Training in Systems Thinking and System Dynamics as an Effective Way to Tackle Complexity in the Management of Organisations

STEFANO ARMENIA

s.armenia@unilink.it

Link Campus University

ALESSANDRO POMPEI

alessandro.pompei@uniroma1.it

Sapienza University of Rome

ANNAMARIA VECCHIO[1]

ing.annamariavecchio@gmail.com

System Dynamics Italian Chapter

Abstract

The biggest challenge for today's organisations is to address the growing complexity of their internal and external environment while gaining a competitive advantage. To do this, the leaders of the organisations must be able to understand this complexity through the knowledge of the environment and the implementation of a governance system based on a decision-making process that considers the enormous amount of data available. Such data must lead to the availability of information that guides the organisations themselves in the learning process.

Sustainable development requires organisations to rethink their goals and/or business models, with effects on their day-to-day activities. Pursuing to become more sustainable is not only a need for marketing reasons but also an opportunity for growth and alignment with emerging trends. However, managing the complexity of sustainability is not straightforward and requires cognitive and practical tools that are able to capture and jointly consider a wide variety of interrelated factors.

Modelling the processes that characterise complex organisations is not an easy task. The aim of this contribution is thus to identify a methodology that helps managers in tackling the challenges that organisations have to adopt when faced with a growing complexity of their internal and external environment, and that might help managers at all levels when analysing various business and management situations, to account for non-linearities, path-dependency and time lags, and that may allow also for organisational and social learning.

[1] Corresponding author.

 ISSN: 2499-1333

The study shows how the System Dynamics approach, identified as a methodology for modelling and simulation, is able to lead to the development of effective skills and strategic learning for the management of organisations and hence support the dynamic evaluations of strategies and performance.

The System Thinking and System Dynamics approach may prove a useful combined tool for next-generation decision-makers, but this approach needs to be understood and learned in order to develop the necessary skills. In particular, this study will show the results of a test conducted with the collaboration of undergraduate university students, who have attended a course about System Dynamics, in order to test their ability to understand the dynamics underlying counterintuitive system behaviour.

1. Introduction

Unpredictability and complexity are two characteristics of our society, as widely recognised in the literature about complexity science, chaos theories and non-linear systems (Chesters, 2004; Holling, 2001; Freeman and Winch, 1957). Technology is definitely an enabling factor for tackling complexity and supporting organisations in their digital transformation process and is aimed not only at satisfying customer requests but at effectively restructuring organisations and how they are managed, so as to increase their value and profitability, through process efficiency and effectiveness.

In the information age, the management of big data is a crucial aspect of the decision-making process. However, the availability of often overabundant amounts of data makes it quite difficult to evaluate the results emerging from them: the issue is to transform a sometimes overwhelming amount of information in actual knowledge for the organisation so that this can provide insights for present and future organisational models and strategies with a view to the sustainability of the organisation itself (Chen *et al*., 2012).

It is also quite important to achieve an understanding of how such data has been generated; in other words, by understanding what are the processes that determine such data, which in turn implies an understanding of the structure of the organisation, and possibly thus also relying on models based on the understanding of the interdependencies among such processes in the organisational system (Kabir and Carayannis, 2013).

Hence, the integration of ICT-based techniques with modelling and simulation has emerged as an interdisciplinary approach to decision making for several research fields, applications and technologies (Armenia *et al*., 2018). In particular, the adoption of impact assessments approaches based on a systemic perspective as well as on simulation can also help overcome the fragmentation between various academic fields, stakeholders engagement, application areas and approaches to innovation in order to make the complex decision-making process more effective and more intelligent, thus accelerating the learning path embedded in a sustainable development for organisations.

Systems Thinking and System Dynamics can support managing today's complexity and dealing with the needed transformation to cope with changing needs and scopes, by providing managers with the needed conceptual tools but also practical ones and by enhancing the current decision tools only based on a data-driven approach thanks to its inherent capability to look at process interdependencies into organisations (Sterman, 1989a, 1989b, 2000; Jackson, 2003; Bach *et al*., 2006).

In general, System Dynamics is a methodology and mathematical modelling technique for framing, understanding, and discussing complex issues and problems. Originally developed in the 1950s to help corporate managers improve their understanding of industrial processes, System Dynamics is currently being used throughout the public and private sector for policy analysis and design, as well as also in various other contexts of knowledge. System Dynamics is an aspect of systems theory as a method for understanding the dynamic behaviour of complex systems (Lyneis, 2003).

System Dynamics has found application in a wide range of areas, as for example population, ecological and socio-economic systems, which usually interact strongly with each other. System Dynamics has also been used widely in the field of education (Warren and Langley, 1999).

In a context of change in education systems and in the academical research, Systems Thinking appears to be a valid alternative in order to help students in speeding up their learning processes. This was confirmed in research studies (Sweeney and Sterman, 2000) where those students applying System Dynamics concepts have achieved on average better performance compared to those who either did not apply it or just said that SD had not been useful to their understanding of production systems. (Armenia *et al*., 2004).

The specific questions the study tried to answer were the following:

- Which are the mental obstacles that organisations find while trying to solve their problems and how they design their own mental models of the reality under examination?
- May Systems Thinking and System Dynamics at least partially help organisations in devising correct solutions? Does a particular background help or improve one's ability to think systemically?
- May Systems Thinking and System Dynamics constitute an effective aid in doing it or instead was only a confusing tool which did not add much to their counterintuitive and non-linear system analysis skills?

Although the systemic approach has excellent potential for learning improvement, in this paper the difficulty of those who will then have to apply the lessons learned is also addressed, trying to understand to what extent they will succeed to master this approach in real-life problems. Our reference sample will be university students as a proxy of those who will enter the labour market.

The paper is structured as follows: Section 2 describes the reference context (managerial and organisational context), explaining why the systemic approach/perspective, with the development of systemic skills/competences, is a key factor for successful managers and improved performance by the organisation. Then, the paper shows the features of System Dynamics and how these may be acquired by students, also showing some previous examples and proposals towards the improvement of the education system by means of this approach. After this overview, the paper describes the functioning of four different experiments (i.e., Bathtub Dynamics, Cash Flow, the Department Store and Manufacturing Case) that were carried out in an Italian university. The results are then showed and discussed. Finally, the final considerations, including managerial implication, and the implications for future research are presented as well as the limitations of this work.

2. The context and the need for systemic perspectives/competences

The management of information and knowledge within organisations has acquired a central role, in relationship with their identity and competitive mechanisms. Learning processes, the level of involvement in decision-making, the ability of knowledge transfer, the relationships between learning and knowledge, as well as the ease with which knowledge can be created and disseminated are central elements in the current economic and competitive model (Rullani, 2004; Simone, 2011).

Knowledge management models within organisations should be able to correctly identify the available knowledge, developing virtuous cycles of generation–accumulation–recombination of knowledge.

Organisational learning is a form of learning that takes place when the members of an organisation, faced with a problematic situation, take action to solve it and make the solution and strategies found as a common heritage of the organisation (Argyris and Schon, 1996). Then, the organisation is learning. Thinking of an organisation capable of implementing the learning dimension internally means conceiving it as an open and dialoguing system not only between the internal actors of the organisation but also between them and the wider social, economic and environmental context; in other terms, it means considering an organisation as a learning organisation (Senge, 1990).

The challenge for organisations is to be managed by leaders able to anticipate and understand the expectations and non-expectations that await the organisation on the road to change within the growing complexity of their internal and external environment. One of the most effective ways to fully understand the dynamics of such a systemic process is the Systems Thinking approach and its operative expression, the System Dynamics.

In order to better understand Systems Thinking and how to guide organisational learning, it is necessary to carry out in-depth studies about the related thought system. Systems theory for modelling and simulating enterprise processes is based on three key concepts: System, Model, Simulation:

- the fundamentals of **Systems Thinking** starting from General Systems Theory (Von Bertalanffy, 1956);
- **Model**, its meaning and different classification, its diverse use together with costs and benefits of its potential development;
- the concept of **Simulation,** which is explored through different methods, putting in evidence the advantages of **System Dynamics modelling and simulation**.

Such basic key-concepts must be learned in order to improve systems understanding before generating an improvement in organisational performances by evaluating the possible outcomes before the reengineering is carried over (i.e., by simulation techniques), understanding systems complexity and behaviours.

Thinking in Systems means moving from the simple observation of events or data towards the identification of patterns of behaviour over time and identifying the underlying structure that generates those patterns behavioural events and those events (Meadows, 2008). The ability to understand and modify those ‘structure’ that are not operating at their best (including our ‘mental models’ and our perceptions) allows us to expand the selection of available choices and thus create more effective long-term solutions to chronic problems (Senge, 1990).

The quantitative declination of Systems Thinking finds its concretisation in the approach of modelling and simulation known as System Dynamics, which is its natural and practical development, based on contents, founding principles and logical constructs (Forrester, 1994).

System Dynamics is a methodology and mathematical modelling technique for framing, understanding, and discussing complex issues and problems. The basis of the methodology is the recognition that the structure of any system, the many circular, interlocking, sometimes time-delayed relationship among its components, is often just as important in determining its behaviour as the individual components themselves. The main idea behind the System Dynamics approach is that 'a system structure defines its behaviour'.

System Dynamics can support organisations in the analysis of large quantities of data, which are often collected for helping strategic decisions. Thanks to SD, it is possible to identify, study and evaluate different strategies, choosing the one that may positively influence the organisation's performance over time. Furthermore, such methodology allows organisations to become 'smart', to learn and, eventually, change their internal processes, in order to improve their chances of achieving their strategic goals. In other words, SD favours the comprehension of the existing dynamics and allows for a decision-making process based on the impact of assessment of various development and/or transformation options.

3. Understanding and learning system dynamics

The next generation of managers will have to think, act and behave as Systemic Leaders in their respective organisations, in order to achieve success in the transformation process. Their role, through Systems Thinking, will be to fully understand how success with customers is optimised thanks to the knowledge of how all the elements of an organisation interact with both internal and external components. This is in contrast with the approach that offers solutions to customers by optimising the operations of the individual parts of an organisation without considering the way in which they interact (Martinez Garcia and Martínez Caro, 2009; Hsieh and Yuan, 2010). But there is more than that: System Dynamics could enable managers to develop more accurate cognitive representations about their business models (Moellers *et al*., 2019); or it could help managers to overcome decisional myopia, shifting the focus of their decision process from a single department to the whole business system (Bivona *et al*., 2019). Moreover, System Dynamics could be an important support tool for project management planning and monitoring activities (Li *et al*., 2009; Yujing *et al*., 2015). The field of application within managerial activities are almost unlimited.

This 'new' holistic approach cannot be easily taught because it is inherently interdisciplinary. Usually, the understanding of Systems Thinking and System Dynamics relies on the knowledge based on computer sciences, management, law and economics and is aimed at developing appropriate skills to deal with complex dynamics that characterise the evolution of organisations, economic systems and societies.

However, the knowledge and mastery of the System Dynamics approach require the comprehension of some key concepts such as accumulation, feedback, delays, non-linearities.

With the aim of contributing to the understanding of the dynamics of learning Systems Thinking and System Dynamics, starting from very young students (K-12 students) and up to university students, the results obtained from the introduction of Systems Thinking and System Dynamics to these clusters have been investigated widely so far.

In 1992, when K-12 system dynamics was still in its infancy, Jay Forrester (1992) wrote *System Dynamics and Learner-Centered-Learning in Kindergarten through 12th Grade Education*. The paper presented the cornerstones for a more effective education based on system dynamics, a description of early work in Tucson championed by Gordon Brown, the necessary ingredients for implementing change in schools, and cautionary advice for the future. Forrester (1992) laid out the reasons and the means to change pre-college education in fundamental ways (Forrester, 1992: 1):

> System dynamics offers a framework for giving cohesion, meaning, and motivation to education at all levels from kindergarten upward. A second important ingredient, "learner-centred-learning," imports to pre-college education the challenge and excitement of a research laboratory. Together, these two innovations harness the creativity, curiosity, and energy of young people.

In 1994, in *Learning through System Dynamics as Preparation for the 21st Century*, Forrester (1994) went further to describe the benefits that a systems education could provide to students and their communities. The experience of the Creative Learning Exchange in Action proved that students who are exposed to the tools of ST/SD have an ability to think critically which helps them both express their thoughts more clearly and understand more complex problems. This ability needs to be documented.

Many other practices proved that young students could learn the basics of system dynamics, and that system dynamics can enrich their educational experience by making it more learner-centred, engaging, cohesive and relevant (Sterman, 1993; Radzicki and Karanian, 2002). This research stream is considered relevant and continuously studied by the academics in various educational contexts, both under (Yurtseven and Buchanan, 2012) and over graduate (Bravo *et al*., 2009) and from engineering/technology (Sterman, 2010) to management courses of study (Kljajić *et al*., 2017). There is, however, still work to do in order to make the systemic approach much implemented and adopted by educational institutes, due to some barriers and difficulties on implementing simulation activities and overcoming the teachers' previous training experience (Fisher, 2011; Skaza *et al*., 2013). Therefore, addressing these difficulties with innovative research activities would give youngsters new ways to learn about complex behaviours and encourage new ways of thinking (Zuckerman and Resnick, 2003).

Building a computer model to run simulation experiments in virtual environments provides also a strong tool to support scenario-based analysis of long-term sustainability of business ideas (Delauzun and Mollona, 1999). It can be valuable in order to foster entrepreneurship in young students. By learning through computer simulation, young entrepreneurs are able to overcome typical biases, such as focusing on neighbourhood search and past decisions, overestimating current capabilities and adopting mimetic behaviours. Furthermore, simulating long-term scenarios represents a testbed of the robustness of a specific strategy, thereby increasing perceived control over the strategy. Using simulation when implementing their strategies by having simulated different scenarios, young entrepreneurs are able to recognise weak signals and better interpreting unfolding behaviours.

4. The experiment

In order to validate the belief that Systems Thinking can be a valid alternative so as to help students in speeding up their learning processes, Professor John Sterman (Sloan School of Management – MIT) has accepted this challenge and tested on his MIT – Massachusetts Institute of Technology – students both their understanding of basic systemic concepts without any prior knowledge of System Dynamics as well as their ability to improve learning skills by means of a System Dynamics education (Sweeney and Sterman, 2000). Other Universities, like WPI, or High Schools (Portland, Wilson High) have afterwards taken up the challenge, fitting it to their own educational environments, thus providing very useful and interesting data, if compared to MIT's experience. Statistical analysis has been carried out on different groups of students and has provided valuable information their behaviour, as well as an interesting collection of all the most frequent and typical mistakes or misunderstandings that may drive us in clustering the reasonings and rationales beyond them.

The questions asked during the test were the following ones:

- May System Dynamics at least partially help students in devising correct solutions?
- Does a particular academic background or do some particular courses help or improve one's ability to think systemically?

The final aim was to inquire if the System Dynamics approach constituted an effective aid or, instead, was only a confusing tool which did not add much to students' counterintuitive and non-linear system analysis skills.

Towards this purpose, and building on the work by Sterman and Sweeney (2000), a study about the students' ability to understand the dynamics underlying counterintuitive system was conducted also in Italy (Armenia *et al*., 2004) at the faculty of Business Engineering, Tor Vergata University, Rome, in order to survey the actual situation of the educational system in Italian universities as well as to draw some more general considerations on the actual Italian educational context. The tasks in the tests were assembled in a slightly different way from those submitted to the students at MIT or other institutions (which may have caused some deviation from average results, as can be seen in the following section).

This has thus constituted a very interesting first experience which allowed the authors to better understand what are those mental obstacles that students find while trying to solve mathematical and/or physical problems, as well as designing their own mental models of the reality under examination.

The test was conducted before and after a System Dynamics module of 5 lessons, as a part of the Production Systems Modelling course, by administering the following tasks (as reported in Sweeney and Sterman, 2000):

- Bathtub Dynamics – Task 1 (BT1);
- Cash Flow – Task 2 (CF2);
- The Department Store – Task 3 (DS3);
- Manufacturing Case – Task 4 (MC4).

The aim was to understand if, and to what extent, SD skills improve the ability to understand the dynamics of systems.

It is necessary to point out again that the tasks were administered before and after the SD module and, as a difference with previous research on this topic, students have been asked to explain what kind of problems they found in the tests. The additional questions posed to students are reported here:

1. Explain the rationale behind your solutions:
   a) Describe in detail the reasoning in answering the four questions of the DS task and how the diagram was interpreted in order to provide a solution;
   b) Describe in detail the reasoning in finding out the solution to the MC task and how the 2 diagrams have been interpreted.
2. Report any difficulties encountered and if there was any particular exam you drew from which helped you in finding a solution.
3. Do you think that studying basic System Dynamics concepts such as S&F dynamics, feedback structure, etc., may have contributed to your systemic skills towards the analysis of complex and/or counterintuitive systems?

The overall composition of the class was comprised of 120 undergraduate students in their last year of a Bachelor Engineering Degree (B.Eng.). Most of them had mainly undergone the following courses: Control Theory, Microeconomics, various Calculus courses (Mathematical Analysis, Algebra, Geometry, Physics, etc.).

As undergraduates at their last year, their age ranged from 20 to 23 (71% were 21 years old). The population was fairly distributed on genders, with a little predominance in male individuals (52% males; 48% females). All were Italian students, but there was no enquiry on the country they were coming from as well as their region of birth.

Moreover, most of the students came from the Management Engineering Specialisation (88%), but there were also students from other specialisations, mostly Logistics Engineering (6%) and Production Engineering (6%). Students were asked to tell something more about their mathematical background, that is, any passed Calculus exams or similar. Collected data allowed to establish that the three more followed courses until then had been Mathematical Analysis, Operations Research, Probability and Statistics.

On the first day of the SD module, only 66 students (group 1) were present and did the test, while on the second test-day, which was the last lesson of the SD-module, 81 students (group 2) were given the test. The increase in test attendance was probably due, as many of the students later told us, to a growing interest in the SD subject, which is not so widespread into Italian Universities, yet.

The first test was a sort of mixture taken from Sweeney and Sterman (2000): it was BT1 and CF2, and every student in the class was given the same test sheet. The students had nearly 30 minutes in order to complete the test, almost double-time if compared to the 'traditional' tests administered in US Universities (MIT, WPI, and so on) (in order to gain, by means of three more questions, some further insight concerning the problems they had in text comprehension, problem-solving, graphical integration, diagram reading, and the like).

The second test consisted of the Ossimitz's Department Store task (DS3 – Ossimitz, 2002) and of Sterman and Sweeney's Manufacturing Case (MC4 – Sweeney and Sterman, 2000). Of course, the main target of this second test mostly consisted in checking whether the number of correct answers would improve or not and, by means of three more questions (as in the case of the first test), understanding whether the wrong answers derived from a wrong comprehension of the text or still from a lack of either mathematical, graphical or systemic skills.

4.1. Bathtub Dynamics – Task 1 (BT1)

The overall performance of 'group 1', that is, the 66 students' group, in terms of correct solutions to the tasks, showed a total average of 0.647 (65%) with a standard deviation of 0.099 (10%).

Most of the students had problems with the coding of item 7, which was about calculating the value of stock. Such result (47% average of correct answers), when compared with results of students from other universities (like MIT, WPI), was quite deluding, especially if considering that this sample had quite a broad range of mathematical concepts as a background. In particular, they had many problems in determining the slope of the stock (56%). It is interesting to note how all of the Logistic Engineers found the correct solution.

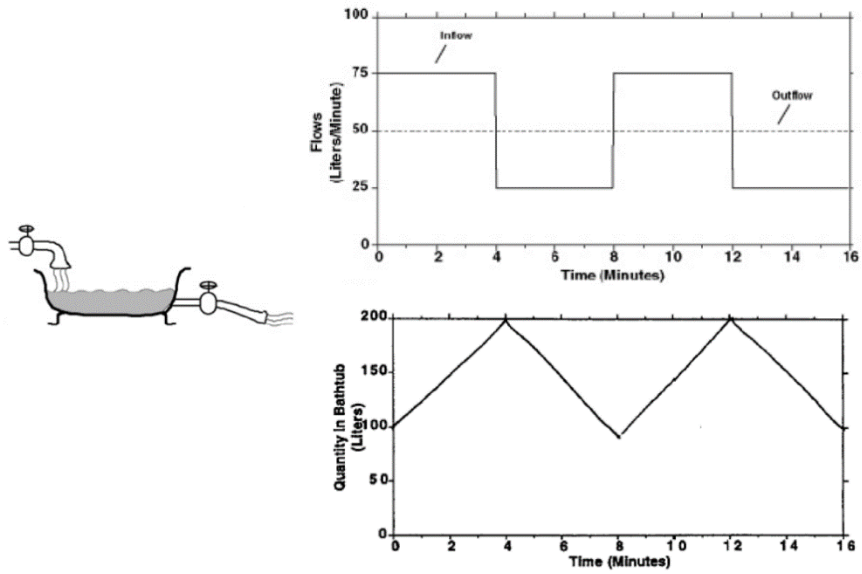

Figure 4.1.1. The Bathtub Dynamics test case (BT1), adapted from Sweeny and Sterman (2000).

4.2. Cash Flow – Task 2 (CF2)

The 'sawtooth wave' task caused even more problems than the 'square wave' one. The same 'group 1' averaged 0.412 (41%) of correct answers with a standard deviation of 0.26 (26%).

By comparing BT1 and CF2 tasks, a big worsening in correct answers was detected for almost each of the posed questions, except for the one related to graph discontinuities, for which 95% of students answered correctly. The most frequent wrong solution was including the so-called 'pattern-matching' problem between inflow and outflow.

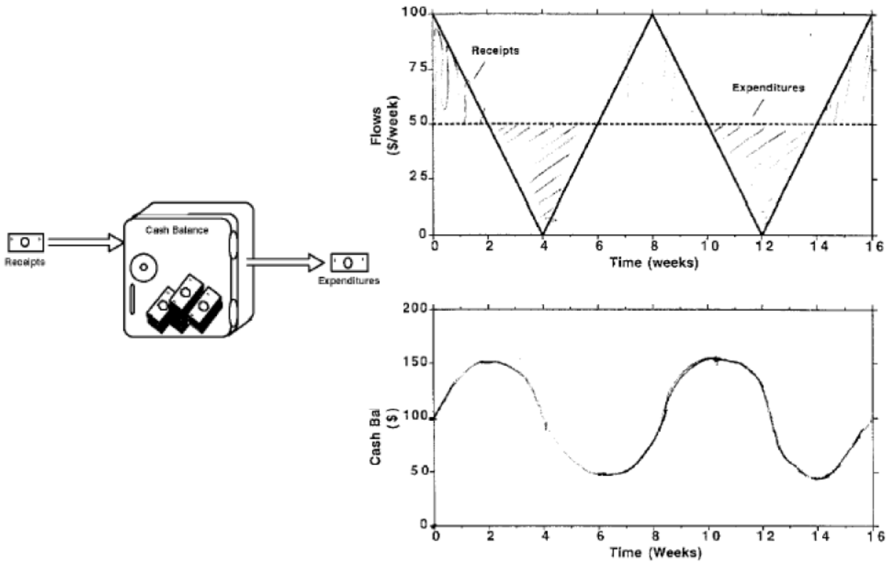

Figure 4.2.1. The Cashflow test case (CF2), adapted from Sweeny and Sterman (2000).

4.3. Department Store – Task 3

Group 1, with the addition of some more students, became as a matter of fact the Group referred to here as Group 2, even if most of the students were exactly the same as in the previous test.

Before this test, all of the students had had a small SD module and had improved their systemic skills as well as developed the concept of stock & flow dynamics, feedback loops, counterintuitive thinking and non-linearities underlying dynamic behaviours of systems; in fact, general performance was much better than the BT1/CF2 one.

The average performance was respectively 0.33 (33%) on Q3 and 0.23 (23%) on Q4 (see Figure 4.3.1), far lower than the performance of students at MIT or WPI. It is interesting to note that, as in the MIT case, most of the students either answered correctly to all the four questions or missed both of the last two. The average of all four questions for the whole Group 2 was 0.61 (61%) with a standard deviation of 0.38 (38%).

 ISSN: 2499-1333

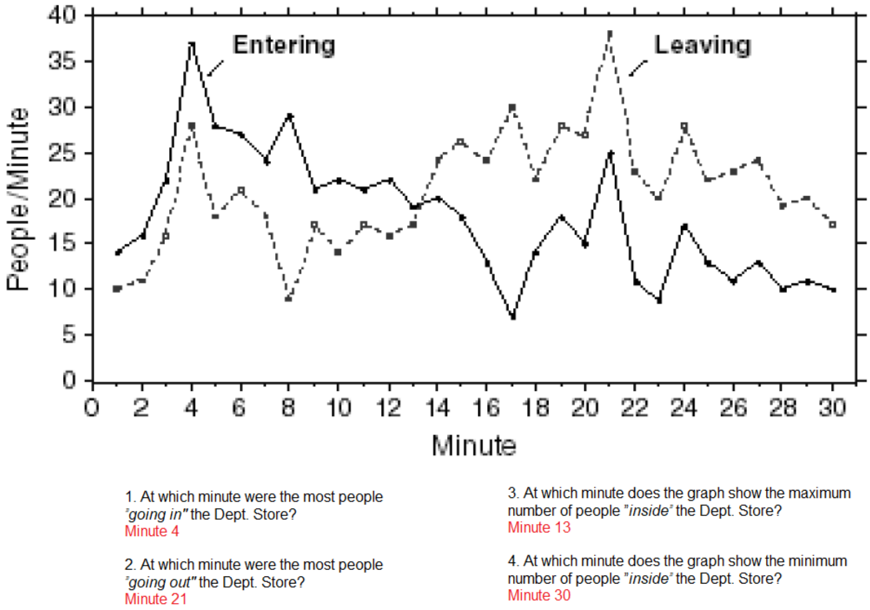

Figure 4.3.1. The Department Store test case (DS3), adapted from Ossimitz (2002).

4.4. Manufacturing Case – Task 4

Even though this task presented more difficulties than the previous one, here the students performed much better than MIT. The performance was quite good. Average performance was 57% against 41% of MIT.

It probably improved because students had relevant experience with such kind of systems (basic knowledge of manufacturing systems already acquired), but we do not have a particular evidence on that, so that it is likely that, by improving their SD skills (by means of the knowledge acquired during the SD module), students have been more capable of providing correct answers. This is confirmed by the presence, on almost each student's sheet, of some SD schemes (Causal Loop diagrams and Stock and Flow diagrams, see in the following) and by the additional question on "how much SD has improved the ability to solve this kind of problems".

Most of the students (62% ~ 74%) were able to understand that the system was starting in equilibrium and how to draw a lag/delay between the change in orders and the response of the production area. Anyway, only 46% showed the correct answer: that is production overshooting orders.

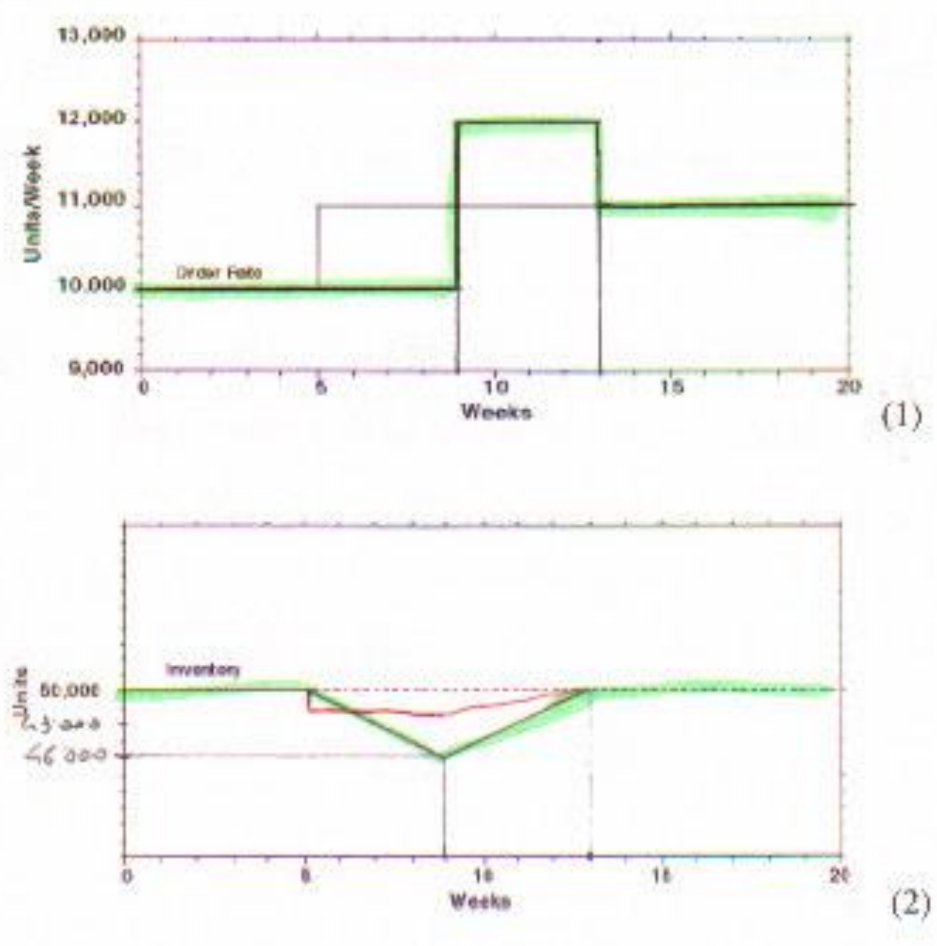

Figure 4.4.1. The Manufacturing test case (MC4), adapted from Sweeny and Sterman (2000).

5. Discussion of results

The results presented in Sweeney and Sterman (2000) and in Armenia *et al*. (2004) suggest that even subjects with previous training and/or background in mathematics and science have a poor understanding of the basic concepts presented in the tests.

Probably such a discrepancy may be mostly due to the fact that the effective students' level of education (i.e., mathematical skills, etc.) was not taken into proper consideration: in other words, probably an inference test concerning statistics on the average performance of students on related exams would help in confirming good results. This issue appears to be confirmed by the fact that a student with a good educational level correctly handling the first task, was then also able to correctly manage the second one. Moreover, it was noticed that students who said to have studied SD in an accurate way were effectively able to positively manage both tests and reported SD disciplines as being very important.

According to BT1 results, Italian students showed an overall poor performance, reaching a rate which was 20% worse than MIT students and 16% worse than those at WPI. However, also taking into consideration such an overall bad performance, there were some correct solutions both to the BT1 and to the CF2 tasks.

According to CF2 results, overall performance was also poor, and the results were 10% worse than those obtained at MIT and 16% worse than those obtained at Portland Symfest.

 ISSN: 2499-1333

The second test (DS3/MC4 – group 2) presents some improvements in overall performance. In fact, the students' performance in the DS3 task was only 4% worse than MIT and 10% worse than WPI. Probably, the received SD module might have had at least some effect in developing the students' systemic skills.

On the MC task, Tor Vergata (TV) students reached good results, 16% better than MIT and only 6% worse than those at the Portland SYMfest. This is probably due to the SD topics learned in the SD module which, according to the main topic of the overall course, were mainly focused on production systems models. Those students presenting a good performance, also show quite a deep interest in SD topics, whereas it was noticed that, on the contrary, as the SD models are not taken into proper consideration, problems in understanding the system's behaviour were rising.

This was confirmed by the fact that those students applying SD concepts (as well as saying that SD had been useful to them) were on average performing better than those who either did not apply it or just said that SD had not been useful to their understanding of production systems. Finally, it is interesting to notice how the joined use of the SD discipline with ones from other scientific areas often underlines the ability to reach excellent results and improved solutions.

6. Final considerations and implications for future research

In recent years, it is clear the emergence of a context where building shared mental models from the base to the top of an organisation and vice-versa is critical to overcome the biases that are typical of a limited vision deriving from the contexts in which the various stakeholders are embedded, and it is evident how a multidisciplinary and systemic approach is needed for an effective decision making and management in such a dynamic and complex context. These considerations are what brought us to believe that an innovative approach to be adopted to build more effective mental models that can help leaders to tackle the challenges of managing a sustainable development for organisations can be the System Dynamics approach.

How can the validity of mental models be determined? The hypothesis formulated by Marafioti and Mollona (2000) states that the validity of a mental model relates to the utility of the latter in order to interpret the cause-effect relationships that link decisions and results. Such an interpretative ability is manifested in two moments:

1. **Ex-ante**: when the strategy is formulated.
   As interpretative (or mental) models grow in richness, strategic analysis earns improved effectiveness in connecting decisions with results that manifest themselves over always longer time horizons or into those contexts only quite weakly linked to the original references.
2. **Ex-post**: during control moment or when evaluating results.
   In such moments, it is crucial to define necessary and sufficient conditions that have generated certain behaviours, explaining the origins of such surprising, deviating or, at least, unexpected manifestations

The System Dynamics approach to modelling and simulating business systems can thus be a connection between control processes, strategic learning and corporate strategy. Simons (1995) states that control, on the one hand, consists in monitoring and reducing the deviation between strategic objectives and the realisation of these objectives while, on the other hand, also stimulates strategic learning.

Learning means refining mental models (potentially defined from a qualitative point of view through Systemic Thinking) of management, that is, continually testing their validity, which lends itself in the final analysis to progressive refinement (with a view to continuous improvement) of the corporate strategy.

This article has reported about some studies aiming at showing how exposure to Systems Thinking and System Dynamics concept can lead those studying and learning it to tackle better with complex problems that are part of today's needs when managing complex organisations in an even more complex and changing environment, by means of an increased ability to build more effective mental models. It was done by using as a proxy some studies learning System Dynamics in several university courses and by referring to previous studies showing this.

However, this study has also some limitations. The first is that the students came almost from one course of study, that is, the Management Engineering Specialisation, so they had some sort of predisposition to mathematics and logics, and this could have affected the results. It would be much insightful to repeat this experiment with students of different courses of study separately or in one more heterogenic class. The other limitation is that this kind of testing is not taking into consideration an incremental complexity in the task to be solved. It would be probably useful and interesting to evaluate the performance of students when solving more articulated problems. An example of this can be constituted by business simulations for higher education[2] and simulations on sustainability for decision-makers learning[3] where an interdependency among issues is relevant and which can be given as a task before and after a wrap-up focused on the unfurling of underlying structure by means of causal loop diagramming and on the evidence of dynamics behaviour.

So, in other words, future development will have to account for differentiation in:

- students' capabilities/skills/knowledge-basis;
- growing complexity/articulation in the tasks to be undertaken.

From such research, it appears that students exposed to the study of System Dynamics concepts have proven to improve their capability of understanding 'stocks & flows' dynamics, the impact of delays and non-linearities as well as (not shown in the tests reported in this paper) of feedback, which is another important component of the ability to think in systems.

From a managerial point of view, this study has relevant implications. First of all, one of the four test cases is relative to a typical inventory problem which is often found in every business reality. The test shows how a problem considered easy to solve at first glance, deserves, indeed, much attention and a systemic point of view. Although it is only a simplistic test, it is a metaphoric expression of how complexity infiltrates managers' everyday life. The education and training of future decision-makers and managers should proceed also through this 'innovative' systemic notions that are all too often overlooked and that instead are key skills for effective management at all levels.

The final consideration that is necessary to make at the end of this work is that there is still a low sensibility connected to the need of training students of all orders and degree on systems

[2] See https://mitsloan.mit.edu/LearningEdge/simulations/Pages/System-Dynamics.aspx (last accessed: April 15, 2019).

[3] See http://sustainerasmus.eu/wp/ (last accessed: April 15, 2019).

thinking and system dynamics, notwithstanding the fact that the United Nations have advocated for a systemic approach for tackling the Agenda 2030 SDGs (Weitz *et al*., 2018), that the World Bank,[4] the UNESCO[5] and UNICEF[6] have stated that Systems Thinking is among the most relevant skills in the new millennium and that the *Laudato Si'* encyclical[7] (by Pope Francis II) is explicitly mentioning a systemic approach towards achieving an integrated Ecology vision for our planet. The authors are currently working in order to fill this gap and bring Systems Thinking in the area of the development of critical thinking skills both in primary, secondary and tertiary education. The road is still long, but there is a growing sensibility on the perceived need to introduce a methodology supporting the integration of a systemic perspective in the way we solve complex problems in our world, which in turn is strictly connected to the need to train youngsters and adults on such new perspective and tools.

Keywords

systems thinking; system dynamics; management of complex organisations; learning processes

Reference list

Argyris, C., and Schön, D.A. (1978), *Organisational Learning*, Reading (MA): Addison-Wesley.

Armenia, S., Di Nauta, P., and Pompei, A. (2018), "Un Nuovo Framework per la Resilienza Decisionale: Il Ruolo della Smart Model-Based Governance", in P.M.A. Paniccia and S. Barile (eds), *Evoluzionismo Sistemico: Il Fascino della Precarietà – Atti di Convegno*, 83–91, Rome: Aracne.

Armenia, S., Onori, R., and Bertini, A. (2004), "Bathtub Dynamics at Tor Vergata University", *Proceedings of the 22nd International System Dynamics Conference (ISDC)*. Available online at http://www.systemdynamics.org/conferences/2004/SDS_2004/PAPERS/327ARMEN.pdf (last accessed: April 15, 2019).

Bach, M.P., Knezevic, B., and Strugar, I. (2006), "Strategic Decision Making in Human Resource Management Based on System Dynamics Model", *WSEAS Transactions on Systems*, 5 (1): 285–292.

Bivona, E., Ceresia, F., and Tumminello, G. (2019), "Overcoming Managers' Myopic Decisions in a Waste Collection Company", *Journal of Modelling in Management*, 14 (4): 1023–1041.

---

[4] See http://blogs.worldbank.org/category/tags/systems-thinking (last accessed: April 15, 2019).

[5] See https://www.researchgate.net/publication/43528535_The_Importance_of_Systems_Thinking_and_Practice_for_creating_Biosphere_Reserves_as_Learning_Laboratories_for_Sustainable_Development (last accessed: April 15, 2019); https://en.unesco.org/news/join-unep-online-course-ecosystem-approach-and-systems-thinking (last accessed: April 15, 2019); https://unesdoc.unesco.org/ark:/48223/pf0000243126

[6] https://agora.unicef.org/course/info.php?id=7293

[7] Available online at http://w2.vatican.va/content/dam/francesco/pdf/encyclicals/documents/papa-francesco_20150524_enciclica-laudato-si_en.pdf (last accessed: April 15, 2019).

Bravo, C., van Joolingen, W.R., and de Jong, T. (2009), "Using Co-Lab to Build System Dynamics Models: Students' Actions and On-Line Tutorial Advice", *Computers & Education*, 53 (2): 243–251.

Chen, H., Chiang, R.H., and Storey, V.C. (2012), "Business Intelligence and Analytics: From Big Data to Big Impact", *MIS Quarterly*, 36 (4): 1165–1188.

Chesters, G. (2004), "Global Complexity and Global Civil Society", *Voluntas: International Journal of Voluntary and Nonprofit Organisations*, 15 (4): 323–342.

Delauzun, F., and Mollona E. (1999), "Introducing System Dynamics to BBC World Service: An Insider Perspective", *Journal of Operational Research Society*, 50: 364–371.

Fisher, D.M. (2011), "'Everybody Thinking Differently': K-12 Is a Leverage Point", *System Dynamics Review*, 27 (4): 394–411.

Forrester, J.W. (1992), "System Dynamics and Learner-Centered-Learning in Kindergarten through 12th Grade Education". Text of remarks delivered on December 21, 1992. Massachusetts (MA): MIT, Sloan School of Management.

Forrester, J.W. (1993), "System Dynamics as an Organizing Framework for Pre-Coiiege Education", *System Dynamics Review*, 9 (2): 183–194.

Forrester, J.W. (1994), "System Dynamics, Systems Thinking, and Soft OR", *System Dynamics Review*, 10 (2-3): 245–256.

Freeman, L.C., and Winch, R.F. (1957), "Societal Complexity: An Empirical Test of a Typology of Societies", *American Journal of Sociology*, 62 (5): 461–466.

Holling, C.S. (2001), "Understanding the Complexity of Economic, Ecological, and Social Systems", *Ecosystems*, 4 (5): 390–405.

Hsieh, Y.H., and Yuan, S.T. (2010), "Modeling Service Experience Design Processes with Customer Expectation Management", *Kybernetes*, 39 (7): 1128–1144.

Jackson, M.C. (2003), *Systems Thinking: Creative Holism for Managers*. Chichester: Wiley.

Kabir, N., and Carayannis, E. (2013), "Big Data, Tacit Knowledge and Organisational Competitiveness", in A. Green (ed.) *Proceedings of the 10th International Conference on Intellectual Capital, Knowledge Management and Organisational Learning (ICICKM)*, 220–227. Washington, DC: The George Washington University.

Kljajić, M., Škraba, A., and Borštnar, M.K. (2017), "Learning and Education Experience in System Dynamics of Management Students: Case Studies", *International Journal of Decision Support System Technology (IJDSST)*, 9 (2): 21–38.

Li, L., Zhang, C., and Li, H.M. (2009), "Application of system dynamics to strategic project management", *2009 First International Conference on Information Science and Engineering*, 4774–4777.

Lyneis, J., and Lyneis, D. (2003), "Bathtub Dynamics at WPI", In *Proceedings of the 21st International Conference of the System Dynamics Society*, New York, USA, July 20–24.

Marafioti, E., and Mollona, E. (2000), *Governare un Sistema Complesso con il System Dynamics: La Nascita di un Hub*, Economia & Management, no. 6, Milan: Etas Libri.

Martinez Garcia, J.A., and Martínez Caro, L. (2009), "Understanding Customer Loyalty through System Dynamics: The Case of a Public Sports Service in Spain", *Management Decision*, 47 (1): 151–172.

Meadows, D.H. (2008), *Thinking in Systems: A Primer*, London: Earthscan.

Moellers, T., von der Burg, L., Bansemir, B., Pretzl, M., and Gassmann, O. (2019), "System Dynamics for Corporate Business Model Innovation", *Electronic Markets*, 1–20.

Ossimitz, G. (2002), "Stock-Flow-Thinking and Reading Stock-Flow-Related Graphs: An Empirical Investigation in Dynamic Thinking Abilities", *Proceedings of the 2002 International System Dynamics Conference*, Albany, NY.

Radzicki, M.J., and Karanian, B.A. (2002), "Why Every Engineering Student Should Study System Dynamics", *32nd Annual Frontiers in Education* (Vol. 1), T4D, *IEEE*.

Rullani, E. (2004), *La Fabbrica dell'Immateriale: Produrre Valore con la Conoscenza*, Rome: Carocci.

Senge, P.M. (1990), *The Fifth Discipline: The Art and Practice of the Learning Organisation*, New York (NY): Doubleday.

Simone, C. (2011), *Conoscenza e Impresa: Percorsi Strategici, Modelli Organizzativi, Casi di Studio*, Padova: Cedam.

Simons, R. (1995), "Control in an Age of Empowerment", *Harvard Business Review*, 73 (2): 80–88.

Skaza, H., Crippen, K.J., and Carroll, K.R. (2013), "Teachers' Barriers to Introducing System Dynamics in K-12 Stem Curriculum", *System Dynamics Review*, 29 (3): 157–169.

Sterman, J.D. (1989a), "Misperceptions of Feedback in Dynamic Decision Making", *Organisational Behavior and Human Decision Processes*, 43 (3): 301–335.

Sterman, J.D. (1989b), "Modeling Managerial Behavior: Misperceptions of Feedback in a Dynamic Decision Making Experiment", *Management Science*, 35 (3): 321–339.

Sterman, J.D. (1994), "Learning in and about Complex Systems", *System Dynamics Review* 10(2-3): 291–330.

Sterman, J.D. (2000), *Business Dynamics: Systems Thinking and Modeling for a Complex World*, Boston (MA): McGraw-Hill Education.

Sterman, J.D. (2010), "Does Formal System Dynamics Training Improve People's Understanding of Accumulation?", *System Dynamics Review*, 26 (4): 316–334.

Sweeney, L.B., and Sterman, J.D. (2000), "Bathtub Dynamics: Initial Results of a Systems Thinking Inventory", *System Dynamics Review: The Journal of the System Dynamics Society*, 16 (4): 249–286.

von Bertalanffy, L. (1956), "General System Theory", *General Systems*, 1: 1–10.

Warren, K., and Langley, P. (1999), "The Effective Communication of System Dynamics to Improve Insight and Learning in Management Education", *Journal of the Operational Research Society*, 50 (4): 396–404.

Weitz, N., Carlsen, H., Nilsson, M., and Skånberg, K. (2018), "Towards Systemic and Contextual Priority Setting for Implementing the 2030 Agenda", *Sustainability Science*, 13 (2): 531–548.

Yujing, W., Yongkui, L., and Peidong, G. (2015), "Modelling Construction Project Management Based on System Dynamics", *Metallurgical and Mining Industry*, 9: 1056–1060.

Yurtseven, M.K., and Buchanan, W.W. (2012), "Educating Undergraduate Students on Systems Thinking and System Dynamics", *2012 Proceedings of PICMET'12: Technology Management for Emerging Technologies*,1837–1844, *IEEE*.

Zuckerman, O., and Resnick, M. (2003), "A Physical Interface for System Dynamics Simulation", *CHI'03 Extended Abstracts on Human Factors in Computing Systems*, 810-811. *ACM*.

 ISSN: 2499-1333