Linking Simulator Functionality with Learning: An Extension of the Taxonomy of Computer Simulations to Support Learning

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System dynamics (SD)-based simulators are used for education, training and experimentation (Davidsen 2000; Größler 2004; Davidsen and Spector 2015). The field of education and training using SD-based simulators measures the effect of simulators on the development of mental models, the dissemination of insights and the development of knowledge (Davidsen 2000). The second field focuses on experimentation using SD-based simulators, research investigates mental models that drive human decision making (Davidsen 2000). While the second field continuously produces new research (see e.g. Moxnes 1998; Moxnes and Jensen 2009; Gary and Wood 2011; Gary et al. 2012), the research on education and training using SD-based simulators falls short. There are a considerable number of articles published to promote simulation for education and training (Machuca 2000; Salas et al. 2009; Sterman 2014), but only a few articles investigate the effectiveness of SD-based simulators on learning and training. It is somehow surprising that within the field of system dynamics, in which simulation is a well-accepted instrument (Rouwette et al. 2004), the effectiveness of simulators for education seems to be accepted and assumed without rigorous examination.

This paper presents a connection of the functionality of SD-based simulators with their learning outcomes. By doing so, we call attention to the missing foundation between simulator design and learning outcomes, while simultaneously providing a starting point to close the gap in the research on the effectiveness of SD-based simulators on education and training.

Scholars have identified numerous types of knowledge. Two well-known types of knowledge are declarative and procedural knowledge (Jong and Ferguson-Hessler 1996; Schunk 2012). Declarative knowledge refers to knowledge about facts, objects and events (Jong and Ferguson-Hessler 1996; Jonassen et al. 1993). Declarative knowledge is referred to as knowledge about 'What' (Maier and Größler 2000) or 'knowing that' (Jonassen et al. 1993). It enables a person to describe objects (Jonassen et al. 1993). Procedural knowledge, on the other hand, refers to knowledge about 'How' (Maier and Größler 2000; Jonassen et al. 1993) – thus it contains actions, procedures and manipulations (Jong and Ferguson-Hessler 1996). It is often also referred to as a skill and the knowledge held by an individual of how to perform a specific set of actions (Rouwette and Vennix 2006). Further, this paper uses the term structural knowledge (Jonassen et al. 1993). It describes how concepts are interrelated and refers to knowledge about 'Why' (Jonassen et al. 1993; Maier and Größler 2000). Declarative knowledge is the basis for procedural knowledge (Jonassen et al. 1993) and procedural knowledge is the basis for structural knowledge. All three types of knowledge have been used in the context of system dynamics (see e.g. Schaffernicht 2005; Maier and Größler 2000; Doyle and Ford 1998; Rouwette and Vennix 2006).

By combining the categories of simulator designs and their distinct characterstics with the aforementioned knowledge types, we can derive which simulator design is appropriate for decision support, education and learning. We further shed light on the function of briefing and debriefing.

Categories of Simulator Designs

	Single action to simulate the model: Learn by comparison across runs	Simulate step by step: Learn by action within a single (or limited number of) run(s)
Singleplayer	**Analysis Tool:** • Simulated with a single action • Contain no information hiding, meaning no 'twists' or big reveals • Focus on learner based discovery • All decisions are made available and accessible • Assumptions made explicit and are sometimes available • Heavy use of comparative graphs (bonus: show cross run statistics)	**Management Flight Simulator:** • Run step by step • More traditional games, real world like • Players power is limited • Limited number of runs/scenarios
Multiplayer	?	**Multiplayer simulators:** • intra-team goal alignment • team and role assignment • time advancement techniques

Connecting Knowledge with system dynamics models

Knowledge	Items in System Dynamics Model
Declarative (Know what, facts)	• Key variables and their connection to reality • Measurements • The Problem description (static) • The Goal • The context of the simulation
Procedural (know how, skills)	• Behavior over time • Porarities • Leverage Points • Correlations
Structural (know why, explain, derive, infer)	• Cause-Effect relations • Feedback Loops • Loop Dominance • Delays

		Knowledge: Declarative	Knowledge: Procedural	Knowledge: Structural	Group Mental Model	Role of: Briefing	Role of: Debriefing
Single player	Scenario Analysis Tool	○	●	●	○	• Detailed briefing about declarative knowledge • Assumptions • Time intensive	• Less time intensive • Discussion about findings (policies, scenarios)
Single player	Management Flight Simulator	●	●	○	○	• Focus on role and context description • Clarify goal • Less time intensive	• Time intensive • Clarify structural knowledge • Reveal causes of twists/hidden model structure • Clarify solution
Multiplayer	Competitive Multiplayer Simulator	●	●	○	◐	• Set rules, goal and roles • Less time intensive	• Time intensive • Clarify structural knowledge • Reveal hidden model structure • Work with individual mental models / interpretations • Solve conflict
Multiplayer	Cooperative Multiplayer Simulator	◐	●	◐	●	• Clarify team and role assignment • Set rules and goals • Explain context	• Clarify each team's mental model, align different team's mental models • Reveal hidden model structure • Solve conflict
Multiplayer	Hybrid Multiplayer Simulator	◐	●	◐	●	• Clarify team and role assignment • Set rules and goals • Explain context	• Clarify each team's mental model, align different team's mental models • Reveal hidden model structure • Solve conflict

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