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Teaching the dynamics of the growth of a business venture through transparent simulations

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Abstract

Achieving rapid and sustainable growth is essential for business ventures to succeed. This being so, future entrepreneurs need to understand and manage the dynamics of business growth. Simulation-based learning environments (SBLEs) have been proposed as effective tools to help learners improve their understanding of complex business problems. However, previous research has found that learners tend to underestimate dynamic complexity. Transparent simulations allow entrepreneurship learners to explore the dynamic complexity of business ventures while accessing the model structure and growth behaviour. Previous studies have addressed some aspects of model transparency and produced inconclusive results regarding their impact on learning effectiveness. This study explores the learning and performance effects of using transparent simulations to teach the dynamics of the growth of a business venture. One such simulation experiment used a system dynamics model that represented the development of an energy service company (ESCO) venture under varying conditions of simulator transparency. Students who were subjected to the more transparent strategy achieved higher performance and demonstrated better comprehension of the business dynamics. However, our findings indicate that the effect to be gained from making only the simulator model more visible is more limited. The structural debriefing (focused on the critical variables and relations) was determinant in improving students' learning regarding the stocks and flows structure in the prospects pipeline. Only after participating in the behavioural debriefing (focused on the relation between model structure, patterns of actions, and system behaviour), were the students able to appreciate the dynamics of the business feedback loops. The research suggests that educators who use complex business simulations should complement model transparency with structural and behavioural debriefings.

Keywords:
Entrepreneurial learning, Business venture, Teaching/learning strategies, Business simulation, System dynamics, Simulation-based learning, Model transparency, Simulation debriefing

1. Introduction

For startups, success consists of achieving rapid and sustainable profit growth. A growth path such as this is essential to ensuring superior financial performance and to improve the likelihood of survival (Patel et al., 2020). The challenge resides in planning to grow quickly while understanding and avoiding the risk of failure (Pearce & Pearce, 2020). As such, entrepreneurs must strongly focus on identifying and managing sustainable high-growth paths (Clarysse et al., 2011). Empirical evidence, however, reveals that most startups fail in the first five years of their life, never having achieved sustainable growth dynamics (Shane, 2009). According to the literature on entrepreneurship, this phenomenon can be explained by the characteristics of human capital (e.g. Dickson, Solomon, & Weaver, 2008). It is possible that more startups could succeed if greater attention were paid to making future entrepreneurs aware of the need to understand and deal with the dynamic complexity involved in the growth of ventures. Indeed, the quality of entrepreneurship education has been questioned by several authors (e.g. Bauman & Lucy, 2021; Neck & Greene, 2011), and largely concerns how well students are prepared for the complexities of entrepreneurship. Several authors in the field advocate that entrepreneurship education is an experiential process (e.g. Hagg & Gabrielsson, 2020; Pittaway & Cope, 2007a; Yamakawa et al., 2016) which cannot be taught by traditional methods, and call for more innovative approaches to teaching and learning that can capture the complex components of entrepreneurship (e.g.; Nabi et al., 2017). According to Pittaway & Cope (2007b), students learn from their experience, so an entrepreneurial learning environment works better when students have the freedom to act and reflect on their results. Such an environment also highlights the double-loop learning process (Argyris, 2002) as a higher form of entrepreneurial learning. Simulation-Based Learning Environments (SBLEs) can provide this type of entrepreneurial learning as they can mimic how entrepreneurs learn in real life from experience. Simulations allow potential entrepreneurs to explore the dynamic complexity of business ventures, experimenting and learning how the business reacts to strategic changes (Cosenz & Noto, 2018). In particular, SBLEs can provide future entrepreneurs with the opportunity to improve their ability to learn how to overcome obstacles when managing the growth of new ventures.

This paper reports on the efforts to teach the dynamics of the growth of a business venture (an energy service company) by means of a transparent simulation-based learning environment. It starts with a short review of system dynamics misconceptions in business management, simulation-based learning, the use of simulations for management education, and the issues of model transparency and simulation debriefing as elements of instructional guidance. Finally, it describes an educational experience with graduate students (attending an entrepreneurship course) to analyse the impact of simulator transparency on learning and performance.

2. Theoretical framework

2.1 Business dynamics misconceptions

An accurate perception of system dynamics is fundamental to understand and successfully manage complex business problems. Unfortunately, research reveals that subjects have difficulty perceiving system dynamics correctly (e.g. Cronin & Gonzalez, 2007; Diehl & Sterman, 1995; Ozgun & Barlas, 2015; Paich & Sterman, 1993; Sterman, 1989, 1994, 2010), which implies that the actions and policies defined to deal with those business problems may be misguided.

We tend to learn when we observe things that occur in response to a specific action. This learning process fails to capture the dynamic complexity of business systems. Complex dynamic systems are characterized by multiple feedback processes, time delays, non-linearities, and accumulations. A significant body of research on business learning and management demonstrates that people tend to underestimate dynamic complexity. According to Sterman (2002), people have a poor comprehension of the basic principles or building blocks of dynamic systems. Empirical studies evidence that subjects have difficulties in perceiving system feedback loops (Diehl & Sterman, 1995; Sterman, 1989), the accumulation processes associated with the relationships between stocks and flows (Cronin & Gonzalez, 2007; Sterman, 2010), recognizing system delays (Ozgun & Barlas, 2015; Sterman, 1994), and linking change and outcomes (Paich & Sterman, 1993). People often think in terms of simple linear relationships such as “A causes B” (Perkins & Grotzer, 2005). The business reality, however, is hardly that simple. Business systems consist of many parts interacting through complex feedback causality (Grotzer, 2012). Feedback systems are cognitively challenging because they force us into circular reasoning: A influences B which influences C which influences A. Feedback loops come in two forms: balancing loops that typically cause a reaction in the prominent system behaviour, and reinforcing loops that typically cause a reinforcement of that behaviour. The interplay between the loops, which constitutes the endogenous structure of a system, determines

the dynamics of the system. People also make judgment mistakes because they misperceive the effects of accumulations within the system (Sterman, 2010). Accumulation processes, that is, processes of change over time, are fundamental to dynamic systems. Accumulations relate variables describing the state of the system and variables specifying changes in state over time, represented by flow rates. Such relationships are also cognitively challenging since, to the human mind, it is not obvious how those flow rates transform the system's state over time.
These cognitive deficiencies prevent people from making optimal decisions (Grotzer, 2012). Research shows, however, that structural knowledge can improve task performance (Capelo & Dias, 2009a).

2.2 Learning and pedagogy in entrepreneurship education

Several authors in the field of entrepreneurship education have emphasized the role that learning environments and pedagogical choices play in developing students' entrepreneurial competences (Fayolle and Gailly, 2008; Jones, 2019; Neck & Greene, 2011; Yamakawa et al., 2016). And, indeed, literature reviews show a significant amount of research focused on teaching and learning methods (Hagg & Gabrielsson, 2020; Nabi et al., 2017; Neck & Corbett, 2018; Neck et al., 2014; Pittaway and Cope, 2007a), including an on-going debate on several aspects pertaining to effectively teach students entrepreneurial skills (Bauman & Lucy, 2021). Scholarly discussions on pedagogy have developed over time from teacher-centred methods, such as lectures, guest lectures, case studies and assigned reading, to more constructivist approaches that focus on student-centred and action-oriented pedagogies (Hagg & Gabrielsson, 2020; Kassean et al., 2015; Nabi et al., 2017; Neck et al., 2014; Pittaway and Cope, 2007b). These include experiential learning (Kolb, 1984), as well as activities such as developing products and services, defining business models and plans, and simulations (Fox et al., 2018).
Various learning theories and approaches have influenced this line of research, namely Kolb's experiential learning theory (Kolb, 1984), problem-based learning (Barrows & Tramblyn, 1980), and the effectuation theory (Sarasvathy, 2001). Kolb (1984) argues that individuals learn from experience through an experiential learning cycle comprising concrete experiences (designed to reflect real-world situations), reflective observation (on the activity performed), abstract conceptualization (of the knowledge embedded in the experience), and application. This theory emphasises the central role that experience plays in the learning process. Problem-based learning is a pedagogical approach which challenges students to solve a complex problem and then, with some instructional guidance, they must learn what they need to know and apply

that knowledge to successfully accomplish the task at hand (Barrows & Tramblyn, 1980). Sarasvathy (2001) defines an entrepreneurial method to deal with uncertainty. This method, which can be used as a pedagogical approach, comprises two forms of logic: causation and effectuation. Causation is based on prediction and implies a planned strategy, while effectuation is based on control and is consistent with emergent strategy, experimentation, flexibility, and stakeholder engagement. Both causation and effectuation logics are needed to successfully exploit new business opportunities.

Another aspect concerns how to integrate practice and theory in the learning process (Bauman & Lucy, 2021; Yamakawa et al., 2016). Traditional or theory-based teaching methods focus on developing students' understanding of the main entrepreneurial concepts and frameworks, while practice-based teaching enables students to experience entrepreneurship (Neck et al., 2014; Yamakawa et al., 2016). According to Yamakawa et al. (2016), both approaches must be combined as students have to learn the theoretical framework and be guided in the practice of entrepreneurial activities.

2.3 Learning cycles and mental models

This research is grounded in the dynamic model of the feedback learning process and the concept of the mental model. From a systems perspective, a mental model is a conceptual representation of the structure of an external system used by people to describe, explain and predict a system's behaviour (Forrester, 1961; Senge, 1990; Sterman, 2000; Capelo & Dias, 2009b). Subjects make decisions and learn in the context of feedback loops (Forrester, 1961). In single-loop learning, they compare information about the state of a real system with pre-established goals, perceive deviations between desired and actual states, and take actions they believe will move the system towards the desired state. Single-loop learning does not change the subjects' mental models. In double-loop learning, information about the business system is not only used to make decisions within the context of existing frames, but also feeds back to modify the subjects' mental models (Argyris, 2002). However, subjects' mental models are not identical with external realities; they are models of the real system that is being represented. Due to cognitive limitations, the mental models that managers use for decision making are necessarily imperfect (Sterman, 2000). A mental model based on wrong or inaccurate assumptions means that there are significant differences between decision-maker perception and the business reality (Capelo & Dias, 2009a, 2009b).

2.4 Learning on the dynamic complexity of business ventures through SBLEs

Simulation-based learning (or model-based learning) environments (SBLEs) have been proposed by researchers from many fields, as important tools for supporting learning processes (Maier & Grobler, 2000). Simulation-based learning (or model-based learning) involves humans interacting with an external, formal model (simulation model) for the purpose of learning (Groesser, 2012). In that definition, a simulation model is an explicit, computer-based representation of essential parts of reality. Simulation-based learning is presented as an example of active learning and discovery learning in line with instructional methods derived from constructivist pedagogy (Landriscina, 2013). It provides an environment where a human learner can experiment with hypotheses (Friedler et al., 1990). This approach provides students with complete simulations they can use to explore, experiment, and practice. Simulation is considered similar to other discovery learning methods (e.g., problem-based learning, experiential learning, active learning), which allow students to ''learn by doing'' through multimedia-rich, interactive, and authentic learning opportunities (Landriscina, 2013). As stated by Groesser (2012), simulation-based learning can be supported in the experimental learning theory (Kolb, 1984), the method of inquiry learning (Bruner, 1961), and scientific reasoning process (Friedler et al., 1990). Research has suggested that the use of SBLEs frequently facilitates inquiry-based learning (de Jong & van Joolingen 1998; Eckhardt et al., 2013; Vreman-de Olde, de Jong, & Gijlers, 2013; Chang et al., 2020) and they are appropriate for promoting critical reasoning (Develaki, 2017) about dynamic, complex systems (Huang et al., 2019).

SBLEs provide support for subjects to experiment, build, and test their understanding of complex problems. In other words, simulation models trigger a process by which learners can improve the mental models they need to develop competence, confidence, and expertise (Davidsen and Spector, 2015). Moreover, using simulation-based learning to engage in inquiry that is otherwise impractical or even impossible, makes it easier to improve learner's mental models (Groesser, 2012a). In particular, studies have shown that simulation-based learning with system dynamics (SD) can support and enhance learning (Alessi, 2009). SD is a scientific approach for computer-based modelling and simulation developed to facilitate our understanding and management of complex, dynamic systems (Forrester, 1961; Sterman, 2000). SD models are expressed graphically in terms of stock and flow diagrams (SFDs) detailing the causal structure of the underlying business system. By using this approach, learners may appreciate the cause and effect structure and the relationships between structure and behaviour (Milrad et al., 2003).

2.4.1 SBLEs in business and management education

SBLEs have become an increasingly routine element of academic programme activities (Fox et al., 2018; Goi, 2019; Hallinger & Wang, 2020; Moizer & Lean, 2010). Studies indicate that students perceive simulation as a more effective teaching method than text-based case study and lectures (Farashahi & Tajeddin, 2018; Prado et al., 2019; Tunstall & Lynch, 2010). SBLEs provide a safe environment, which allows for experiential learning without the stress-related obstacles that are met in reality (Grobler, 2004). Additionally, computer simulations of business systems objectively address certain special management issues and try to abstract details and isolate them from confounding factors (Isaacs & Senge, 1994). This abstraction makes it possible to focus on the learning of important and specific business themes.

Several studies have evidenced the positive learning effects of using simulations in various domains of management and business education. For instance, Capelo et al. (2015) and Burdon and Munro (2017) investigated the use of simulations on accounting courses; Huang and Hsu (2011) explored the use of online games to teach personal finance concepts; Pasin and Giroux (2011) analysed the effects of simulation on operations management education; Capelo and Silva (2020) and Sarkar (2016) used simulations on supply chain management courses; Nisula & Pekkola (2012) and Hwang & Cruthirds (2017) focused on ERP learning; Vos and Brennan (2010) applied simulation games in marketing classes; Loon, Evans, and Kerridge (2015) investigated the use of strategic management simulations. Bianchi and Bivona (2000) used interactive learning environments linking SD and accounting models as a teaching aid in the education of small business entrepreneurs. Also, in the entrepreneurship domain, Cosenz and Noto (2018) conceptualized an approach, designated Dynamic Business Modelling, which combines business model representation schemas with SD as a strategy simulation-based tool to support the learning processes of would-be entrepreneurs.

However, whilst the benefits of SBLEs are often discussed in the literature, there is still a need for more research addressing how the learning potential of such environments might be enhanced (Davidsen & Spector, 2015). According to the literature, the effectiveness of SBLEs depends on many factors, e.g., a critical thinking disposition (Bell & Loon, 2015), intrinsic motivation and engagement (Buil, Catalán, & Martínez, 2019), the method of instruction

(Capelo & Silva, 2020), and type of facilitation (Qudrat-Ullah, 2014; Hughes & Scholtz, 2015). The present study explores an approach combining model transparency and simulation debriefing.

2.5. Model transparency and simulation debriefing

2.5.1 Model transparency

Simulator transparency is related to what extent the structure and behaviour of the computational model are revealed to the students using the SBLE. In opaque ('black-box') simulations, subjects can experience the simulator, but the computational model is concealed. In transparent ("glass-box") simulations, the variables and relations included in the model are visible to the students in the form of diagrams with nodes and connecting links between them (Landriscina, 2013). As stated previously, SD learning environments may provide transparent simulations by showing stock and flow diagrams describing the causal structure of the business systems they represent. Through this approach, subjects may access the cause and effect structure of the simulation model and identify and understand the emerging behaviour (Groesser, 2012). Traditional business games are typically of the black-box type and, as described earlier, previous studies with that type of simulator have revealed that subjects have difficulty perceiving system dynamics correctly (e.g. Cronin & Gonzalez, 2007; Paich & Sterman, 1993; Sterman, 1989). This would suggest that opaque simulations could lead students to form incorrect mental models because they do not provide insight into the underlying model structure and behaviour (Landriscina, 2013). As students interact with an opaque simulation, they tend to automatically define and attribute rules to the system. Learning progresses through a process of trial and error whereby the players, despite not really knowing the origin of the results obtained, base their decisions on those rules. These rules may match those included in the model, but they might also be wrong or incomplete. Having no way to determine this could lead to faulty learning with little chance of correction (Machuca, 2000). The use of transparent simulations has been proposed in the literature to obviate the problem of developing model misconceptions (i.e., misinterpretations of the model structure and behaviour) that may interfere with later learning. Nonetheless, transparent simulations involve additional information in the form of diagrams, which benefit only those learners who can correctly understand and interpret those diagrams (Landriscina, 2013). For example, students who are not conversant with systems dynamics have difficulty recognizing and comprehending dynamic structures as they are not able to properly read and interpret causal-loop-diagrams and stock and flow diagrams (Alessi, 2000; Davidsen & Spector, 2015; Jensen, 2014).

The literature indicates that model transparency (compared to an opaque situation) may enhance learning and performance, although some of the results were mixed or inconclusive and occasionally even negative (Capelo & Silva, 2020; Cheverst et al. 2005; Grobler et al., 2000; Kopainsky & Alessi, 2015; Machuca, 2000). Machuca (2000) found that transparent simulations are beneficial with regard to supporting management learning in complex organisations. The study of Grobler et al. (2000) evidences that students interacting with a more transparent business simulator produce better outcomes. Cheverst et al. (2005) found that although users prefer transparency, they do not necessarily benefit from it. Kopainsky and Alessi (2015) report that participants provided with the more transparent strategy demonstrated a better understanding of the underlying model, but their performance was equivalent to those in less transparent conditions. More recently, Capelo and Silva (2020) analysed the learning effects of using transparent simulations and exploratory guidance (that is, guiding learners so they are able to explore the simulation by themselves). They found that while the transparent strategy combined with exploratory guidance is beneficial with regard to understanding both model structure and behaviour, making only the model transparent has a more limited effect.

Previous studies seem to indicate that effective learning requires students to identify the structure of the simulator model and, also, to recognise the relationship between structure and behaviour (e.g. Capelo & Silva, 2020). However, the ability to infer behaviour from structure in complex, dynamic business systems is a very advanced skill. As such, instructional support is required to facilitate effective learning (Davidsen and Spector, 2015).

2.5.2 Simulation debriefing

Previous research suggests that most of the learning in a simulation experience comes from the debriefing session (Crookall, 2010; Kriz, 2010; Lederman, 1992; Van der Meij, Leemkuil, & Li, 2013). A debriefing session is characterized as a facilitated or guided reflection in the experiential learning cycle, structured around a set of questions that encourages students to reflect on their experience in simulations (Fanning & Gaba, 2007).

Research on inquiry learning with simulations (e.g., de Jong & van Joolingen, 1998; de Jong, 2006) has shown that students operating in complex simulation environments generally encounter difficulty in all phases of the inquiry process. According to the cognitive load theory (Sweller, 2020), the complexity of the simulation model may exceed the working memory limits of participants. This takes on special relevance in simulation-based learning environments characterized by a high number of interacting elements that require simultaneous processing in the working memory. Consequently, the instructional method should prevent against 'high load' situations, by incorporating 'cognitive tools' aimed at guiding and supporting students' activities (de Jong et al., 2018). As such, the debriefing method may be incorporated in the instructional support, by asking students about any difficulties regarding their comprehension of the model structure and behaviour and discussing these with them (at the end or between simulation runs). An approach such as this can motivate learners to reflect on the simulation experience in their quest to comprehend game behaviour and its causes. In other words, debriefing may help learners to overcome misconceptions about dynamic and complex tasks and thereby make it possible to improve mental model construction (Pavlov et al. 2015; Qudrat-Ullah 2007, 2014). Thus, debriefing influences the potential of SBLEs in such a way that students may improve their task performance and learning in dynamic tasks.

Previous research on debriefing in simulation studied the effects on learning and performance (Lacruz & Americo, 2018; Qudrat-Ullah, 2014), and discussed how to design debriefing sessions (Grund & Schelkle, 2019; Pavlov et al. 2015; Van der Meij et al., 2013). In the simulation experiments conducted by Qudrat-Ullah (2014), students were involved in different combinations of pre-task, in-task, and post-task discussions. The objective was to help participants understand the structure and behaviour of the simulation model. While these discussions generally improved students' mental models and task performance, the participants involved only in pre-task facilitation performed poorly. Lacruz and Americo (2018) examined the performance of MBA students in a business simulation task and found that the group of students exposed to debriefing outperformed the group not exposed to the debriefing. The results of the study conducted by Van der Meij et al. (2013) evidenced that the performance of students who participated in individual self-debriefing improved more than that those participating in the collaborative self-debriefing. As previously mentioned, the study conducted by Pavlov et al. (2015) considered whether a structural debriefing would facilitate students' learning about the structure of an operations management simulator. The authors concluded that students successfully completed all the steps of the debriefing protocol, but they required considerable time to do so. Grund and Schelkle (2019) tested two different versions of a simulation game: one that integrated debriefing into the game itself, while the other version used classic post-hoc debriefing. Results indicate that in terms of motivation and learning outcomes, it is more favourable to integrate debriefing into the game.

Previous research on simulation-based learning has addressed the model transparency issue and has shown beneficial effects. Although the studies reported provide important advances, they are not conclusive and call for further investigation (Davidsen & Spector, 2015). The following sections describe an experiment aimed at exploring the learning and performance effects of using an SBLE representing the dynamics of the growth of a business venture, under varying conditions of simulator transparency.

3. Research Hypotheses

This study investigates whether a model transparency approach that includes model visibility and structural and behavioural debriefings can improve the learning potential for teaching the dynamics of venture growth, and thereby lead to enhanced student understanding of their main concepts and performance.

The learning outcomes refer to the students' understanding of the simulated system, in terms of structure and behaviour, and to their performance in the simulation task. From a model-based learning perspective, students use the simulations to form an initial mental model and develop it into a target conceptual model (the same one underlying the simulation model). Adequate mental models of the problem dynamics are necessary in order to consistently take effective actions. Thus, the analysis of subjects' learning is based on their actions related to specific dynamic aspects of the simulator model. As the students deal with the simulator dynamics, (they interpret the situation and mentally simulate the consequences of selected actions) they define and implement courses of actions which reflect their comprehension about the structure and behaviour of the simulator model.

The expected relations and hypotheses are based on the following variables:

Level of model transparency (LMT). This variable represents the transparency level of the simulator. The level of model transparency indicates the extent to which the structure (the key variables and relations) and behaviour of the simulation model are revealed to students when they perform the simulation task.

Comprehension of model dynamics (CMD). This variable reflects how students comprehend the structure of the simulation model (representing the growth of a business venture) and are able to infer its dynamical behaviour.
Performance (P). The performance of this simulation task is measured in terms of the financial value created by the venture.

This study assumes that students using business simulations through a model transparency approach, which involves model visibility and structural and behavioural debriefings, have the opportunity to build more appropriate mental models, and will thus perform better in the simulation task. This leads to the first and second hypotheses.

Hypothesis 1: The level of transparency of the simulation model positively influences the level of comprehension of the model dynamics.
Hypothesis 2: The level of transparency of the simulation model positively influences performance.

4. Method

The hypotheses defined in this study and presented in the previous section were tested with an experiment in which students interacted with a simulator. This section presents an overview of the simulator, describes the participants and the experiment conditions, and enumerates the research variables.

4.1 Simulation Model

System dynamics (SD) has been used as a methodology for designing SBLEs (Alessi & Kopainsky, 2015) and also appears to be an effective and relevant tool for creating underlying formal simulation models for research purposes (Größler, 2001; Repenning, 2003). In several areas of management research, computer simulators based on SD models are used as a means to explore subjects' understanding and behaviour in complex situations. In particular, they are well-accepted and frequently used as instruments for investigating human cognition and decision making in complex business situations (Sterman, 1989; Paich & Sterman, 1993; Sengupta & Abdel-Hamid, 1993; Howie et al., 2000; Capelo & Dias, 2009a). Moreover, SD emphasises transparent (or glass-box) simulations rather than opaque (or black-box) simulations. Consequently, we considered the SD model to be an appropriate research tool for our problem.

The purpose of this SBLE is to teach concepts related to the growth of a business venture. By using this SBLE, students will be able to appreciate the dynamic complexity involved in a business venture and the performance effects caused by system misconceptions. In particular, the students will be able to observe the development of clients as they work through various stages in an adoption pipeline: the word-of-mouth (WOM) mechanism explaining how clients evolve from potential to full adopters; the market impacts of building and using a partner network; how staff decisions are crucial to drive venture growth by assuring appropriate levels of skilled and experienced teams; the performance effects of the learning curve; and the importance of balancing the development of business resources and the financial constraints.

Energy efficiency projects based on energy performance contracting (EPC) consist of the implementation of measures that enhance energy efficiency. EPC is an agreement between the facility user or owner and the supplier, also known as energy service company (ESCO). Under EPC, the ESCO designs and puts together a set of measures to improve energy efficiency, or a green energy project, finances this investment, and utilises the stream of gain flows from energy savings, or the renewable energy produced, to repay the investment.

The SBLE incorporates the same mathematical model based on the SD that had been used in previous research (Capelo et al., 2018), and in which policies to support ESCOs were investigated.

The SD model includes some reinforcing (R) and balancing (B) feedback relationships that represent the dynamics of the development of an ESCO venture (Capelo et al., 2018). Figure 1 depicts those loops.

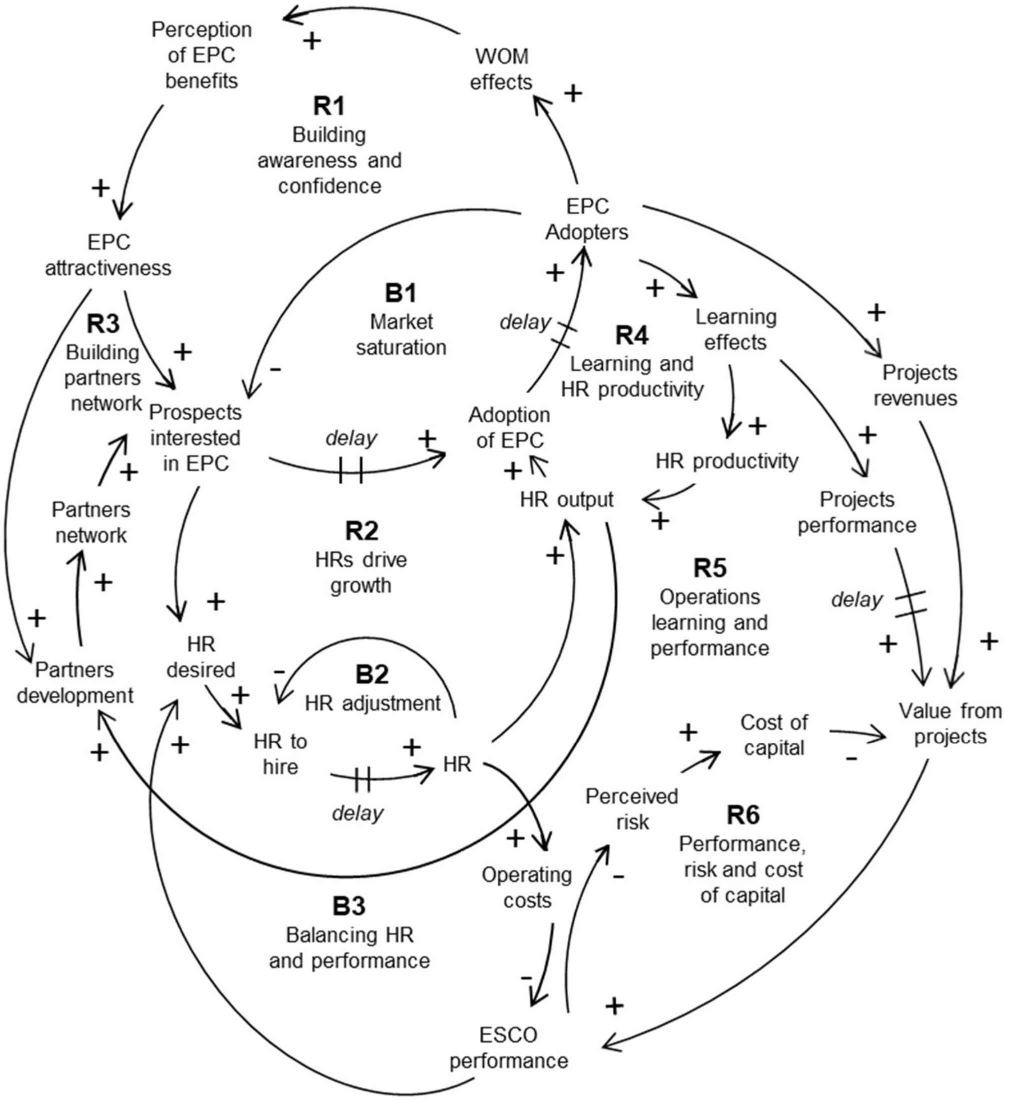


Fig. 1 Causal loop diagram representing the development of an ESCO venture

R1 - Reinforcing loop "Building awareness and confidence": As the first prospects implement EPC projects with the ESCO, they may contact other prospects, make them aware, make them interested, and encourage them to engage in EPC projects. Note on R1: The adoption process will be extremely long because prospects need to be moved up through several phases until they become full EPC adopters (this is indicated by the time delay symbols placed in the links between "Prospects interested in EPC", "Adoption of EPC" and "EPC Adopters").

B1 - Balancing loop "Market saturation": Market saturation induces a balancing loop that limits the growth of EPC adopters. The more EPC adopters in the system, the fewer the potential projects and the lower the expected new profits from EPC.

R2 - Reinforcing loop “HR (human resources) drives growth”: As more prospects become interested in implementing EPC projects with the ESCO, the workforce required to be able to capture those business opportunities increases, driving HR adjustment decisions. By hiring new employees, the firm will be able to assign additional HR effort to business operations, and thus more prospects will become EPC adopters.

B2 - Balancing loop “HR adjustment”: This balancing loop seeks to adjust the number of employees in the firm. The parameter HR to hire is defined as the difference between desired workforce (HR desired) and existing workforce (HR). The link between HR to hire and HR includes a delay representing the time needed to recruit, hire, and train new employees.

B3 - Balancing loop “Balancing HR’s costs and Performance”: As the firm hires new employees, the operating costs increase and impact negatively on the financial performance. This balancing loop seeks to adjust the desired workforce (HR desired), by considering eventual financial constraints. Note on B3: the workforce is critical to the success of the venture. The main task of these employees is to develop a market and feed the prospect pipeline. In the first years, this workforce is costly because the firm does not yet have any revenue. Therefore, this business venture should avoid an overabundance of personnel, as that would drain their cash flow. However, the firm must have enough personnel with sufficient skill to effectively sell and develop EPC projects.

R3 - Reinforcing loop “Building partner network”: As the firm develops new partners, they use their networks to influence and acquire new EPC clients, accelerating the diffusion of EPC, which in turn makes the ESCO more attractive to potential partners.

R4, R5 - Reinforcing loops “Learning and HR productivity “and “Operations learning and performance”: These are virtuous loops of learning-accumulation of experience. As the ESCO employees are engaged in EPC projects they gain further experience and improve their technical, financial, marketing, sales, and management abilities to develop the market, and thus they improve their productivity in all the ESCO activities.

R6 - Reinforcing loop “Performance, risk and cost of capital”: As the ESCO improves performance and increases value creation through EPC business, shareholders will start seeing the EPC business as less risky and will gradually require a lower interest rate.

The simulation model is divided into four different sectors: Market (prospect pipeline), HR (human resources), Operations (this sector addresses the assignment of business activities to human resources), and Finance. The market contains commercial buildings that have potential for EPC projects. The model representing the process of market development depicts the adoption cycle as working through a series of stages. Figure 2 presents a stock and flow diagram of this model sector. Potential prospects are moved up through four stages until they become full EPC adopters: Interested (gaining prospect interest), Audits in Progress (selling and performing energy audit), Projects in Progress (contracting and implementing the EPC project), and EPC Adopters. The adoption process will be extremely long and costly because prospects need to be moved up through the four stages, which involves operating costs and capital expenditures, until they become full EPC adopters and finally start to produce revenues. The stock Partners represent firms that will help the ESCO to inform and persuade new prospects. The rates of flows that accumulate the stocks are determined by employees' efforts (informing prospects, selling audits, developing and implementing projects). Partners and the word of mouth (WOM) effect also influence the inflows of interested prospects.

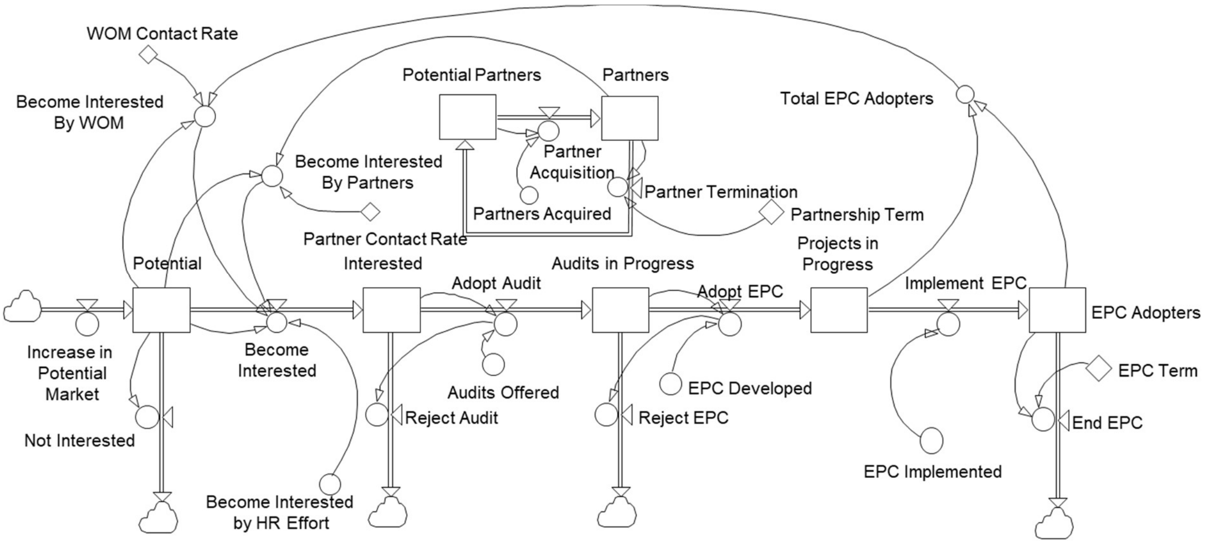


Fig. 2 Stock and flow diagram of the market sector

The HR sector of the simulation model (Fig. 3) includes a co-flow structure with two stocks. The stock labelled HR consists of the number of relevant employees (project managers) in the firm, and the stock HR Experience represents their accumulated job experience. The HR Hiring Rate is the flow into the stock HR, and it is diminished by the HR Leaving and Downsizing rates. Employees learn and accumulate abilities as they are engaged in job activities. This co-flow structure provides the average experience of the employee, which influences the variable Learning Effects Factor that reproduces the learning curve for productivity from job experience.

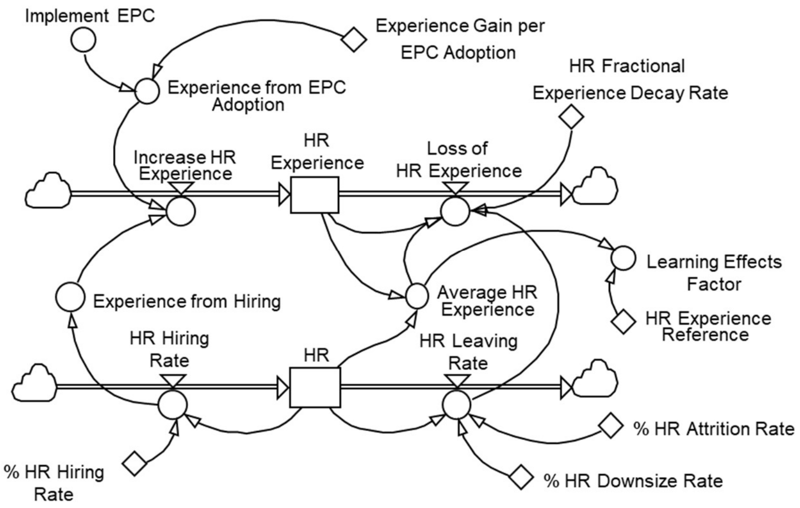


Fig. 3 Stock and flow diagram of the human resources sector

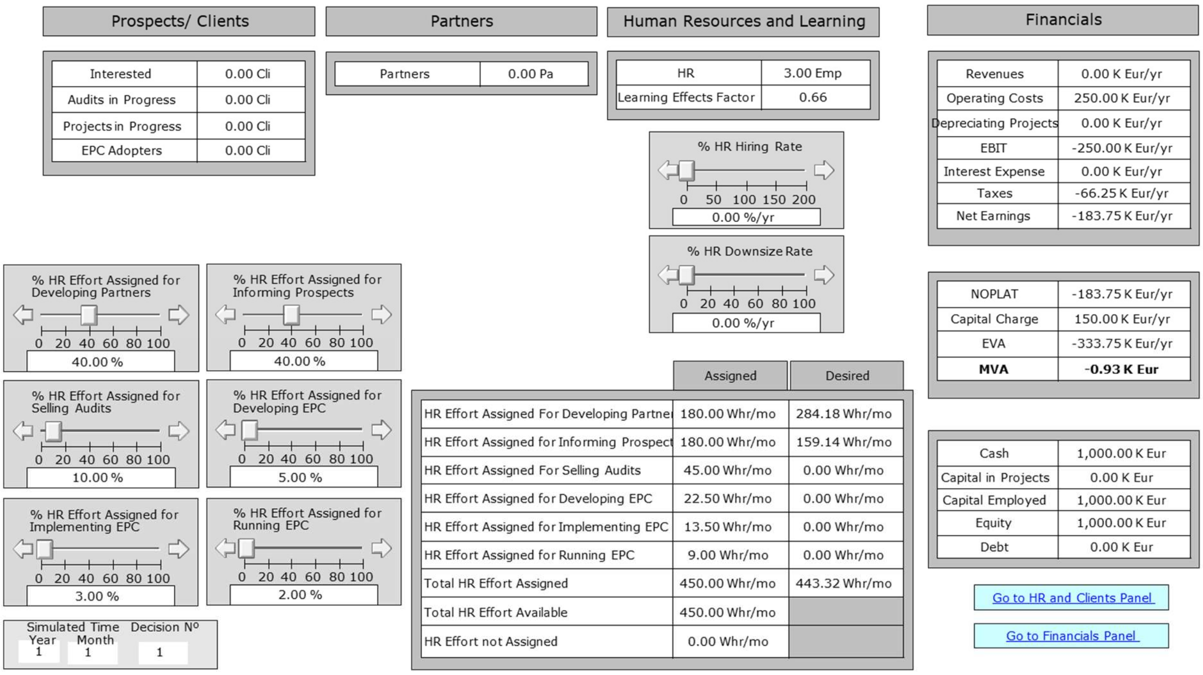
The cash flow, equity, debt, capital in projects, EVA (economic value added) (Young and O'Byrne 2000), and MVA (market value added) are addressed in the finance sector of the model, which describes the process of value creation over time. A more detailed description of the business case and simulator model can be found in Capelo et al. (2018).

4.2 Simulation Task and Interfaces

Participants run a realistic simulator of an ESCO venture, making critical decisions every six months until the end of the third year and every year thereafter for a simulation period of ten years. They analyze the business status and make the following decisions: (1) hiring or (2) firing employees and assigning the business operations (3) informing prospects, (4) developing partners, (5) selling audits, (6) developing EPCs, (7) implementing EPCs, and (8) running EPCs to employees, in order to properly feed the prospect pipeline and get the firm to produce revenues. The number of employees determines the labour costs and those assignments influence operating costs, capital expenditures and revenues (which only come in after prospects become full EPC adopters). The participants analyse the feedback information in order to determine further decisions on human resources and assignments.

The initial conditions and model structure were the same for all participants. The participant objective was to develop those critical and interrelated resources (employees and their experience, partners, different stages in the prospects pipeline, energy projects, and capital) at appropriate rates and levels in order to gain and keep prospects moving up until they become full adopters (and start to produce revenues), operate efficiently, and maximize value creation. Performance is measured in terms of MVA.

The simulator provides two alternative interfaces. One represents an opaque simulator and the other a transparent one. The interface includes six screens. The first screen (the control panel presented in Figure 4 and Figure 5) allows participants to adjust simulation parameters (employees and their assignments) and includes tables presenting measures, such as the levels of partners and each stage in the prospect pipeline, the number of employees and their learning factor, and the employees' efforts both desired and currently allocated for performing each business activity. In the transparent interface, the control panel provides the information about the partners and the prospect pipeline included in a stock and flow diagram, as presented in Figure 5. The second and third screen present the historical behaviour over time for key variables related to human resources and learning, levels and flows of the prospects pipeline, and financials. The other screens, only available in the transparent interface, show the CLD and the SFDs described above (Figures 1, 2 and 3).



Prospects/ Clients

Interested	0.00 Cli
Audits in Progress	0.00 Cli
Projects in Progress	0.00 Cli
EPC Adopters	0.00 Cli

Partners

Partners	0.00 Pa

Human Resources and Learning

HR	3.00 Emp
Learning Effects Factor	0.66

% HR Hiring Rate 0.00 %/yr

% HR Downsize Rate 0.00 %/yr

Financials

Revenues	0.00 K Eur/yr
Operating Costs	250.00 K Eur/yr
Depreciating Projects	0.00 K Eur/yr
EBIT	-250.00 K Eur/yr
Interest Expense	0.00 K Eur/yr
Taxes	-66.25 K Eur/yr
Net Earnings	-183.75 K Eur/yr

NOPLAT	-183.75 K Eur/yr
Capital Charge	150.00 K Eur/yr
EVA	-333.75 K Eur/yr
MVA	**-0.93 K Eur**

Cash	1,000.00 K Eur
Capital in Projects	0.00 K Eur
Capital Employed	1,000.00 K Eur
Equity	1,000.00 K Eur
Debt	0.00 K Eur

% HR Effort Assigned for Developing Partners 40.00 %

% HR Effort Assigned for Informing Prospects 40.00 %

% HR Effort Assigned for Selling Audits 10.00 %

% HR Effort Assigned for Developing EPC 5.00 %

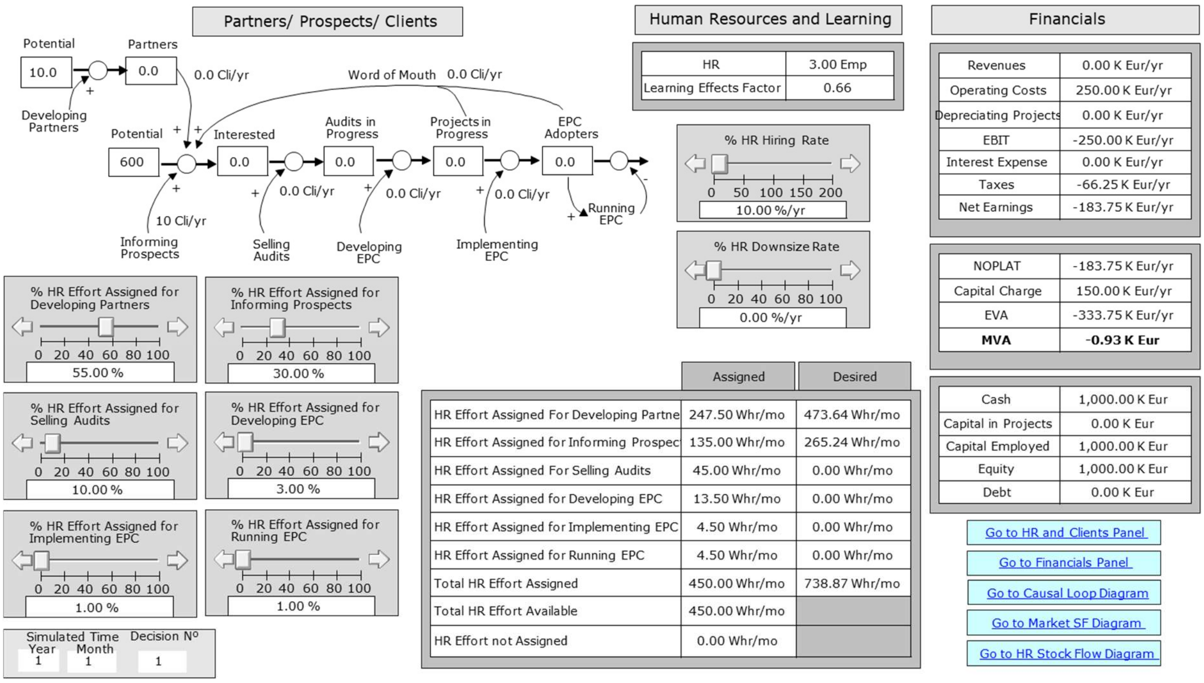
% HR Effort Assigned for Implementing EPC 3.00 %

% HR Effort Assigned for Running EPC 2.00 %

	Assigned	Desired
HR Effort Assigned For Developing Partne	180.00 Whr/mo	284.18 Whr/mo
HR Effort Assigned for Informing Prospect	180.00 Whr/mo	159.14 Whr/mo
HR Effort Assigned For Selling Audits	45.00 Whr/mo	0.00 Whr/mo
HR Effort Assigned for Developing EPC	22.50 Whr/mo	0.00 Whr/mo
HR Effort Assigned for Implementing EPC	13.50 Whr/mo	0.00 Whr/mo
HR Effort Assigned for Running EPC	9.00 Whr/mo	0.00 Whr/mo
Total HR Effort Assigned	450.00 Whr/mo	443.32 Whr/mo
Total HR Effort Available	450.00 Whr/mo	
HR Effort not Assigned	0.00 Whr/mo	

Simulated Time Year	Month	Decision Nº
1	1	1

Fig. 4 Control panel of opaque interface



% HR Effort Assigned for Developing Partners: 55.00 %
% HR Effort Assigned for Informing Prospects: 30.00 %
% HR Effort Assigned for Selling Audits: 10.00 %
% HR Effort Assigned for Developing EPC: 3.00 %
% HR Effort Assigned for Implementing EPC: 1.00 %
% HR Effort Assigned for Running EPC: 1.00 %
% HR Hiring Rate: 10.00 %/yr
% HR Downsize Rate: 0.00 %/yr
Simulated Time Year 1 Month 1, Decision Nº 1

HR	3.00 Emp
Learning Effects Factor	0.66

	Assigned	Desired
HR Effort Assigned For Developing Partne	247.50 Whr/mo	473.64 Whr/mo
HR Effort Assigned for Informing Prospec	135.00 Whr/mo	265.24 Whr/mo
HR Effort Assigned For Selling Audits	45.00 Whr/mo	0.00 Whr/mo
HR Effort Assigned for Developing EPC	13.50 Whr/mo	0.00 Whr/mo
HR Effort Assigned for Implementing EPC	4.50 Whr/mo	0.00 Whr/mo
HR Effort Assigned for Running EPC	4.50 Whr/mo	0.00 Whr/mo
Total HR Effort Assigned	450.00 Whr/mo	738.87 Whr/mo
Total HR Effort Available	450.00 Whr/mo	
HR Effort not Assigned	0.00 Whr/mo	

Revenues	0.00 K Eur/yr
Operating Costs	250.00 K Eur/yr
Depreciating Projects	0.00 K Eur/yr
EBIT	-250.00 K Eur/yr
Interest Expense	0.00 K Eur/yr
Taxes	-66.25 K Eur/yr
Net Earnings	-183.75 K Eur/yr

NOPLAT	-183.75 K Eur/yr
Capital Charge	150.00 K Eur/yr
EVA	-333.75 K Eur/yr
MVA	**-0.93 K Eur**

Cash	1,000.00 K Eur
Capital in Projects	0.00 K Eur
Capital Employed	1,000.00 K Eur
Equity	1,000.00 K Eur
Debt	0.00 K Eur

Fig. 5 Control panel of transparent interface

4.3 Research Variables

This section summarises the use of the variables that were defined in the research model. The learning outcomes, comprehension and performance of model dynamics are assessed against benchmark values. This method has been applied in previous studies (e.g., Diehl & Sterman, 1995; Kopainsky et al., 2015; Paich & Sterman, 1993; Sterman,1989).

Level of model transparency (LMT). This variable is calculated as the sum of three components which are measured as follows:

Level of model visibility (LMV). This variable features two degrees. In the low degree (low LMV), the students perform the simulation task without accessing any structural information of the simulator model. In the high degree (high LMV), the students have access to the CLD and selected SFDs of the simulator model during the simulation task.

*Level of structural debriefing (LSD)***.** This variable features two degrees. In the low degree, the students perform the simulation task without prior structural debriefing. In the high degree, the students have participated previously in a structural debriefing.

*Level of behaviour debriefing (LBD)***.** This variable features two degrees. In the low degree, the students perform the simulation task without prior behavioural debriefing. In the high degree, the students have participated previously in a behavioural debriefing.

*Comprehension of model dynamics (CMD)***.** This variable is calculated as the average of four components which are provided by the SD model and measured as follows:

Human resources drive growth (HRDG). How students comprehend the causal loops R2, B2, B3, and R6 from the causal loop diagram. These causal loops describe how employees can drive the growth and success of the venture. This component is measured by combining the following two dimensions:

HRDG1 - How students deal with R2 (HRs drive growth) and B2 (HRs adjustment) by adjusting the number of employees needed to drive the growth of the venture, in the first five years. This variable is measured in terms of the average number of employees and is rated on a continuous scale (from 0 to 1) against reference values.

HRDG2 - How students consider B3 (Balancing HRs costs and Performance) and R6 (Performance, risk and cost of capital), in the first five years, by assuring appropriate levels of skilled staff and avoiding an overabundance of personnel that would drain the cash flow and cause the financial collapse of the venture. This variable is measured in terms of equity per employee and is rated on a continuous scale (from 0 to 1) against reference values.

Building awareness and partner network (BAPN). How students comprehend the causal loops R1 (Building awareness and confidence) and R3 (Building partner network) and their role in feeding the prospect pipeline. This component is measured through the following two dimensions:

BAPN1 – How students build and take advantage of a partner network. This variable is measured in terms of the average fraction of work hours assigned to acquired and manage business partners and is rated on a continuous scale (from 0 to 1) against reference values.

BAPN2 – How students understand and take advantage of the WOM effect (which freely feeds the prospects pipeline) by not assigning unnecessary effort to capture new prospects in the final five years. This variable is measured in terms of minimizing the average fraction of unnecessary work hours assigned to informing new prospects and is rated on a continuous scale (from 0 to 1) against reference values.

Prospects pipeline (PP). How students understand the structure that represents the adoption cycle as working through a series of stages in an adoption pipeline, assigning own employees' efforts to each activity so that prospects are rapidly and smoothly moved up until they become full adopters and finally start to produce revenues. This component is measured through the following two dimensions:

PP1 – How students minimize over-accumulations of prospects in the pipeline stages, which delay the adoption process and correspondent cash inflow. This variable is measured in terms of minimizing the average under-assigned work hours per desirable work hour and is rated on a continuous scale (from 0 to 1) against reference values.

PP2 – How students minimize depletions of prospects in the pipeline stages, which can cause under-utilization of human resources and corresponding undesirable costs. This variable is measured in terms of minimizing the average over-allocated work hours per desirable work hour and is rated on a continuous scale (from 0 to 1) against reference values.

Human resources learning (HRL) – How students understand the co-flow structure that accumulates employees and their experience as well as the associated causal loops R4 (Learning and HR productivity) and R5 (Operations learning and performance) which reproduce the learning curve for productivity from job experience. This component combines the following two dimensions:

HRL1 – How students develop and retain experienced employees. This variable is measured in terms of the average experience per employee and is rated on a continuous scale (from 0 to 1) against reference values.

HRL2 – How students take into account the progress in learning and productivity, in the final five years, by not hiring unnecessary employees. This variable is measured in terms of minimizing the average unnecessary work hours per desirable work hour and is rated on a continuous scale (from 0 to 1) against reference values.

Performance (P). The performance of this simulation task is measured in terms of the financial value created by the venture, indicated by the final value of the parameter MVA (market value added). This variable is rated on a continuous scale (from 0 to 1) against reference values of MVA.

4.4 Participants, Apparatus, and Procedure

In order to test the hypotheses, we conducted a laboratory experiment using two groups: a control group (CG) of students who interact with an opaque simulator and do not participate in debriefing sessions - lowest LMT (low LMV, low LSD, and low LBD) - and an experimental group (E) that uses a transparent simulator and participate in debriefing sessions - high LMV, high LSD (in the second and third simulation runs), and high LBD (in the third simulation run). Figure 6 presents the experiment procedure.

Treatment		Experimental Procedure							
		a) Lecture on CLD and SFD	b) Objectives and task description	c) Instructions about the simulator	d) First simulation run	e) Structural debriefing	f) Second simulation run	g) Behavioural debriefing	h) Third simulation run
CG	Low LMT low LSD low LBD		●	●	●		●		●
E	High LMT high LSD[a] high LBD[b]	●	●	●	●	●	●	●	●

(a) low LSD in the first simulation run; (b) low LBD in the simulation runs 1 and 2

Figure 6. Experimental procedure.

This research was conducted at ISCTE, a business graduate school in Lisbon. The experiment involved two classes of entrepreneurship courses with 45 students in total. One of the authors acted as instructor in these classes. Each of the three different treatments was assigned randomly to one of the two classes: groups CG (with 23 students) and E (with 22 students) The participants did not know the business game and had no previous experience with the simulator.

According to Kirschner et al. (2011), collaborative learning may outperform individual learning in high-complex cognitive tasks. This is because collaborative learning allows a group of participants to process information with a lower cognitive load. At the same time, however, there are simulation-based learning studies showing that collaborative learning is not more effective than individual learning (e.g. Lin et al., 2018; Stouten et al., 2017). The results of Proserpio & Magni (2012) noted that the perceived learning of the individual is influenced more by human-computer interaction factors than by group dynamics. Consequently, as research findings on this issue are inconclusive, the present experiment was carried out individually in class with one participant per computer.

All participants were given a full experiment guide including: description and objective of the simulation task; case text; instructions for accessing and starting the simulator; instructions for interacting with the simulator; simulation guide; and instructions for interpreting causal loop diagrams and stock and flow diagrams (only for participants using a transparent simulator). The decisions made in the simulation and its results were automatically stored in a protected spreadsheet on the participant's computer. The initial conditions and model structure were the same for all participants.

In the simulation experiment, the students were asked to run the venture and maximize value creation. They were involved in a dynamic decision-making process. They analyzed business status using the simulator interface, utilized this information to review strategy and decision making, and then repeated the process. Participants from group CG ran the firm by using an opaque simulator interface (Figure 4); in group E the firm was operated using a more transparent interface (Figure 5).

To succeed in this simulation task, participants needed to identify and understand the cause-and-effect relationships among critical variables, particularly those included in the CLD and SFDs described above. As all resources had to be consistently developed, participants needed to recognize and address both delay and stock accumulation effects, especially those related to the process of feeding the prospect pipeline. Such model complexity has been demonstrated to negatively influence both formation of accurate mental models and task performance (Diehl and Sterman, 1995; Ozgun and Barlas, 2015).

Moreover, subjects who are not conversant with systems dynamics have additional difficulties in recognizing and comprehending dynamic structures as they are not able to properly read and interpret causal-loop-diagrams and stock and flow diagrams (Alessi, 2000; Davidsen & Spector, 2015). In order to obviate these problems, we complemented structural transparency with structural and behavioural debriefings. The students from group B participated in a debriefing session (after the first simulation run) focused on the model variables and relations. Then (before the third simulation run) they were involved in discussions about the relation between model structure, courses of actions, and behavior.

According to the cognitive load perspective (Sweller, 2020), the complexity of the model may exceed the working memory limits of participants. This effect takes on special relevance in simulation-based learning environments that are characterized by a high number of interacting elements requiring simultaneous processing in working memory. In situations of this type, students must mentally integrate dynamically changing multiple representations of information, while carrying out complex tasks, such as testing hypotheses or exploring alternative courses of action (Landriscina, 2013). Past research found that students operating in complex simulation environments generally have considerable difficulty in all phases of the inquiry process (de Jong 2006). To obviate these problems, previous studies (van Borkulo et al.,2012; Elsawah et al., 2017; Mulder et al., 2015) suggested that participants need to be guided through the simulation model, with task complexity being gradually increased (number of variables and relations in the task). This approach to managing model complexity (known as model progression) allows participants to incrementally build mental models. In order to minimize these potential problems and increase the instructional effectiveness, the instructor starts the structural debriefing session by describing the CLD and SFDs to the students in the form of step-by-step guided tours, gradually including the model variables and relations. Similarly, the behavioural debriefing begins with a phased explanation of the behaviour of critical variables and their relation to the model structure.

The experiment procedure involved two sessions and had the following steps (Figure 6).

Session 1. This session involved only the participants from experimental group (E). The literature (Groesser, 2012) pointed out that the extra information provided by the transparency of SD models can only benefit learners who are able to read and interpret stock and flow diagrams (SFDs). Thus, the students received a lecture on CLDs and SFDs, so that they were able to read and interpret the CLD and SFDs available in the simulator interface.

Session 2. In this session, the students performed the simulation task over three simulation runs. They first read the introduction with the overall description and the objectives of the simulation task, then the participants read the instructions for accessing, starting and running the simulator. Some simulation rounds were conducted to familiarize participants with the game interfaces and commands. In the control group, the three simulation runs were performed sequentially (for approximately 20 to 30 minutes each).

During the simulation task, the participants from the experimental group were encouraged to read and interpret the CLD and SFDs available in the game interface. The participants from group E, after performing the first simulation run, participated in a structural debriefing (lasting approximately 40 minutes). The instructor described the CLDs and SFDs in the game interface in the form of a step-by-step guided tour, gradually including variables and relations, and cleared up all the doubts raised by students concerning the model variables and their relations. The participants then performed the second simulation run followed by a behavioural debriefing. This debriefing (lasting approximately 60 minutes) focused on the relation between the model structure, courses of actions, and corresponding dynamical behaviours. The instructor first described the main challenge of this simulation task, which is how to successfully manage the growth of the venture in order to overcome the *death valley* of negative financial performance and start value creation. The reference modes for the critical variables and corresponding desirable and "fear" scenarios were explained. Then, a debate on how certain model structures (included in the model CLD and SFDs) can support sustainable growth was moderated by the instructor, namely: the role of human resources and its learning (causal loops R2, B2, R4, and R5, and HR co-flow structure); how to effectively feed the prospect pipeline by taking advantage of the partner network and the WOM effect (causal loops R1 and R3); the importance of matching effective employees' assignments to business activities so that prospects are rapidly and smoothly moved up until they become full adopters and finally start to produce revenues (stock and flow structure of the prospects pipeline); and the problem of draining the cash flow and causing the financial collapse of the venture (causal loops B3 and R6). Finally, the students from group E performed the third simulation run.

5. Results and Discussion

As described above, in order to investigate whether model transparency influences comprehension of the model dynamics (CMD) and the performance achieved (P), we conducted an experiment with two groups of participants - a control group (CG) and an experimental one (E) – in which, students from the experimental treatment were subjected, through three simulation runs, to increasing levels of model transparency. These ranged from being only shown diagrams of the model structures (LMV) to having additional structural (LSD) and behavioural (LBD) debriefings. The results are shown in the following tables.

Table 1 presents the mean values, standard deviations, and sample sizes for the variables CMD and Performance corresponding to the two treatments. The lowest mean values for the variables CMD and Performance were found in the first simulation run. That means that participants from group E, with access to information concerning the structure of the simulator model, did not show better model comprehension and performance. This result may be explained by their lack of experience with the simulator. In order to start the process of building and calibrating their mental models about the simulated system, the students needed to complete a first simulation run. These results are someway consistent with the findings reported by Qudrat-Ullah (2014) that subjects only submitted to pre-task facilitation perform poorly. In simulation run 2, participants in group E (model visibility with structural debriefing) on average showed higher

CMD (mean=0.312) and higher Performance (mean=0.254). As students from group E were engaged in a structural debriefing (after the first simulation run), they had the opportunity to clear up any misinterpretation of the diagrams provided by the transparent interface. For simulation run 3, the higher values for CMD (mean=0.458) and Performance (mean=0.455) were also exhibited by participants from group E. After the second simulation run, the participants from group E were involved in a behavioural debriefing where they discussed and resolved any doubts they had about the relation between model structure, patterns of actions, and corresponding expected behaviours. This helped them to improve their comprehension of the model dynamics even more and enhanced their performance in the simulation task.

Table 1. *Means and standard deviations for variables CMD (comprehension of model dynamics) and Performance for each simulation run and treatment group*

			CMD - Comprehension of the Model Dynamics		P - Performance	
Treatment	Description	N	Mean	SD	Mean	SD
	Simulation Run 1					
CG	Low LMV, low LSD, low LBD	23	0,214	0,120	0,093	0,105
E	High LMV, low LSD, low LBD	22	0,197	0,123	0,096	0,123
	Simulation Run 2					
CG	Low LMV, low LSD, low LBD	23	0,282	0,130	0,146	0,124
E	High LMV, high LSD, low LBD	22	0,312	0,134	0,254	0,153
	Simulation Run 3					
CG	Low LMT, low LSD, low LBD	23	0,275	0,154	0,184	0,135
E	High LMT, high LSD, high LBD	22	0,458	0,144	0,455	0,196

Variable definitions: LMV - Level of Model Visibility; LSD - Level of Structural Debriefing; LSD - Level of Behavioural Debriefing.

Table 2 presents the results of a paired-samples t-test of significance for differences in means between pairs of simulation runs within treatment groups. The differences in means for the pair SR3-SR1 (which compares the mean values of the third to the first simulation run) are significant (at $p<0.1$ for group CG and at $p<0.01$ for group E) for both treatment groups. This suggests that, on average, all the treatment groups enhance CMD and Performance as they progress in the task from the first to the last simulation run. However, group E participants showed, on average, the biggest improvements.

Table 2. *Paired-samples t-test of significance for differences in means for the variables CMD and Performance between pairs of simulation runs within treatment groups*

	CMD - Comprehension of the Model Dynamics			P - Performance		
Pair	Mean Difference	SD	p-value	Mean Difference	SD	p-value
SR 2 - SR 1						
CG	0,069**	0,032	0,044	0,053*	0,031	0,099
E	0,115***	0,030	0,001	0,158***	0,043	0,001
SR 3 - SR 1						
CG	0,062*	0,034	0,081	0,091**	0,034	0,013
E	0,261***	0,045	0,000	0,360***	0,058	0,000
SR 3 - SR 2						
CG	-0,007	0,023	0,776	0,038	0,024	0,124
E	0,146***	0,045	0,004	0,202***	0,059	0,003

***p<0.01, **p<0.05, *p<0.1

The results found for the pair SR2-SR1 (which compares the second to the first simulation run), suggest that, on average, participants from group E who are submitted to an additional structural debriefing improve their CMD and performance more than those using the opaque simulation. Consequently, the variable LSD seems to positively moderate the impact of LMV on CMD and Performance. Similarly, from the second to the third simulation run (pair SR3-SR2), the differences in means are only significant for group E (transparent simulator), which means that, on average, participants who receive an additional behavioural debriefing improve their model comprehension and performance more than those using opaque simulation. Consequently, the variable LBD also seems to positively moderate the impact of LMV and LSD on CMD and Performance. These findings seem to evidence a learning difficulty, frequently mentioned in the system dynamics literature (Davidsen & Spector, 2015), which is that it is difficult to develop an understanding of how the behaviour of a complex system emerges from its underlying causal structure. As the participants from group E were involved in an additional behavioural debriefing, they acquired a sharper comprehension of the dynamic behaviour of the simulation model.

Table 3 shows the results of multivariate regression analyses of CMD and Performance on the independent variables. In order to analyse the degree of improvement in participants' comprehension and performance throughout the task, we considered the independent variable Simulation Run (SR). The regression models were refined by performing a stepwise procedure in order to exclude the variables that did not seem to significantly explain the dependent variables, and to preserve the most significant explanatory variables. Regression analysis for CMD on the independent variables LMT and SR shows significant effects for LMT (β=0.279, p<0.001) and SR (β=0.347, p<0.001). Regression analysis of Performance also shows significant effects for LMT (β=0.420, p<0.001) and SR (β=0.384, p<0.001). Consequently, the variable LMT (level of model transparency) seems to positively influence CMD and Performance. Thus, regression results support hypothesis 1 (the level of transparency of the simulation model positively influences the level of comprehension of the model dynamics) and hypothesis 2 (the level of transparency of the simulation model positively influences performance). As we hypothesized, the results strongly confirm that students learn and perform more effectively if the simulation approach combines model visibility with structural and behavioural debriefings. These processes combined gave participants from group E a significant cognitive aid that accelerated their learning about the relationships between the structure and behaviour of the simulated system, and thus resulted in an improved performance.

Table 3. *Regression results for all independent variables*

	Dependent Variables			
	CMD - Comprehension of Model Dynamics		P - Performance	
Independent Variables	Stand. Beta	p-value	Stand. Beta	p-value
LMT - Level of Model Transparency	0,279***	0,000	0,420***	0,000
SR - Simulation Run	0,347***	0,000	0,384***	0,000
Adjusted R^2	0,246		0,395	
Regression on the components of Level of Model Transparency				
LMV - Level of Model Visibility	-	-	-	-
LSD - Level of Structural Debriefing	0,181*	0,062	0,283***	0,001
LBD - Level of Behavioural Debriefing	0,253**	0,016	0,310***	0,001
SR - Simulation Run	0,202**	0,024	0,200**	0,012
Adjusted R^2	0,266		0,431	

***p<0.01, **p<0.05, *p<0.1

Table 3 also presents the regression analysis for CMD and Performance on the three components of LMT. Regression analysis for CMD shows no significant effects for LMV, and significant effects for LSD (β=0.181, p=0.062), LBD (β=0.253, p=0.016), and SR (β=0.202, p=0.024). Regression analysis of Performance shows no significant effects for LMV and significant effects for LSD (β=0.283, p=0.001), LBD (β=0.310, p=0.001), and SR (β=0.200, p=0.012). These results suggest that by increasing only model visibility, students do not learn and perform more effectively. Even though students benefited from a more transparent interface (showing the causal-loop-diagram and some stock-and-flow diagrams of the simulator model), they were not more successful in comprehending the model dynamics and performing the simulation task. As pointed out by Groesser (2012), the extra information provided by the transparency of SD models can only benefit learners who are able to read and interpret SFDs. Thus, one possible explanation is that as the participants were not conversant with the system dynamics approach, despite having received a lecture on CLDs and DFDs, they were not completely enabled and motivated to read and interpret the model diagrams.

We can conclude that the structural debriefing was determinant with regard to improving students' learning and performance. Executing the task with a transparent interface after being subjected to a structural debriefing session significantly improved the students' comprehension and performance. This finding is consistent with some of the literature on learning from transparent models. For example, Grobler et al. (2000) also reported that a presentation on the structure of a business simulator improves the ability of participants to control that system, and had a positive influence on their task performance. As the participants enhanced their knowledge on the model variables and relations, they were able to make better use of the more structured information provided by the transparent interface and improve their ability to control and manage the task, which led to better performance.

The behavioural debriefing was also determinant in improving students' comprehension and performance. The results strongly evidenced that the behavioural debriefing gave participants a powerful means to reflect on counter-intuitive behaviours that emerge from some dynamical structures. This accelerated their learning about the dynamics of the simulated business venture and enhanced performance. This finding is consistent with the results reported by Capelo and Silva (2020) who contend that by visualising model diagrams, subjects are able to acknowledge certain cause-and-effect relations but fail to mentally infer the model behaviour. This conclusion is in line with a learning difficulty frequently mentioned in the system dynamics literature (Davidsen & Spector, 2015): that it is difficult to develop an understanding of how the behaviour of a complex system emerges from its underlying causal structure. These results reinforce an assumption already articulated in previous research (Kopainsky & Sawicka, 2011;

Qudrat-Ullah, 2014) - that it is important to facilitate in order to improve a subject's performance and their understanding of system dynamics.

Table 4 shows the results of regression analyses of the four components of CMD on the independent variables. Regression analysis for HRDG (Human resources drive growth) shows no significant effects for LMV and LSD, and significant effects for LBD (β=0.361, p=0.019), and SR (β=0.220, p=0.014).

Table 4. *Regression results on the components of CMD: HRDG - Human resources drive growth; BAPN - Building awareness and partner network; PP - Prospects pipeline; HRL - Human resources learning*

	CMD - Comprehension of Model Dynamics							
	HRDG		BAPN		PP		HRL	
Independent Variables	Stand. Beta	p-value	Stand. Beta	p-value	Stand. Beta	p-value	Stand. Beta	p-value
LMV	-	-	-	-	-	-	-	-
LSD	-	-	0,198*	0,052	0,287***	0,001	-	-
LBD	0,361***	0,000	0,288***	0,005	-	-	-	-
SR	0,220**	0,014	-	-	-	-	0,320***	0,000
Adjusted R^2	0,254		0,183		0,075		0,096	

***p<0.01, **p<0.05, *p<0.1

The variable HRDG measures how students comprehend the causal loops that describe the role human resources capacity plays regarding the trajectory of the venture's sustainable growth. The firm must start with enough staff to effectively develop a market and feed the prospect pipeline. However, as this work force is costly because the firm does not yet have much revenue, the students must avoid an overabundance of personnel that would drain the cash flow and cause the financial collapse of the venture. The positive influence of SR means that students throughout the simulation runs improve their learning on how to effectively adjust the personnel level. These findings also seem to indicate that students interacting with the transparent interface only develop a more effective comprehension of that causal structure after being submitted to the behavioural debriefing. This dynamical structure (R2, B2, B3, and R6 from the causal loop diagram of Figure 1) combines reinforcing and balancing feedback loops which may generate counter-intuitive behaviours and frequently lead to financial collapse. As the students participated in the behavioural debriefing, they were able to appreciate those feedback loops and improved their comprehension and ability to control the growth of the venture by properly adjusting the level of employees and avoiding financial collapse.

Regression analysis for BAPN (Building awareness and partner network) shows no significant effects for LMV and SR, and significant effects for LSD ($\beta=0.198$, $p=0.052$) and LBD ($\beta=0.288$, $p=0.005$). This variable measures how students understand the causal loops R1 (Building awareness and confidence) and R3 (Building partner network) and their role in feeding the prospect pipeline. The regression results suggest that students only improve their perception on these dynamical structures when they are submitted to the debriefing sessions included in the transparent condition. The structural debriefing enhances students' comprehension, which is improved even more after they have participated in the behavioural debriefing.

The causal structures associated with the variables HRDG and BAPN include feedback and delay complexity factors. Ozgun and Barlas (2015) also found that feedbacks significantly worsened performance when they acted together with delays. Similarly, our experiment reveals that students initially have significant difficulties in dealing with those complexity factors. However, our results seem to indicate that both structural and behavioural debriefings contribute towards overcoming those difficulties.

Regression analysis for PP (Prospects pipeline) shows only significant effects for LSD ($\beta=0.287$, $p=0.001$). This variable refers to how students comprehend the stocks and flows structure, representing the adoption cycle as working through a series of stages in an adoption pipeline, and assigns own employees' efforts to each activity so that prospects are rapidly and smoothly moved up until they become full adopters and finally start to produce revenues. Similar to Cronin and Gonzalez' (2007) findings, it seems that the visual representation of that stock-and-flow structure could make understanding the relationship between flows and stocks of prospects more difficult. Our results reveal that students only improve their learning on this dynamical structure if they interact with the transparent interface where the control panel shows the levels and flows related to the prospect stages in a stock and flow diagram (Figure 5), and have previously discussed the meaning of the variables and relations included in the prospect pipeline in the structural debriefing. Thus, we can conclude that the structural debriefing was specifically determinant with regard to improve students' learning of the stocks and flows structure in the prospects pipeline.

Regression analysis for HRL (Human resources learning) shows only significant effects for SR ($\beta=0.320$, $p<0.001$). This variable measures how students understand the process that accumulates employee's experience as well as the associated causal loops R4 (Learning and HR productivity) and R5 (Operations learning and performance) which reproduce the learning curve for productivity from job experience. This result suggests that, regardless of the level of transparency, students gradually appreciate the learning factor and enhance their ability in developing and retaining experienced employees throughout the simulation task. We can conclude that the transparent conditions do not influence student's comprehension of this concept.

The results of this present study reinforce some of the assumptions associated with the learning theories and approaches presented in the theoretical framework. As students progressed throughout the simulation task, they enhanced their comprehension and performance through an experiential learning cycle (Kolb, 1984). At the same time, students improved their mental models of the business system as they were engaged in a double-loop learning process (Argyris, 2002; Sterman, 2000). Our experiment also evidences the combination of the two forms of logic advocated by Sarasvathy (2001). The participants applied causation logic as they initially (based on their previous knowledge and case description) defined their strategy for launching the business venture. As the simulation experiment evolves, the students progressively learn, adjust their strategy, and more effectively control the business system, in line with effectuation logic. Additionally, this simulation task also reflects the pedagogical approach proposed by Yamakawa et al. (2016) as, through this simulation task, the students have the opportunity to integrate theory and practice concerning the growth of business ventures.

6. Conclusion

The present study tests hypotheses about the impact of simulation transparency on students' learning about the dynamics of venture growth. It was hypothesised that learning and task performance would benefit from making the simulator more transparent by (1) showing students the causal-loop and stock and flow diagrams of the simulator model and providing debriefing sessions focused on the (2) structural (discussions about the variables and relations included in the model) and (3) behavioural (discussions about the relation between the model structure, patterns of actions, and corresponding expected behaviours) aspects of the simulation model. The regression analysis supported hypotheses H1 (the level of transparency of the simulation model positively influences the level of comprehension of the model dynamics) and H2 (the level of transparency of the simulation model positively influences performance).

The regression analysis for the components of the comprehension of the model dynamics on the components of the model transparency reveals the following findings and conclusions: (1) This business simulator does not become more transparent to subjects just by showing the model diagrams. (2) The structural debriefing was determinant with regard to improving students' learning, particularly on the stocks and flows structure in the prospects pipeline. (3) The behavioural debriefing was also determinant in improving students' comprehension and performance. For instance, only after participating in the behavioural debriefing, were the students able to appreciate the feedback loops revealing how to adjust the work force in order to obtain sustainable growth of the venture and avoid financial collapse.

6.1 Contribution

This study offers useful contributions to the management education field by reinforcing the importance of combining business simulators with specific instructional techniques as a basic strategy to improve learning in complex business situations. In particular, the results of this experiment reveal how best to use a simulator to improve learning of concepts related to the growth of a business venture. Our findings strongly confirm that a business simulator for learning purposes can be significantly enhanced with the introduction of model visibility and debriefing sessions. Specifically, the learning that occurs between simulation runs might be accelerated by applying structural and behavioural debriefings with an instructor. Under these conditions, an SBLE offers students opportunities to better learn about complex business problems. This is because the students, through an active learning process, develop a systemic and dynamic understanding of the business problem by progressively building and mentally inferring a causal model (mental model) that represents the critical cause-and-effect relations.

6.2 Limitations and future research.

Although the results suggest that simulation-based learning in the business and management field can be improved by introducing model visibility and structural and behavioural debriefings, there are a number of potential limitations to this experiment.

A significant obstacle of transparent simulations is that the high visibility of a model can only favour students who are able to read and interpret the graphic representations of that model (by using CLDs and SFDs in the case of SD models). As such, instructors must verify that students understand the code used to express the model.

The present experiment applies debriefing sessions as an instructional strategy (designated as structural and behavioural debriefing) intended to foster learning. However, that procedure involves a substantial amount of time. As the time available for the simulation task is limited, further research should investigate alternative support procedures to make such a learning approach more feasible for the classroom.

Furthermore, there are also potentially several methodological limitations to the current investigation. The research method was based on a quasi-experimental design, as there was no random allocation of students to the experimental and control groups. Each group (including the control group) consisted of students from one class; had it been otherwise, the participants would have had different educational activities in the same classroom, which would have been difficult to control and could have jeopardised the experiment. Standardised student-teacher relationships, class size and classroom features were also difficult to control. As this experiment was considered part of the course assessment process, the authors assumed that students would be motivated to perform the task.

The experiment was designed assuming that the students had no previous knowledge about model structure and behaviour. However, as a pre-test was not applied, the researchers could not be certain whether the students possessed prior related knowledge that could explain their level of comprehension of the simulator model.

Finally, the findings reported in this article are based solely on graduate students.

Despite these limitations, this study should be of interest to the many educators who teach business and management subjects through SBLEs.

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