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# System Dynamics and Intelligent Agent-Based Simulation: Where is the Synergy?

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ABSTRACT

Pedagogical research has demonstrated that while traditional teaching methods can be useful for imparting factual information ("cold knowledge"), simulations and video games are more effective in teaching decision-making processes ("warm knowledge"). Advances in video game creation allow the development of multi-agent, artificial society simulators with capabilities for modeling physiology, stress, emotion, and course-of-action decision-making. This new approach enables superior understanding of the complexity in organizations and their relevant business environments. This in turn provides an opportunity for game-play that helps promote better decision-making.

System Dynamics also allows managers to make their understanding of business problems explicit and improve upon them. This occurs by modelling structures (e.g., relationships, policies, incentives, etc) that underlie behaviour of systems. While system dynamics acknowledges the critical role of personal and organizational mental models (e.g., motivations, values, norms, biases, etc.) as the foundation or key influencers of structure, it does not explicitly model mental models, nor does it take into account decision makers 'mood'. In contrast, in Agent-Based Modelling (ABM), organizations are modelled as a system of semiautonomous decision-making parts (purposeful individuals) called agents). Macro-behaviour is not simulated; it emerges from the micro-decisions of individual agents. In this work, each agent individually assesses its situation and makes decisions based upon value hierarchies of goals for action, preferences for artefacts, and standards for behaviour.

In ABM, agents have a bounded rationality that is subject to stress, time pressure, and emotive forces. At the simplest level, an agent-based model consists of a system of agents and the relationships between them. Experience with agent-based modelling shows that even a simple agent-based model can exhibit complex behaviour patterns and provide valuable information about the dynamics of the real world system that emulates them. In this paper the two different simulation approaches to learning effectiveness, i.e., the agent-based modelling and systems dynamics are compared conceptually and the potential synergy between them is discussed. As such this paper is theoretical and exploratory in nature. Further studies are needed to provide empirical evidence to the observations and theories put forward in this paper.

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INTRODUCTION

The purpose of this paper is to provide key characteristics of a learning system designed to foster the assimilation of a systems thinking mindset and associated skills in the learning manager. To arrive at this purpose, the authors will discuss research into learning in general and the three challenges faced by such a learning system. The first challenge is that such a system requires the most difficult learning objective – changing a mental model – rather than easier objectives such as skill acquisition and information transfer. The second challenge is to integrate collaboration and team-learning in the learning system without sacrificing the individual's ability to progress in a self-paced fashion. The third challenge derives from the fact that the goal of this system is to foster learning at the highest level of content – understanding and wisdom – rather than data, information, or knowledge. Given that the desired outcome is to promote the most complex learning, the authors will then discuss why a simulation/game approach is best suited for this task. They will then evaluate various simulation games available in an attempt to identify the key characteristics essential to an effective learning system aimed at the assimilation of systems thinking itself. Finally, they will provide, in skeleton form, a design for such a learning system.

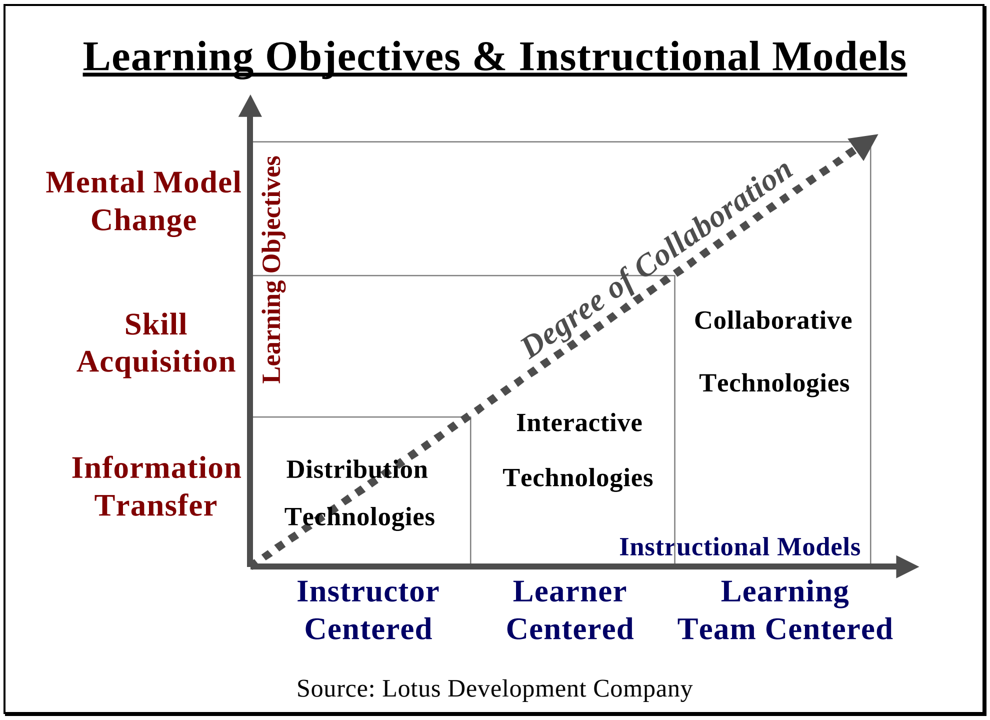
Research has shown the following retention rates for various methods of learning[1]:
10% for what is *seen*
20% for what is *heard*
30% for what is *seen and heard*
70% for what is discussed with others
80% for what is used in real life
95% for what is taught to others

The first three methods of teaching, which have lower retention rates, are attained by classroom teaching and through reading. A simulation approach is more effective in capturing the higher rates of retention, because it allows for communication between the players and requires that players teach each other (possibly virtual) players lessons of the game. Furthermore, a simulation approach enables the decision makers to appreciate the increasing complexity in multi-divisional organizational structures. It provides participants with a realistic framework of competing and cooperating decision makers, which act within a multi-divisional organization. The decision makers have the opportunity to base their actions upon other decision maker's decisions and learn from each other and their own mistakes. The simulation allows all the decision makers to come away with a better comprehension of the dynamics of operating in a modern day business environment.

A simulation as a learning environment has other distinct advantages:
User-driven, not instructor-driven. Learn through immersion.
Develop learnt theoretical concepts into practical and applicable skills.
Teach other (virtual or real) players the game.
Encourage a systems view of the business world.
Fun, captivating, consistent, compelling and cost-effective learning experience.

The graph shown below illustrates the spectrum of learning methods and the resulting outcomes that simulations can achieve. The two important aspects of teaching are the instruction model and the learning objective. Instructor-centered and learner-centered teaching methods are effective only for knowledge and skill transfer. Behavioral and mental model changes are not achieved through these methods. There are many technologies and simulations available, which can teach managers focused skills and knowledge.

[1] **Source: The Association of Libraries**

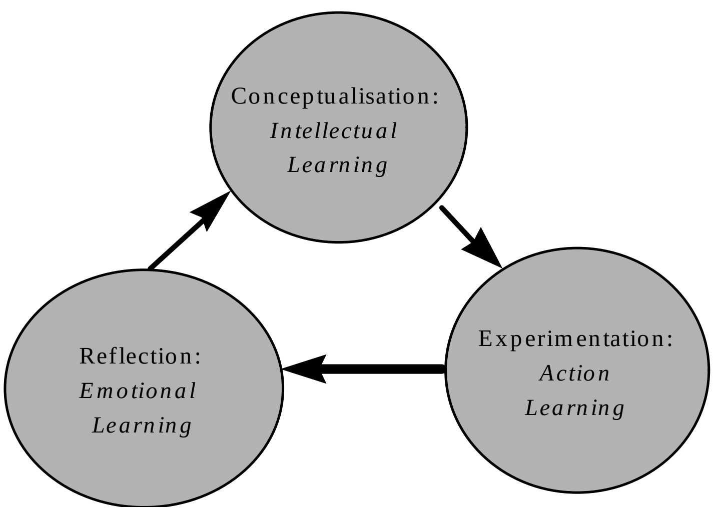



The Spectrum of Learning methods

The third challenge in learning is to help the learner to climb the hierarchy of the content of learning, i.e., to move from data to wisdom. This will require designing learning experiences where the learner is provided with a prospect for acquiring, generating, and retaining data, information, knowledge, understanding, and wisdom.

BEYOND COGNITIVE LEARNING: THE LEARNING CYCLE

The learning cycle is a ‘holistic’ approach to learning, which goes beyond cognitive learning. The learning cycle embodies three elements: *Conceptualization* or Intellectual Learning, *Experimentation* or Action Learning, and *Reflection* or Emotional Learning. This process is analogous to TQM’s continuous improvement known PDCA (Plan-Do-Check-Act). The learning cycle is shown below.




The Learning Cycle

*Conceptualization* is the learning associated with the mind – it is the intellectual or cognitive learning. Conceptualization deals with theories and hypotheses regarding the reasons why things happen and how they work. In the conceptualization phase learning outcomes from experimentation and reflection are reviewed and adjusted. This step requires fresh and lateral thinking.

*Experimentation* refers to 'learning by doing', where new theories and hypotheses are tested in a 'laboratory' environment. Experimentation is the foundation of the 'scientific method'. In social contexts such as restructuring and policy testing, cost and time are often key impediments to experimentation. Conventional testing methods are often too expensive and time consuming, thus prolonging experiment time. The learning lab compresses experimentation time and thereby shortens the learning cycle. Short learning cycles permit a significant increase in the number and speed of experiments and lead to rapid learning. Leavitt et al. (1995) coined the term 'Hot Groups' to refer to groups within organizations that are deeply dedicated to learning. Organizations where Hot Groups flourish, such as Bell Laboratories, place a high value on the 'scientific approach' and search for the 'truth'. These organizations welcome and encourage experimenting with new ideas, and are constantly searching for ways to advance their boundaries.

*Reflection* is the third element of the Learning Cycle. It allows team members to pause and think through their experiments. This engages one's 'feelings' and emotions (i.e., attitudes, biases, resentments, etc.) in addition to hard facts and sanitized results. Thus, reflection can be thought of as 'emotional learning'. This is perhaps the most neglected area of the learning cycle. Too often management focuses on hard 'data', ignoring the emotions that are attached to this information. As a consequence, loyalties are lost and commitment to management edicts becomes superficial and at best callous.

## THE BUSINESS CHALLENGE

To illustrate the importance of systems thinking in the business world, below is an excerpt from the writings of Vince Barabba, of Corporate Strategy & Knowledge Development at General Motors:
The mechanistic mindset of the industrial age encouraged us to think about managing businesses as if they were made of replaceable parts – like pieces of a jigsaw puzzle. The metaphor fit reasonably well for that era. When one starts a puzzle, one knows how many pieces one is supposed to have, and the chances are that they are all there. Each of the parts will interact with only a small portion of the other parts. If we start the puzzle and then leave to do something else anyone else could come in and without any communication, experience or training, continue to solve the puzzle. If any of us had trouble trying to put the pieces together, the picture on the box reveals the one ultimate solution.

This puzzle metaphor fit reasonably well for most of the twentieth century– it does not, however, fit well for today's environment. Today's business and societal challenges are more complex than that. We operate in a world characterized by increasing complexity and an accelerating rate of change. It is an environment consisting of constantly changing processes, relationships and components, more like the molecular structure than a jigsaw puzzle. Depending on how the elements come together, we can end up with an entirely different outcome than we expected. And when you impose external forces (both positive and negative) on that environment, the elements can change position and even interact in a different manner.

In order to understand the source and solution to modern-day business problems, linear and mechanical thinking should give way to non-linear and organic thinking, more commonly referred to as systems thinking. The approach of systems thinking is fundamentally different from traditional thinking methodology and analysis. By definition, analysis means breaking up a problem into constituent parts and finding the solution to each individual part separately. This method of solving problems works in most scenarios, but modern day business is a dynamic process driven by many variables, each of which is dependent on the other. Breaking up a business problem into bits and pieces does not always achieve the optimal outcome. Systems thinking on the other hand, views an organization as a system, and how the problem under consideration interacts with other constituents of the system of which it is a part.

Examples of areas where systems thinking has proven to be most effective:[2]

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[2] **http://www.thinking.net**

Complex problems that require the participants see the “big picture” and not just their part.
Recurring problems that were not solved or made worse through traditional analysis.
Situations where an action affects (or is affected by) the environment surrounding the issue.
Problems whose solutions are not obvious.

The challenge for multi-national, multi-sectored enterprises that face exactly these types of dilemmas is to sponsor research and development of learning environments that can help (1) its executives to better recognize how locally desirable decisions can cause or sub-optimal solution (or at least an alternative systems solution) to specific problems, (2) to visually display and explain the impacts of decisions and parameter changes in one area that cause impacts in other areas, and (3) to provide coaching and sensitivity studies that help executives to find alternative, more systemically desirable answers.

SURVEY OF CURRENT SIMULATIONS AND METRICS OF EFFECTIVE BUSINESS SIMULATIONS

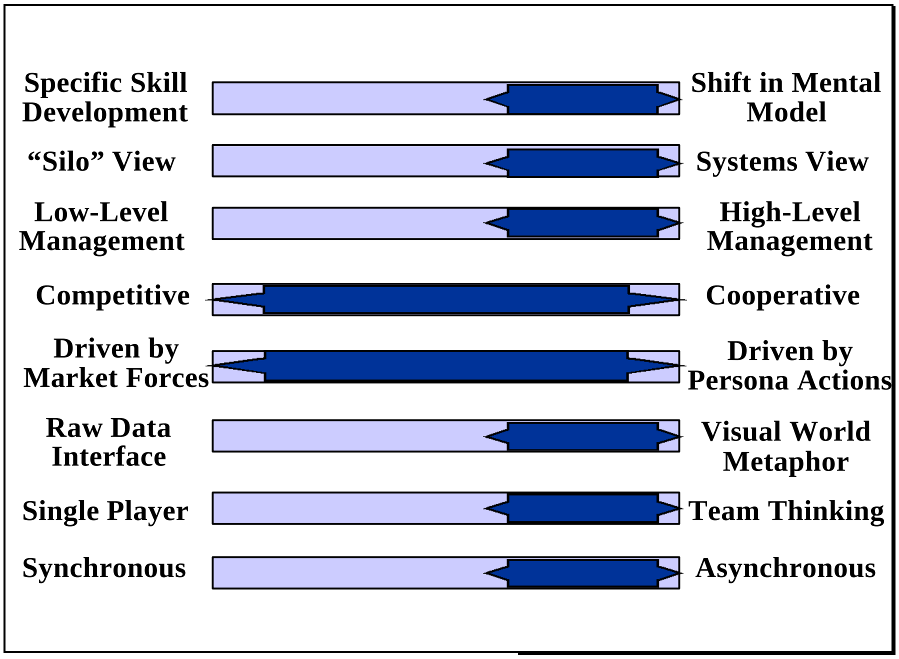
There are a number of simulations and games with various characteristics that are relevant to the above challenge that are available in the marketplace. Various aspects of many of the most commonly known commercial computer games, such as EA’s SimCity, as well as business strategy simulations used by major corporations and business schools for educational purposes, such as McGraw-Hill’s Business Strategy Game, were recently examined by a group of researchers at the Ackoff Center. Among the games studied was The Beer Game. Available in several online formats, The Beer Game is widely acknowledged to be the first business strategy game.

This research led to the development of a set of eight dimensions on which to categorize any simulation, which is described below. A total of fifteen games were played extensively, each of which demonstrated one approach to achieving what was deemed “ideal” along one or more of the scales that were created by the researchers. The games reviewed by the researchers are listed below.

Selected Simulations/Games:

| | |
|---|---|
| 1. Boom & Bust Enterprises Management Flight Simulator | 8. Mike’s Bikes |
| | 9. Oil Producer Microworld |
| 2. Business Management Laboratory | 10. PDA Sim |
| 3. Caesar III | 11. Political Tycoon |
| 4. Capstone | 12. StratSim |
| 5. Crumby & Co. | 13. Threshold Competitor |
| 6. Gazillionaire | 14. Wall $treet Raider |
| 7. Market Place | 15. The Web-Based Beer Game |

The eight most important characteristics of effective business simulations were selected, and subsequently a categorization system that can be applied to rate any business strategy game was created.



Characteristics of effective business simulations

Each dimension is measured along a continuum from one extreme to the other. The simulations rated using this system showed different levels of success towards achieving the combination of factors that would make them most effective. This diversity is appropriate as each game is intended for different purposes ranging from simple home entertainment through semester-long MBA competitions to intensive corporate training programs. The set-up of the game also determines other aspects such as whether it is conducted online by an administrator in real time; interactively among competing classmates, co-workers, or other online players; or as a stand-alone application in which a single player or team of players competes against the computer (manifesting the ‘market forces’).

The first and most essential criterion for this type of simulation is that it not merely impart to users specific skills or novel strategies, but really causes users to shift their “mental model”, their internal representation of the market and the role of their organization within that system. This shift, as was discussed earlier, is the most lasting and effective mode of learning. (An example of the shift in mental model might be transcending the “silo” organizational view and utilizing instead a holistic systems view.)

Inherent in this approach is the fact that the simulation must force the user to operate at a high level of management so that he or she is not continuously occupied by concern for the mundane details of day-to-day operations, and is therefore able to see the ‘big picture’.

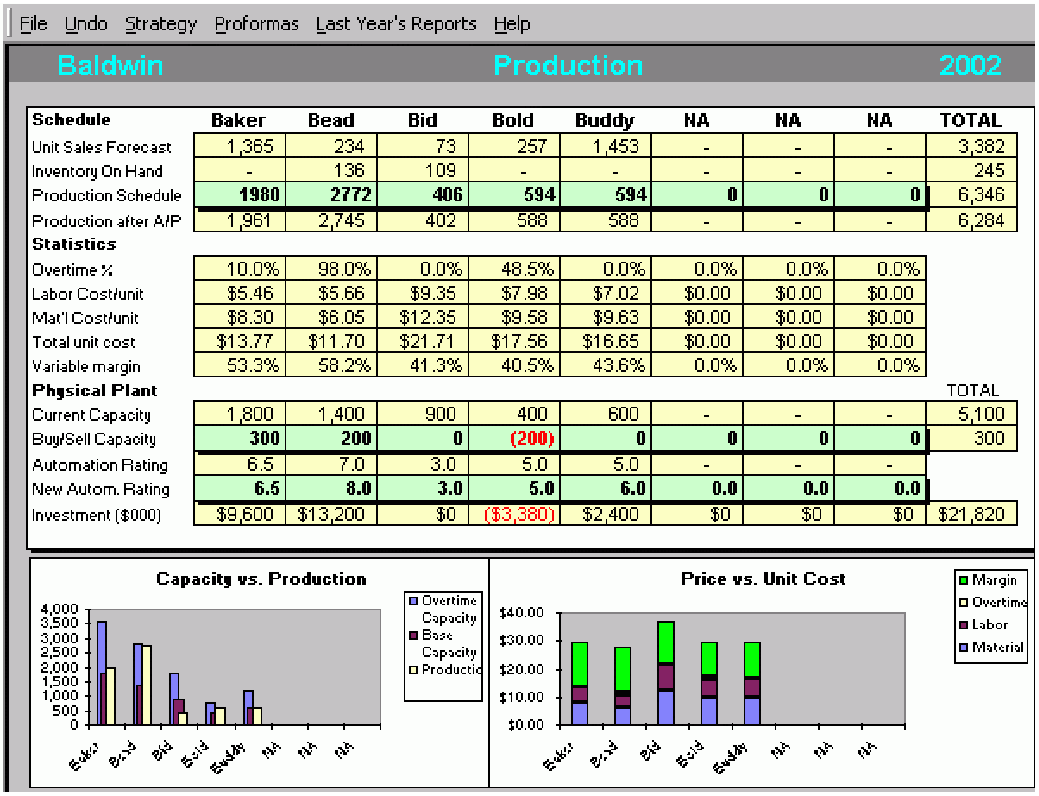
The ideal simulation should have elements of both competition and cooperation. There should be a degree of cooperation between elements of an organization, whether these are individuals, departments, or divisions.

At the same time, in order to effectively and realistically model a successful corporation, incentives must be in place that inevitably foster a degree of competition, in addition to the obvious need for competitive forces outside the corporation to model the market.

Almost all the business strategy simulations studied involved extensive interaction with raw numbers and, at best, summary bar graphs and pie charts to inform decision-making, input these decisions, and observe resulting performance. A user interface typical of current business strategy simulations is pictured below.

A typical user business strategy simulation interface

Because immersion visual learning is proven to be more effective, however, a better user interface would be analogous to the transition from command-based computer operating systems to Windows-type systems, where visual interaction is intuitive and more realistic.




| Schedule | Baker | Bead | Bid | Bold | Buddy | NA | NA | NA | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| Unit Sales Forecast | 1,365 | 234 | 73 | 257 | 1,453 | - | - | - | 3,382 |
| Inventory On Hand | - | 136 | 109 | - | - | - | - | - | 245 |
| Production Schedule | 1980 | 2772 | 406 | 594 | 594 | 0 | 0 | 0 | 6,346 |
| Production after A/P | 1,961 | 2,745 | 402 | 588 | 588 | - | - | - | 6,284 |
| **Statistics** | | | | | | | | | |
| Overtime % | 10.0% | 98.0% | 0.0% | 48.5% | 0.0% | 0.0% | 0.0% | 0.0% | |
| Labor Cost/unit | $5.46 | $5.66 | $9.35 | $7.98 | $7.02 | $0.00 | $0.00 | $0.00 | |
| Mat'l Cost/unit | $8.30 | $6.05 | $12.35 | $9.58 | $9.63 | $0.00 | $0.00 | $0.00 | |
| Total unit cost | $13.77 | $11.70 | $21.71 | $17.56 | $16.65 | $0.00 | $0.00 | $0.00 | |
| Variable margin | 53.3% | 58.2% | 41.3% | 40.5% | 43.6% | 0.0% | 0.0% | 0.0% | |
| **Physical Plant** | | | | | | | | | TOTAL |
| Current Capacity | 1,800 | 1,400 | 900 | 400 | 600 | - | - | - | 5,100 |
| Buy/Sell Capacity | 300 | 200 | 0 | (200) | 0 | 0 | 0 | 0 | 300 |
| Automation Rating | 6.5 | 7.0 | 3.0 | 5.0 | 5.0 | - | - | - | |
| New Autom. Rating | 6.5 | 8.0 | 3.0 | 5.0 | 6.0 | 0.0 | 0.0 | 0.0 | |
| Investment ($000) | $9,600 | $13,200 | $0 | ($3,380) | $2,400 | $0 | $0 | $0 | $21,820 |



For the purpose of developing a business strategy simulation for managers in large corporations to transform their ways of thinking, the ideal design will most likely need to be asynchronous. This would allow users to progress at their own pace and not feel they are wasting time being taught ideas they already know. Finally, in order to create the circumstances for effective learning as defined along the categories discussed here, the simulation cannot be single-player in the sense that the user is the only factor effecting change on the simulated market system.
The set-up must foster team thinking. The effective business-learning simulation should:

Simulate managerial decision making in complex and distributed settings.
Enable competitor behaviors emerge that result in decisions that form the performance. Obstacles (judgment biases) for the good of the larger system.
Demonstrate emergent macroscopic behavior.
Allow the decision makers teach someone else.
Enable the decision makers fall prey to (or avoid) the identified fallacies.
Make possible to base each decision on uncertain and incomplete information.
Continue to pose value for future sessions and not a just a one-shot-game or exercise.
Allow the players to observe directly the effects of their decisions on emergent patterns of behavior.
Provide a medium for intercommunication between the decision makers throughout the simulation, allowing them to exchange information, observation, advice, threats, etc.
Allow decision makers to share with each other their experiences and intuition.
Help executives to better recognize how selecting locally desirable decisions may result in sub-optimal solutions.
Visually display and explain the impacts of decisions and parameter changes in one area that impact in other areas.
Allow decision makers to view the processes of change rather than just snapshots, and

Enhance rather than hinder systems thinking.

Selecting “Systems thinking”, as the foundation and the organizing principle for the effective business-learning simulation development, has profound consequences on design considerations.

Systems thinking is first and foremost a point of view and a methodology arising out of this viewpoint. It is often said, “Systems thinking is a lens through which you can look at the world and that lens determines what you see. Also, it often determines what you do about what you see.” As Russell Ackoff states: “it is not disciplinary. Disciplines are categories used in filling information, knowledge, and understanding. They are different aspects of the same reality, not different realities. Systems are real, and reality is not disciplinary.” Therefore, the study of systems goes beyond both disciplinarily and interdisciplinary. Metadisciplinary "systems thinking" implies the use of holistic theories.

In “systems thinking” the orientation is on social systems, i.e., social systems that are purposeful systems containing purposeful parts and are themselves contained in a larger purposeful system. This puts the focus on properties of systems that their parts do not have, on the functions of systems within the larger systems that contain them, and on the effects of the properties of the system on the parts. It is more concerned with the way parts of a system interact than act, and, most importantly, with purposes of the parts, the system, and the systems that contain it.

In other words, "systems thinking" is geared towards the two problems with which a social system has to contend in addition to "self-control." These are: (1) "humanization" problems – how to design and manage a social system so that it better serves the purposes of its parts; and (2) the “environmentalization” problem – how to design and manage a system so that it better serves the larger system of which it is a part (including the markets it serves). An appreciation is required for the fact that *purpose* (a matter of choice) is the most critical classifying variable used in distinguishing social systems from other types of systems.

This is an era where we are witnessing an explosion of technologies with which to construct simulations and training games, and the relative merits of each approach has yet to be fully mapped or understood. Further, there is evidence that no single simulation tool is suitable and that the ideal system might draw from two or more methods. Some of the methods of interest include:

<u>System Dynamics:</u> A set of difference equations that is ideal for macro-behavior modeling and process delay handling and for complex feedback loops in cyclic systems.

<u>Discrete Event Simulation:</u> The use of stochastic processes for modeling random fluctuation and non-determinism in order to study system behavior. Often used in a Monte Carlo approach.

<u>Parametric Game Theoretic (Agent Swarms):</u> The use of very simple agents of a few parameters or utility functions in systems of tens of thousands of agents, each with individualized utility functions, that interact on cellular automata (taurus), enabling the study of emergent behavior and development of equilibrium and market dynamics. It is popular to combine this approach with learning methods such as genetic algorithms, neural nets, or evolutionary programming to study survival of the fittest and adaptive behavior.

<u>Cognitive Agents:</u> A broad categorization of techniques for modeling how agents reason about problem spaces, derive utilities from emotional arousal on value hierarchies, and behave in bounded rational manners due to stress and other limitations.
In particular, in agent-based modeling, organizations are modeled as a system of semi-autonomous decision-making parts (purposeful individuals) called agents (in contrast to other approaches where social systems, for the purpose of simplicity, are reduced to unrealistic microcosms). Macro-behavior is not simulated; it emerges from the micro-decisions of individual agents. In this work, each agent individually assesses its situation and makes decisions based upon value hierarchies of goals for action, preferences for artifacts, and standards for behavior.

Also, agents have a bounded rationality that is subject to stress, time pressure, and emotive forces. At the simplest level, an agent-based model consists of a system of agents and the relationships between them. Experience with agent-based modeling shows that even a simple agent-based model can exhibit complex behavior patterns and provide valuable information about the dynamics of the real world system that emulates them.

Agent-based platform helps the decision makers to better understand their organization and its relevant business environment as an organized complexity. In particular, it fosters seeing emergence of behaviors and inter-relationships rather than linear cause and effect chains. This allows the decision-makers to view the processes of change rather than just snapshots. In this framework, one can study learning, adaptation, and the rise and fall of new *market equilibrium* as a function of the emotive reactions, desires, and stressors of the agent participants.
It is therefore, important to note that through the simulation, the reality (market system) is shown to be comprised of a variety of elements (detailed complexity), relationships (seeing inter-connections), and interactions (dynamic complexity) with which decision makers must deal.

Can we design the game and characters in such a way that they will continue to pose value for future sessions (i.e., not just a one-shot game or exercise)?

## THE SYSTEM DYNAMICS APPROACH

A primary objective of System Dynamics is to design simulation models that can help to improve decision-making and policy development. Indeed, the System Dynamics simulation models, providing a "safe" environment for testing strategies and policies, help "learners" and in particular managers to improve their mental models and to better understand the dynamic of complex systems i.e. the company. The common goal of these models, also called, in a learning context, Interactive Learning Environment Management Flight Simulator - is to stimulate managers in order to gain a systemic view of the overall organization during the decision-making process (Sedehi et al., 2000).

### Microworlds And Learning Laboratory

Microworlds or management flight simulators (MFS) are 'live' models of real-life situations. They are 'virtual worlds' or "constructed microcosms of reality" in which managers can experience a day in the life of the company. In SD, simulation models are converted into Microworlds by adding user-friendly interfaces. They compress time and space and allow for interactive experimentation and scenario modeling.

One of the most powerful uses of Microworlds is a learning laboratory setting. Learning lab is a process as well as an environment whereby a group (i.e., management team) can learn together. The purpose of the learning lab is to enable managers to experiment and 'see' the consequences of their actions, policies and strategies. The learning lab process follows the three steps in a learning cycle. This often results in finding inconsistencies and discovery of unintended consequences of actions and decisions, before they are implemented.

A learning lab is distinct from the so-called management games. In management games, the players are required to compete - design the 'best' strategy to 'beat ' other players or teams. The competitive nature of management games often encourages individualistic and aggressive behavior with little attention for insights and deep learning. The Learning Lab, in contrast, aims to enhance *learning*, to gain deeper understanding and insights into why systems behave the way they do, to test theories and mental models, and to discover inconsistencies and 'blind-spots' in policies and strategies.

A significant benefit of the learning lab stems from the process by which the participants reveal, examine and test their mental models and those of their organization.
Other benefits of the learning labs include:

Align strategic thinking with operational decisions.
Connect short-term and long-term measures.
Facilitate integration within and outside the organization.
Allow experimentation and learning.
Balance competition with collaboration.
Cooperate to find a solution.

### Managerial 'Practice' Field

In the last decade, the concept of team and teamwork has received a great deal of attention. Numerous companies have reorganized their work around teamwork. From factories to hospitals, titles like manager and supervisor have been replaced by roles such as ‘facilitator’ and ‘team leader’. Despite this level of attention to team and teamwork the expected benefits have been marginal at best.

It is widely acknowledged that the notion of practice field is by and large absent in work environments. In this context “practice” means allowing time and space to experiment with new ways, try different approaches and most importantly, make mistakes without the fear of failure. It is ironic that while making mistakes is indispensable to learning, yet so much organizational systems and energy are devoted to the prevention and masking of mistakes! The consequence of the lack of practice and learning is that most organizations only achieve a small fraction of their potential - about 5% percent, according to Jay Forrester. The learning lab used as a practice field allows learning to become an integral part of managerial work - it facilitates learning to become institutionalized.

## Learning Lab And Emotional Learning

Dealing with mental models is the most challenging and frightening aspect of learning, especially in-group settings. As individual’s “egos” are at stake, this is fraught with risk and emotions. Mental models are formed throughout one’s life. Family, school, religion, culture, and social norms play important roles. Therefore, modifying one’s mental model is not a small matter. The most effective way to check one’s mental models is to *experience* alternative realities first hand and see their implications with a new ‘lens’. “It is never enough just to tell people about some new insight. Rather, you have to get them to *experience* it in a way that evokes its power and possibility” In this context, according to Senge and Sterman, learning labs can deal with mental models at three levels, as described below:

*Mapping* mental models - This step begins at the Conceptualization phase. Here, the learning lab participants articulate and clarify their assumptions, views, opinions, and biases regarding the issue at hand.

*Challenging* mental models - The participants identify and discuss inconsistencies and contradictions in their assumptions. This step will begin at the Conceptualizations phase and will continue to the experimentation phase.

*Improving* mental models - Having conducted experimentation and testing, the participants reflect on the outcomes. This may alter, adjust, improve and harmonise their mental models.

The ‘laboratory’ setting provides a neutral and ‘safe’ space for the participants to create a shared understanding of complex and endemic issues. The following characteristics of the learning lab provide a powerful catalyst for alignment of divergent mental models in the organization.

The environment is neutral and non-threatening. The emphasis is on learning and theory building (what we don’t know), not on winning or display of knowledge.
Lack of hierarchy. Managers and staff are equal in this environment. The traditional hierarchy is eliminated in this setting.
The response time is fast. Hence, the feedback cycle is short, which leads to rapid learning.
There is no cost or ‘loss of face’ attached to failure. Hence, it is safe to make mistakes. In fact, mistakes provide opportunities for learning.
People can see the consequences of their actions first-hand. No one attempts to convince anyone else or force his or her preconceived views. People learn through sharing and group interactions.

## Implications For Managers

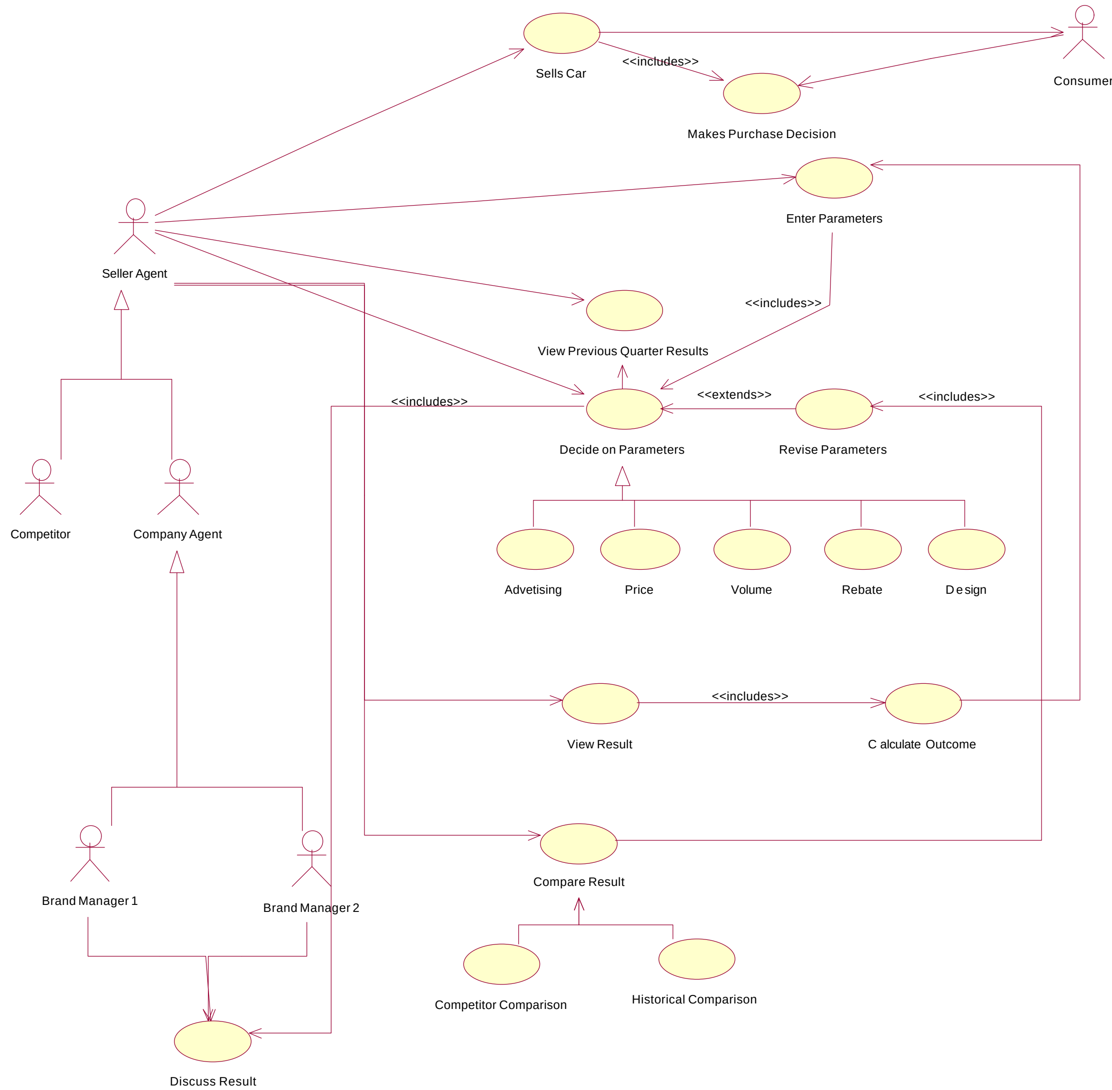
The practice field and the Learning lab concepts have fresh and challenging implications for managers and their role. They suggest that leader/manager should think as a *scientist*, be open to and welcome hard questions, experiment with new ideas, and be prepared to be *wrong*! This requires managers to learn Systems Thinking and modeling skills and use them not just for ‘solving’ problems but also as powerful tools for communication, team building and organizational learning. This means that effective leaders can become “designer” of the ship. Once they design new strategies, policies or procedures then the manager/leader should create a practice field for the staff to experience and experiment with new designs and learn for themselves and from each other. As has been observed in organizations such as Hanover Insurance, learning lab can play a significant role in clarifying and changing mental models. There are no true opportunities in a manager’s daily work to engage in lengthy and drawn-out experimentation, thus learning in a ‘laboratory’ setting is the next best thing. SD and agent based modeling provide powerful mediums where managers can experiment and test theories and learn rapidly. Agent modeling complements and enhances SD simulations by adding the emotional learning dimension to the model.

This process allows the Learning lab participants to examine and test their long-held assumptions regarding chronic and complex issues and gain deeper understanding of the underlying dynamics affecting systems. The outcome will be shared understanding and group learning.

## THE INTELLIGENT AGENT- BASED TECHNOLOGY APPROACH

In order to demonstrate the emergence of complex behavior from relatively simple activities a simple simulation model of the business could be constructed. As Gilbert and Troitzsch (1999) state that “even when agents are programmed with very simple rules, the behavior of the agents considered together can turn out to be extremely complex.”

In a simple simulation model where there are three distinct classes of decision makers, i.e., real decision makers, competitors’ decision makers and consumer decision makers, there are two distinct classes of agent technology that could be utilized in the development of such a business simulation game.




It is very important to be mindful of the choices that are available for the developers and the importance of developing a rich model. Some of the critical considerations are explained by Silverman, et al. (2002):

"…without a deeper model, one often is unable to adequately explain how or why the outcomes occurred at the level of specific individuals. Those who model emergent social structure tend to model only the surface characteristics of individuals, using only very few expected utility equations….Without deeper, richer models, they are unable to explain either the root sources of individual agents' boundedness or their micro-decision processes…..A delicate balancing act and pursuit of complementary approaches, thus seems warranted at their early stage in the study of mental representations of motivations…"

## Competitor Agents

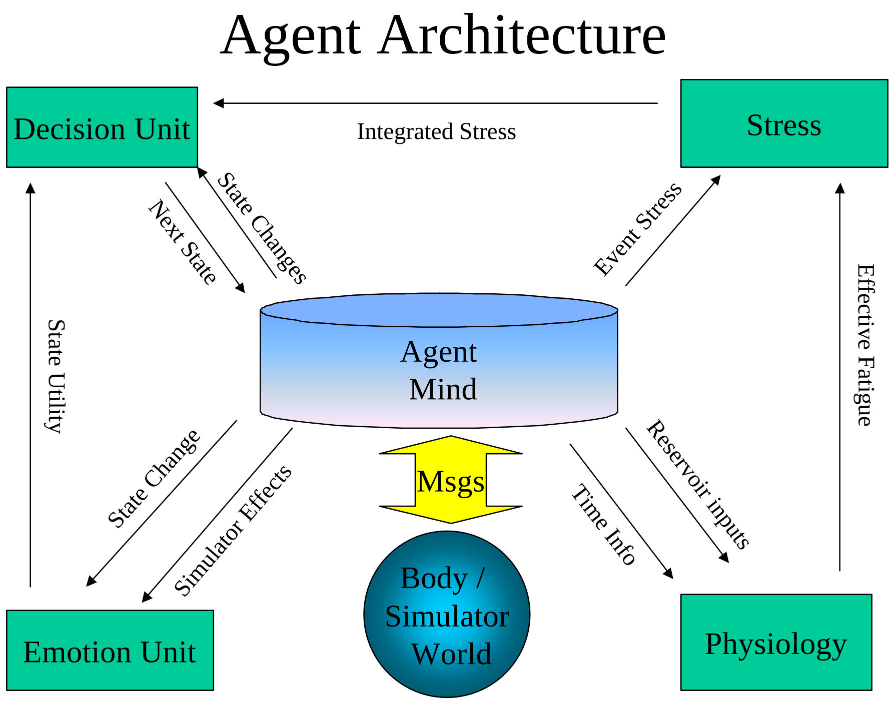
Based on the above considerations, in the simple game described, the competitor agents could use Markovian decision processes subject to emotional constraints to produce realistic human-like behavior and decisions and the market simulation could be built around cellular automata that evolve macro-market behavior from the micro-decisions of individual purchasing agents.

Human behavior modeling frameworks can be effectively synthesized and deployed in agent decision processing. These models help to systematically capture and illustrate individual differences in socially intelligent agents. For example, how can agents be created to systematically reflect contextually relevant emotions and personality, and further, how do these affect their decision-making behavior? The idea that humans are rational actors whose decisions are often clouded by emotion is as old as Western thought. Until recently, artificial intelligence research concentrated primarily on the "rational" aspect of this, reasoning that since the problem of making good decisions is so difficult in itself that to introduce emotion into the equation would make the performance of the agent even worse. Recent theories suggest a quite different relationship: that emotions are a vital part of the decision-making process that manages the influence of a great deal of competing motivations. According to these theories, integrating emotion models into agents will yield not only better decision-makers, but also more realistic behavior by providing a deep model of utility. The agent framework that has been developed at the Ackoff Center uses a detailed hierarchy of a goals, standards, and preferences to model the motivations of a human decision maker.

For example, in such a game, competitor agents should be built using this framework. The general framework includes four principal sub-units – a decision unit, emotion unit, stress unit, and physiology unit.

The strength of this agent architecture is that it produces agents whose decisions are both culturally and physiologically grounded. Since physiology and stress are not particularly significant to this application, however, we will de-emphasize the stress and physiology units but leave the decision and emotion units in place. This will result in agents that choose courses of action based on an emotional hierarchy.

Emotion may not seem particularly necessary for accurate representation of corporate decision-making, but the definition of emotion implies a reliance on cultural norms and goals that are quite applicable to the corporate domain. By building a goal hierarchy within such agents, one could demonstrate that their decision-making reflects a particular corporate culture and management philosophy. These agents will not necessarily act dogmatically, but their actions will reflect a reliance on real socio-cultural belief structures. This will allow us to model the decision making of an organization’s competitors quite realistically. In addition, it is possible to quickly and easily change the competitor simulated by the agents simply by swapping out their emotional hierarchies.




Market Simulation

Simulating the market is best achieved by using cellular automata. A cellular automata is a grid-like system of simple agents that interact with their neighbors to produce complex social phenomena. Market model could employ a large population of spatially situated agents governed by simple decision rules. These rules take into account both global variables (the types of cars available, advertising, etc) and the purchasing behavior and other properties of the surrounding agents. In this way, an extensive list of agent properties is not needed. In fact, the cellular automata approach benefits from having as simple a model of each individual agent as possible. Properties could easily be limited, for example, to income, cultural/ideological affiliation, and current car owned without sacrificing the accuracy of the market simulation.

Each agent makes its own purchasing decision based upon the decision rules, so the behavior of any individual agent is easily understandable and relatively deterministic. While the behavior of any given consumer agent is quite simple, the interactions between the agents and the patterns that emerge from those interactions can be extremely complex. Therefore, it is feasible to construct diverse and interconnected societies of consumers that accurately reflect available population demographics. Taken as a whole the interactions between agents allow a complex, dynamic social network to emerge. As a result, cellular automata can simulate subtle market dynamics much more effectively than competing analytic models.

The systems approach suggests that complexity resides in the relationships between elements of a larger system, not necessarily in the internal functionality of those elements. The strength of the cellular automata model lies in its ability to faithfully capture relationships among the individual agents. In a market simulation, the rationale behind the purchasing decision of an individual agent is not nearly as important as the trends exhibited after aggregating the purchasing decisions of a diverse population. By utilizing simple agents with complex interconnections, our market simulation sacrifices behavioral complexity at the level of the individual but is well able to model the complexity of the market itself. This approach will result in a market simulation that is much more realistic and responsive than more traditional economic models.

## CONCLUSION

This paper explores the conceptual frameworks for agent based and system dynamics approaches to modeling and group leaning. While system dynamics has been around for nearly half a century, agent based modeling is relatively new. On a conceptual plane, this paper concludes that there exist both differences as well as synergies between the approaches. However, further studies are called to shed empirical light on the subject.

A cursory comparison of System Dynamics and Agent-based Modeling indicates the following difference in the two approaches given the characteristics outlined below:

| **CHARACTERISTICS** | **SYSTEM DYNAMICS** | **ABM** |
|---|---|---|
| Scope | Focus on Content (Micro) | Focus on Context (Macro) |
| Modeling approach | Stock & Flow and CLD | Agent-based |
| Behavior | Is the result of structure (model) | Emerges as the result of interaction amongst agents |
| Modeling Focus | Business/Physical processes | Human/Social processes |
| Application | Problem-solving and Understanding | Learning |
| Degree of realism | Moderate | High |

As stated by Gilbert and Troitzsch (1999), " a systems dynamics model is an indivisible whole." This may be viewed as a weakness of system dynamics approach in that behavior remains a function of structure (model relationships defined a priori). In contrast, in agent based modeling, "emergent" behavior could be expected as a result of agents' interactions. This is a key difference between the two approaches. Despite their differences, strong synergies exist between the two as SD and ABM can be used in a complementary fashion. Both ABM and SD represent strong mediums for transforming information to knowledge and understanding (doing things right). With experience and perseverance, new insights and understanding could be translated into wisdom (doing the right thing). However, The transition from knowledge to understanding and wisdom may not be immediate or transparent. This requires a shift in mental models though experimentation and group learning. Both SD and ABM are powerful tools for group learning. Used appropriately and in the context of learning environments, these tools could bring about much needed organizational transformation and alignment of vision.

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