies should also record the methods modellers find most effective in communicating the impact of resource utilisation on queuing.

1. Introduction

It is often assumed that clients of simulation experience significant learning through involvement in model building (Robinson, 2004; Rouwette, Korzilius, Vennix, & Jacobs, 2011). Although this *high involvement hypothesis* is plausible, it is difficult to measure client learning in practice and little empirical evidence exists to validate the theory. Exploration of the role involvement in model building plays in client learning is important. Particularly as the effort needed to build a discrete-event simulation (DES) model may affect study feasibility or limit scope due to a fixed budget of time (Cochran, Mackulack, & Savory, 1995; Law, 2007; Pidd, 2004; Robinson, Nance, Paul, Pidd, & Taylor, 2004). In fact, given a fixed budget of time, a modeller may choose not to involve clients in model building, but instead reuse an existing or generic simulation model (Bowers, Ghattas, & Mould, 2012; Fletcher & Worthington, 2009; Robinson et al., 2004). For example, the time saved by reusing a model of a whole hospital could instead be used for experimentation (Günal & Pidd, 2011) or, where no time is available for model building, pre-built models could be used to rapidly educate clients in approaches to improvement, for instance in lean (Robinson, Radnor, Burgess, & Worthington, 2012). Given that reuse is occurring in practice, it is important to understand how client learning is influenced by the reduced involvement in model building and the increased opportunity for experimentation offered by model reuse.

To address this issue, this paper details a laboratory experiment where learning is measured using Argyris and Schön's (1996) theory of action and learning loop framework. We seek to investigate if the effect can be demonstrated empirically; to understand the mechanisms that aid client learning from involvement in building and reuse; and to explore the factors that inhibit learning from simulation. Comparisons are made between the learning novice simulation clients (undergraduate business students) experience in an emergency department (ED) setting, given different degrees of involvement in model building, reuse and experimentation time. Participants are explicitly tasked with learning how to increase the proportion of patients meeting the four hour wait time target within UK EDs and also satisfying their own definitions of effective

* Corresponding author. Tel.: +44 01392 726086; fax: +44 01392 421009.
E-mail address: thomas.monks@pcmd.ac.uk (T. Monks).

0377-2217/$ - see front matter
http://dx.doi.org/10.1016/j.ejor.2013.10.003

performance (typically aiming for resource utilisation to be close to 100%). Measurement focuses on single-loop learning: participants' learning of strategies to meet these objectives within the ED; their attitudes towards the management of resource utilisation; and their choice of variables in experimentation.

The paper is structured as follows. Firstly, the learning themes from the simulation literature are briefly summarised and classified using formal definitions of learning taken from Argyris and Schön's (1996) theory of single and double-loop learning. Secondly, the design, materials and predictions for the experiment are detailed. After presenting the results there is a discussion of the possible learning mechanisms in the experiment and how evaluation studies might incorporate the results.

2. Simulation and learning

This section provides a discussion of the conceptual and theoretical background for understanding our experiment and its results. This begins with a discussion of the overarching high involvement hypothesis and how it is typically expressed in the simulation literature. This is followed by an overview of Argyris and Schön's framework of single and double-loop learning and a review of studies of learning from simulation and the complementary field of behavioural operations.

2.1. The high involvement hypothesis

Detailed studies of client learning in DES and the wider simulation community are relatively rare compared to publications on models and their results. Of those that do tackle learning and practice, discussions often refer to the hypothesis that involving the clients in model building provides much of the learning useful for aiding decisions (Alessi, 2000; Andersen, Richardson, & Vennix, 1997; Paich & Sterman, 1993; Robinson, 2004; Rouwette et al., 2011; Rouwette, Vennix, & Mullemkom, 2002; Thomke, 1998; Ward, 1989). The outcomes of client involvement in model building might take an anecdotal form in general discussion; for example, 50% of benefit of modelling is gained simply by building the model with client involvement (Robinson, 1994). More usefully, it might take a more testable form by referring to specific learning outcomes, such as those listed in Table 1.

Common to all of the formulations listed in Table 1 is the theory that a simulation client has a simple predictive mental model of how the system under study behaves. Involvement in model building is hypothesised to aid clients to recognise their own implicit assumptions (Andersen et al., 1997), refine and change mental models (Rouwette et al., 2011; Thomke, 1998), enhance creativity in problem solving (Robinson, 2004), and generalise knowledge so that it can be transferred to other similar problems (Alessi, 2000; Lane, 1994; Thomke, 1998).

To illustrate the high involvement hypothesis using these definitions, consider a manager in an ED that aims to simultaneously reduce patient waiting times and increase the utilisation of ED resources to, her definition of optimality, 100%. Implicitly the manager believes that achieving these aims is just a question of resources working hard(er) to meet the targets and hence does not recognise any trade-off between the two objectives. Under the assumptions of the high involvement hypothesis the manager, through her involvement in model building, would recognise the limitations of her mental model and refine it. One way to conceptualise this refinement is as the change in an individual's attitude(s) towards controllable variables (Thomke, 1998) or competing implementation options (Rouwette et al., 2011). For example, our ED manager may now realise that she should consider the trade-off between utilisation and waiting times when making resource decisions. If the manager has learnt correctly her attitude towards 100% utilisation of resources will decrease in strength while her attitude towards allowing a reduction in resource utilisation to achieve lower waiting times will have increased.

2.2. Single and double-loop learning

A well-known framework for learning is Argyris and Schön's (1996) theory of single and double-loop learning. The starting point to understanding the framework is to assume that an individual's mental model comprises a set of variables that govern what to do or how to act in relevant situations. These governing variables constrain the actions (or decisions) individuals will take given a particular situation.

Argyris and Schön's empirical work illustrates that most individuals will attempt to keep their governing variables within acceptable limits. For example, assume our healthcare manager finds that her new ED management policies are achieving 95% utilisation of nurses, but very long waiting times in ED. As our manager's expectations have not been met, her attitude towards the management policy will be less favourable and she will attempt to find new policies that do keep governing variables within acceptable limits. Learning of this type is called *single*-loop learning: a change in attitudes towards various management actions to keep governing variables within acceptable limits. When a mismatch in expectations prompts the manager to reflect on her own mental model she undertakes a *double* learning loop: a change in governing variables and a change in actions to keep them in acceptable limits.

The learning framework set out by Argyris and Schön's framework applies not just to business management situations, but also the approach to learning or more formally the *learning systems* individuals employ. Bakken, Gould, and Kim's (1994) experiment, using System Dynamics models, illustrates the impact of learning systems. In the experiment students and managers (executive MBAs) used a training simulation model, set in the same domain as the managers worked, followed by a second model with the same underlying behaviour but set in a different domain. All participants had to achieve a high profit with both models. In the training game, the managers followed the management approaches they used in real life. The students, having no experience of the real world system, used many alternative approaches and were rewarded with many negative (bankruptcy) as well as positive outcomes. Surprisingly, the students substantially outperformed managers in the second model.

To explain this result, the difference in learning systems between the managers and students must be examined. The governing variable the managers were attempting to satisfy was

Table 1
Formulations of the high involvement hypothesis.

- Implicit mental models of the system converted into explicit mental models (Andersen et al., 1997)
- Refined mental models for managing the system (Rouwette et al., 2011; Thomke, 1998)
- Improved creativity and generating new ideas for improving system performance (Robinson, 2004);
- Abstraction of general principles from models that can be transferred elsewhere (Alessi, 2000; Lane, 1994; Thomke, 1998)