Group model building as a pedagogical strategy to simulate Covid-19 Epidemic

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***Abstract*— The work in this paper aimed to follow the ideas of group model building in order help undergraduate students to model and learn about Covid-19 epidemic as it was developing in Mexico. Two key bodies of knowledge were used in this endeavor: Group model building and system dynamics. Group model building is a technique that helps people to interact and learn about complex situations. System dynamics is a computer-aided approach that helps researchers and practitioners to learn about complex systems in order to inform courses of action.**

Learning through group model building process required students and teachers to review stages such as: Establishment of a reference group; construction of initial models, model improvement through scenario discussions; reporting outcomes and discussion of strategic courses of action.

The reference group included three type of stakeholders: Owners of transnational companies based in Toluca City (Mexico), authorities of Toluca Municipality and undergraduate students of a higher education institution. All meetings with the reference group were online due to epidemic restrictions. The SIR model was the basis of the initial dynamic model. Improvements of the initial model were possible through the discussions between students, teacher and the reference group and concluded with a model that reflected the difference intensities of Covid-19 infection and outcomes not contemplated in the original model. Analysis of the modified model included the identification of possible leverage points of the system. Students and teacher used the modified system dynamic models in order to create different scenarios changing key variables and leverage points, as a result meaningful discussions and learning about the developing epidemic in Toluca City emerged. Students reflected not only upon the usefulness of system dynamic models to simulate locally Covid-19 epidemic but also were able to reflect upon the group model building process.

Finally, students and teachers were able to communicate their findings and recommended courses of action to the reference group. Findings included forecasts of mild and severely infected population of Toluca City as well as possible number of hospital admissions. In this way the reference group had informed models about pessimistic, most likely and optimistic scenarios and the different courses of action they required. The reference group reported they used this information in order to acquire adequate quantities of medical equipment to avoid infections among doctors, nurses and hospital personnel.
Keywords— Group model building, system dynamics, SIR model.

Keywords *System dynamics, group model building, SIR model, Covid-19, engineering teaching*

I. Introduction

System dynamics could be defined as a computer-aided approach based on simulation of feedback loops in order to model and analyze systems which evolve over time. Its main goal is to learn about complex situations and to help decision makers in strategy and policy formulation [1]. It is considered part of the more general systems thinking approach [2]. A core tenet that system dynamic courses try to instill among students is that the internal structure of a system, rather than external factors, is responsible of its behavior [3]. Therefore, a great deal of time that teachers and students spend on higher education courses is directed to uncover such structures. It could be argued that every structure represents a particular "mental model", which are tentative explanations of how different stakeholders think a complex situation is generated and its consequences [4]. In order to elicit the different understanding about complex situations, researchers and practitioners often use participatory-oriented approaches such as group model building.

During the development of Covid-19 epidemic one of the authors of this paper taught on-line four system dynamics courses for higher education students. The setting was Toluca, a city in central Mexico with almost two million people and with an economy based on manufactured products for the automotive and pharmaceutical industries.

This paper describes how students, teachers and a reference group engaged in a group model building process. Thorough this process they created and simulated dynamic models of Covid-19 epidemic as it was developing in Toluca City (2019-2021); such models allowed student to learn about system dynamics and create different scenarios in order to inform local authorities about the development of such epidemic. Models also helped to address and answer research questions such as: Which elements of the group model building are more relevant to teach system dynamic? Does the complex situation Covid-19 epidemic could motivate engineering students in order to build significant dynamic models and foster learning? Finally, the resulting models, scenarios and proposed courses of action were presented to municipal authorities in order to help inform local strategies. Section II of this paper introduces the basic ideas of the system dynamics approach and group model building process while Section III describes how students and stakeholders developed system dynamic models about Covid-19 in Toluca City. Finally, Section IV reports learning outcomes and lessons to be applied in further courses.

II. GROUP MODEL BUILDING AND SYSTEM DYNAMICS

A. The system dynamics approach

The first body of knowledge used in the courses described in this paper was system dynamics. System dynamics is a computer-aided approach that helps researchers and practitioners to learn about complex systems in order to inform courses of action. It relies heavily on concepts such as reinforcing and balancing feedback loops; stock and flow diagrams, delays and the analysis of resulting dynamic behavior [5].

System dynamic models resemble the ones shown in Figure 1. They represent entities (tangible or intangible) that move over time through a network of stock and flow variables which are further connected through feedback loops. Feedback could be reinforcing (leading variables to an ever-growing or ever-decreasing behavior) or balancing (leading variables to converge to a constant value). The combination of reinforcing and balancing feedback loops usually lead to complex and counterintuitive system behavior [3]. In order to be computer simulated, all stocks, flows, and auxiliary variables require to be expressed as equations and constants.

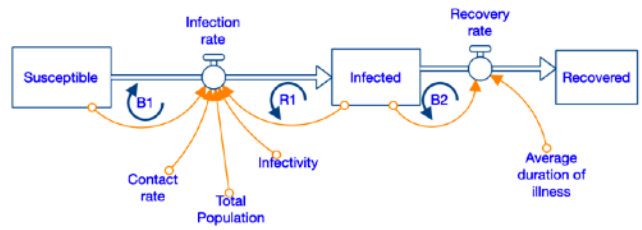

Figure 1: A system dynamics representation of the SIR Model

For example Figure 1 shows the SIR model which was proposed by Kermak and McKendrick [6] and more recently used by Ford [7]. It describes people flowing through stocks: Susceptible, infected and recovered populations. Susceptible population becomes infected through the infection rate flow; in turn, infected population recovers through the recovery rate flow. Infection rate flow opens or closes depending on variables such as contact rate, total population and infectivity and from feedback loops R1 and B1.

The result of dynamic models are graphs and tables that show the dynamic behavior of the stocks over time as shown in Figure 2. Such behavior often shows counterintuitive and unexpected results including situations in which solutions create further problems, perpetuate addiction to external solutions, aggressive escalation and sudden overshoot and collapse [3]. As a result, system dynamic models are useful to explain the development of complex situations and help researchers and practitioners to create informed policies and courses of action. In this paper, teachers used the SIR model as a basis to understand the development of Covid-19 in Toluca City in an academic setting.

The system dynamic courses described in this paper followed the next stages: Problem identification, system conceptualization, model formulation, parameter estimation, analysis of resulting behavior and sensitivity testing, establishing model validity, and policy analysis [5].

B. Group model building as a learning strategy for engineering.

The second body of knowledge used in the higher education courses described in this paper was the group model

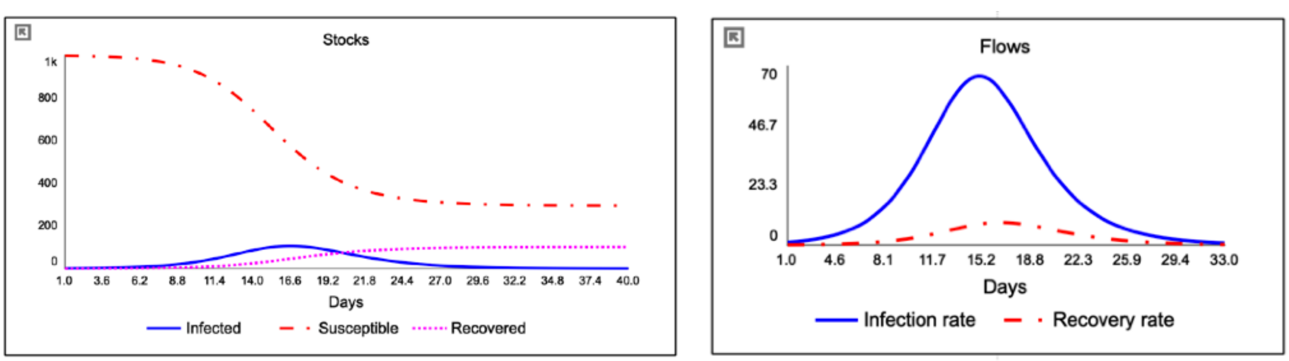

Figure 2: Example of dynamic behavior over time

building process. According to Meadows [3], a pervasive characteristic of complex situations is that their stakeholders often maintain different views about them, including their causes, structure and consequences. These views are better expressed as "mental models" which represent individuals' beliefs about how a system works or a complex situation is generated and evolves. Authors such as Cabrera and Cabrera [8] and Sterman [4] argue that, since mental models represent subjective beliefs, they are partial and often incomplete representations of complex situations.

In order to have a more comprehensive understanding of these situations, researchers and practitioners often require to elicit the different mental models that stakeholders maintain. As a result, several participatory approaches to model building have emerged, for example. Group model building [9, 10], the World Café [11], Open space technology [12] and Future search [13].

Group model building is defined as a process aimed to express, debate and structure mental models stakeholders have in order to create shared meaning and inform strategy while dealing with a complex situation [9]. It requires researchers and partitioners review stages such as: Establishment of a reference group; construction of initial models, model improvement through scenario discussions; reporting outcomes and discussion of strategic courses of action. The next section describes how teachers and students engaged in a group model building process to create system dynamics models of Covid-19 to provide advice to Toluca City municipality and other stakeholders during the epidemic (2019-2021) in Mexico.

III. Following the Group Model Building Process in a Higher Education Course during Covid-19 Epidemic

A. *Establishment of a reference group*

According to Midgley [14] it is possible to identify guidelines that could help researchers and practitioners to "sweep in" meaningful, rightful and necessary stakeholders into a reference group. However, fewer advice is provided about who should trigger the formation of such group. In the present paper, the reference group was formed as follows: During the Covid-19 epidemic in Toluca City (Mexico) a "control room" was created in order to take decisions about medical equipment needed in hospitals in order to avoid infections among doctors, nurses and hospital personnel. Such "control room" was a group which consisted of three types of key stakeholders representing different views and capabilities regarding the development of Covid-19 in the city:

- A group of eight owners of transnational companies based in Toluca City and their advisers. They had the capacity of importing great quantities of medical equipment through their respective departments of international suppliers and acquisitions.

- Six members of Toluca City municipality including, occasionally, the Mayor of the City. They had access to public resources, facilities and local information on real time. Their interest was to minimize the economic impact of Covid-19 in Toluca City. Toluca is a city inside a valley in central Mexico, sixty-four kilometers east from Mexico City. It has a population of almost two million people and its main industries are automotive, pharmaceutical and processed food.

- Finally, six academics and administrative personnel of a higher education institution based in Toluca City who had quick access to expert advice on matters such as biotechnology, logistics, public policies, mathematical and forecasting models. One of the authors of this paper was included in this group and was teaching at the time system dynamics courses to undergraduates students of industrial engineering. As a result, students of such courses had access to non-confidencial information generated by the control room.

B. *Construction of the initial the model*

Students and the teacher of the course used the SIR model as shown in Figure 1 as the initial model in order to begin the learning approach to modeling dynamic systems. Because of its simple structure, students considered the outcomes of the initial model simulation to be unrealistic in terms of new cases per day and the extremely rapid spread of the desease in Toluca City. As a result they began to ask questions to the reference group in a regular basis in order to create a more realistic model. In turn, members of the reference group understood the students' views about the epidemic and contributed with their own views in the modeling process.

C. *Model improvement*

Interactions between the reference group and students enhanced the initial SIR model in order to cover concerns such as:

- Feasibility of voluntary isolation of economically active population and its impact in the local economy as well as forced isolation of groups considered vulnerable such as primary, secondary students and elderly population.

- Minimum number of Covid-19 tests to be applied per day; the average delay time of their results; the percentage of reliability of such tests and their impact in new cases per day in Toluca City.

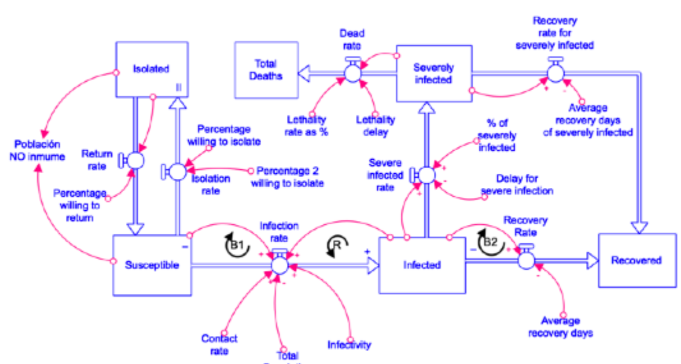

Figure 3: An improved SIR system dynamics

- Scenario creation through different percentages of infected population that developed severe symptoms and required hospital admission; and the resulting saturation of health facilities of Toluca City.
- Degree of success of effective quarantine of new detected cases with different average recovery days and its impact on new emerging cases.
- Effect of eventual vaccination of susceptible population taking into account the effectiveness of vaccines and the critical number of vaccinated individuals in order to achieve what epidemiologists know as herd immunity.
- Sensitivity analysis based on different infectivity rates of Covid-19 virus (probability of a susceptible person getting the desease after a contact with infected population) which were unknown at the time of the study.
- Mortality rate and total number of deceased population and its comparison with civil service death registers per day and per month.

Figure 3 shows one of the improved SIR models that students created through the interaction with the reference group and information they provided.

D. Reporting outcomes and discussing strategies

Because the system dynamic courses took place during Covid-19 epidemic students and teacher reported some relevant outcomes and suggested possible courses of action. For example:

- Sensitivity analysis based on the infectivity rate showed that the intensity of Covid-19 epidemic in Toluca City was going to be far severe (number of mild and severely infected) than originally believed and informed by municipal authorities.
- Regardless the different delays modeled, all scenarios showed that the duration of Covid-19 epidemic in Toluca City was going to last at least two years with at least three or four waves of high number of infected.
- Although Covid-19 tests were beginning to be implemented massively, daily infections were higher than the current official reports. This led students to conclude that a more aggressive campaign of isolation was desirable and the use of face masks as much as possible in order to reduce the contact rate.
- Probably the most important outcome students generated were weekly quantitative approximations of new infected people and new hospital admissions. As a result, members of the "control room", specifically owners of transnational companies based in Toluca City, took more informed decisions about the necessary medical equipment to import and supply to hospitals and medical facilities with the support of local municipal authorities.

IV. LEARNING OUTCOMES

Learning outcomes about group model building as a pedagogical strategy to learn system dynamics could be summarized as follows:

First, students realized that creation and participation of a reference group is crucial in order to gather relevant information about a current complex situation because relevant information is necessarily scattered among different stakeholders. On the one hand, municipal authorities were in possession of daily data about the development of the epidemic in Toluca City: Number of positive diagnostic results, number of deceased people per day. On the other hand, information about incoming Covid-19 tests, vaccines and sanitary equipment was possible through owners of transnational companies based in Toluca City. Finally, access to mathematical models and simulation techniques was possible through involvement of higher education experts.

Second, following the ideas of McCradle-Keurentjes [10] students confirmed that model building is an ongoing process that demands time (in this case months) as opposed to one or two group sessions. Through exposure and discussion of several versions of the SIR model students realized that members of the reference group took time to modify their initial believes of a epidemic and to incorporate others' perspectives and information. For example, members of the reference group initially believed that epidemics behaved as one big wave rather than several. Some believed that epidemics last months rather than years. Others were unaware of its possible catastrophic economic effects and required time to modify initial beliefs and hopes emerged as a critical factor for group model building.

Third, students witnessed how reference group's sense of ownership of the models facilitated decision making and allocation of resources. Students in Mexico often believe that rigorous questioning of their assumptions and results indicates disregard and neglect of their academic work. However, in this academic courses students appreciated that ample exposure and questioning of models and assumptions helped to build trust on results. Therefore, continuous involvement of the reference group was crucial to build a sense of ownership of models and results and to facilitate decision making. As a result, the creation, participation and continuous interaction between students and the reference group emerged as a critical factor in group model building.

Finally, teaching system dynamics by creating models of an ongoing phenomenon as it develops, as opposed to reliable models and guided cases of study, provided motivation, encouragement and boosted interest among engineering students as reflected in the institutional student opinion survey (ECOA). Modeling complex situations, with their uncertainty, as they develop may challenge teachers and students because information may be incomplete, reliable models unavailable and, overall, results may be difficult to explain, counterintuitive and differ from reality. However, modeling complex situations as they develop may provide students with a sense of learning through significant models and social contribution.

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