International Journal of Instruction *July 2021 ● Vol.14, No.3*
e-ISSN: 1308-1470 ● www.e-iji.net *p-ISSN: 1694-609X*
pp. 1-16

Article submission code: 20200708204839
Received: 08/07/2020
Revision: 18/11/2020
Accepted: 11/12/2020
OnlineFirst: 05/04/2021

Fostering System Thinking Learning by Combining Problem-Based Learning and Simulation-Based Learning Approaches

João Alberto Arantes do Amaral
Prof., Federal University of Sao Paulo, Brazil, *jarantes@alum.mit.edu*

Felipe Fregni
Prof., Harvard University, USA, *felipe.fregni@medicaltli.org*

This article presents findings regarding a Systems Thinking graduate course that took place in 2019, involving 11 graduate students from the University of São Paulo. The course followed a combination of problem-based learning and simulation-based learning approaches. The students were challenged to model the dynamics portrayed in short-films, documentaries, and case studies. Comics were used to illustrate key points. Our research goal was to analyze the educational components of this program qualitatively. We collected qualitative data using questionnaires and in-deep interviews and analyzed following a systemic analysis. Our findings are: (a) Creating models of situations portraited in videos and case studies helped the learning of qualitative modeling tools by motivating the students and promoting knowledge sharing. b) Computer simulation improved the learning of quantitative modeling tools, fostered critical thinking skills, and increased the understanding of the system's structures and patterns of behavior. c) Comics helped the students to comprehend complex issues.

Keywords: systems thinking, problem-based learning, simulation-based learning, modeling, teach and learning

INTRODUCTION

The twelve weeks' Systems Thinking' course was offered during the first semester of 2019 to graduate students at the University of São Paulo. The objective of the course was to present the theory of systems thinking and to foster students' ability to model systems and systemic problems using qualitative modeling tools (causal loop diagrams) and quantitative modeling tools (stock and flow computer models). The course was held in an enhanced technology environment, a smart classroom. Every student had access to a desktop computer in which the simulation software VensimPle© had been installed. All computers have internet access, and the professor made use of an interactive whiteboard to present the lectures.

Citation: Arantes do Amaral, J. A., & Fregni, F. (2021). Fostering system thinking learning by combining problem-based learning and simulation-based learning approaches. *International Journal of Instruction*, 14(3), 1-16. https://doi.org/10.29333/iji.2021.1431a

The course was designed following a combination of problem-based learning and simulation-based learning approaches. In each class the students were challenged to solve different types of problems. First they worked individually, then in groups of three students and then sharing their findings. They followed a three-phased problem-based learning approach (Fregni & Gimenez, 2020) that combined simulation-based learning activities (Table 1).

Table 1
The three-phase problem-based learning approach (based on Fregni & Gimenez, 2020)

	Phase 1- Problem Analysis	Phase 2- Self-direct learning	Phase 3- Reporting
Classroom activities	Analyze the problem presented. The problem was presented in different ways (videos or case-studies)	Individual-modeling Activities Creation of a causal-loop diagram-CLD (or computer model) that represents the systemic structure of the problem presented. Understand the system's structure and its patterns of behavior (by means of analysis of CLD or by running the computer model). Group-modeling activities Do the same activities, this time in group of three students, aggregating the models created into a single model.	Presentation of the models created. Discussion of the insights gained with the problem

The problems varied from lecture to lecture (APPENDIX 1). During the first half of the course, the students were challenged to create causal loop diagrams to represent the dynamics portrayed in assigned short videos, case studies, and documentaries. In the second half of the course, the students were asked to create and run computer models and perform computer simulations. Students were assigned readings and documentaries to watch. They were also asked to do an MIT Opencourseware case-study and read comic strips (APPENDIX 2).

Theoretical Review

Researchers point out that learning is a constructive process (Glaser, 1991) of building new knowledge upon prior knowledge (Fregni, 2019; Gijselaers, 1996; National Research Council, 2000). In addition to that, studies (Craik, 1952; Gini-Newman & Case, 2018) revealed that learning is a continuous process of enhancement of the preconceived ideas and concepts that one holds about how the world works (Gijselaers, 1996; National Research Council, 2000).

However, the world works in a complex way: it has a myriad of intertwined systems (Bossel, 2007). Therefore, understanding the world is not an easy job: people use psychological models to create meaning from it by simplifying its complexities (Sterman, 2010). Researchers named these models as 'mental models' (Cook & Wind, 2006; Senge, 2014). Scholars point out that mental models evolve during one's lifetime (Norman, 1983), as people interact with each other (Denzau & North, 2000) or when they are subject to a formal educational system (Senge et al., 2012). Individuals also change mental models through informal and accidental learning processes (Watkins & Marsick, 1992).

Nevertheless, mental models may fail to represent the real world (Meadows, 2008) adequately. Individuals may try to understand the world based on limited, confusing, or ambiguous information (Meadows et al., 1982; Sterman, 2010). To make matters worse, individuals may also filter and distort the information they receive from the world (Sterman & Sweeney, 2007). Mental models may also fail to explain the dynamic complexity of systems (Sterman, 1994). Moreover, individuals may not be fully aware of the existence of mental models. Therefore, teaching systems thinking involves making students conscious of their own mental models and supporting them to see how these models can and should, in some instances, change.

How to enhance mental models? Researchers have used simulation-based learning (thereafter SBL) to make individuals understand the flaws and limitations of their mental models (Forrester, 1997; Sterman, 1994). Simulation-based learning allows sharing mental models through group model-building activities (Richardson & Andersen, 1995; Vennix, 1999). Computer simulation allows us to understand complex problems and to figure out the structures of the system that drive the patterns of behavior (Meadows, 2008; Sterman, 2006). More than that, it allows us to run simulations under different time horizons, allowing compress time and space, therefore speeding up the learning process (Guzdial et al., 1996; Sterman, 2010).

A problem-based learning approach can also help students grasp the complexities of the world more quickly (Nursa'ban et al., 2019). Problem-based learning (PBL) provides hands-on experience (Suwarno et al., 2020), promotes inquiry opportunities (Ramdiah et al., 2018), and fosters critical thinking skills (Boleng et al., 2020; Larmer et al., 2015; Lukitasari et al., 2019). Some scholars have used video cases as stimuli in PBL-centered courses (Bosse et al., 2010). Others have used storytelling (Hung et al., 2012) and text-based cases (Lestari et al., 2020; Wilson, 1996). Researchers have also used humor to reduce stress and facilitate learning (Chauvet & Hofmeyer, 2007).

Researchers (Murphy et al., 2011) have studied the theoretical aspects of merging problem-based learning and simulation in order to create an innovative pedagogy in nursing courses. Other scholars (Walshe et al., 2013; Roh et al., 2014) reported the benefits of combining both educational approaches, also in the nursing context, by using videos and data about patients to trigger the simulations. In addition to that, researchers (Soderberg & Price, 2003) pointed out the benefits of combining problem-based learning and computer simulation to engage the students and to foster class discussion in biology courses. Other scholars (Mann et al., 2011) have used problem-based learning and web-enabled computer simulation in educational leadership programs. More than that, scholars (Spinello & Fischbach, 2004) also have combined problem-based learning and online simulation in public health courses.

However, it seems that there is still a gap in knowledge about combining problem-based learning and simulation-based learning to enhance learning in Systems Thinking courses.

We aim to address this gap by qualitatively analyzing our program's results to discuss the initial results and feasibility of such a program.

Research question

How to foster the learning of system thinking concepts by combining problem-based learning and simulation-based learning approaches?

METHOD

Research design

This research followed a qualitative approach, collecting data using structured interviews (Yin,2015). The structured interview is a valid way of collecting data in qualitative studies, combining questionnaires and in-deep interviews (Adamson et al.,2004; Langley,2004). The questionnaire was sent to the participants one week before the final class, and the individual interview was done at the final class. The interviews helped to clarify issues that were not clear enough in the answers to the questionnaire.

Participants

The study sample was all students enrolled for the Systems Thinking course: eleven graduate students from the departments of Electrical Engineering (1 student), Geography (1 student), Biological Sciences (2 students), Education (3 students), Veterinary Medicine (1 student), Psychology (1 student), and Languages (2 students) from University of São Paulo. They were aged between 32 and 52. Only one student had previous experience in computational simulation.

Research instrument

The qualitative data were collected by means of a questionnaire sent to the students by email and by interviews. The questionnaire had six open-ended questions (APPENDIX 3). We designed the open-ended questions to understand the students' perspectives about their learning based on classroom activities (individual and group modeling) they perform. More than that, we also wanted to know about the adequacy of the problems we delivered by different means (video and case-study based modeling activities). We used a structured interview to clarify the issues that were not clear enough for the students' answers to the questionnaires.

The research procedure

As we described previously, the questionnaire was delivered by email in the 11th week of the course. The students returned us their answers one day before the final class. The in-deep interviews were developed in the final class (12th week). We interviewed each student for approximately 20 minutes (in order to have a better understanding of the issues raised by their answers to the questionnaire) and took notes.

Data analysis

The data was organized into recurrent themes following a language process method (Graham et al., 2001). First, we compiled the data from questionnaires and the notes taken. Then we grouped similar data. After that, we made a recombination of the groups into wider categories, the so-called recurrent themes (Bradley et al., 2007). We interpreted the data by means of a system dynamics' modeling tool, a causal loop diagram. Causal loop diagram is a system dynamics' modelling tool that has been used in qualitative analysis (Arantes do Amaral, 2019; Burck, 2005; Yearworth & White, 2013), since it helps to understand the course's systemic structures (the interactions between the positive and negative feedback loops) that were responsible for the patterns of behavior of the students (Arantes do Amaral & Frazão, 2016). In other words, by connecting the variables of the recurrent themes, we were able to reveal the systemic structure that drove the course's dynamics, explaining the consequences of each educational action taken.

Validity and reliability

The validity of qualitative studies can be understood as to how precisely the study reveals the points of view of the subjects of the study (Creswell & Miller, 2000). Since the data was collected from all the population's elements and analyzed considering the recurrent themes (Yin, 2015), we may affirm that the study is valid.

The rigor's reliability was assured: we followed a well-established research approach (Noble & Smith, 2015), with well-defined phases and procedures (Golafshani, 2003), allowing other researchers to follow a similar approach.

FINDINGS

We analyzed the data, finding the following recurrent themes (thereafter RT):

RT1: *Creating causal loop diagrams to represent real-life situations presented in short-videos allowed the development of systems thinking skills.*

One student stated:

"Watching the short-videos was excellent and useful to my learning. At the beginning of the course, it was not easy to create the causal loop diagrams; it was a challenge. The short-movies allowed to connect the theory with real-life problems."

Another student observed:

"The modeling process became gradually easier for each model we developed. I think the videos were excellent! We learn a lot about models and systems and real-life problems as well. Learning became more significant."

RT2*: The group-modeling activities promoted knowledge sharing among the team members.*

One student made the following comment:

"I think the group-modeling experience was very positive: in many cases, classmates had figured out causal relationships and dynamics that I had not noticed. The exchanging of ideas was very helpful."

Another student made the following observation:

"Evidence-based research shows that learning is a social activity; I learned more when I shared my knowledge with my peers. During the teamwork activities, I had to explain my reasoning, listen to my peers, analyze different points of view. The models we created in the group were better models than the models we created individually. Group-modeling activities enhanced the process of creation of the models."

RT3: *Creating models of dynamics described in documentaries promoted in-depth analysis of systemic problems, giving the students a better understanding of complex systems.*

One student observed:

"The documentaries portrayed complex and intertwined problems. Therefore, identifying the dynamics turned out to be a relevant exercise for learning the main concepts presented in our course."

Another student pointed out that the documentaries complemented the modeling exercises done previously:

"It was very interesting to work with documentaries; they use an accessible language and address many aspects of a systemic problem (the documentary Cowspiracy is an example of that). As we have already created models of the dynamics presented in short films, it became easier to identify the dynamics the documentaries portraited because we were more attentive and trained for that."

RT4: *The individual assignments based on written case studies and MIT homework, although challenging, fostered learning.*

Some students reported that the MIT case-study was difficult, but they were able to do it. One student explained:

"The MIT homework was challenging: we followed a very detailed modeling process for the first time. This was intellectually stimulating."

Another student pointed out the importance of the support of peers:

"Doing the MIT homework initially by myself was difficult; the support of my colleagues helped me to have an understanding of the model I was required to create.

The learning process was very meaningful!"

One student also let us know that written assignments facilitated the process of creation of models:

"Creating models based on texts was easier than creating models based on videos. The text facilitated to understand the dynamics that I was asked to model. It was very interesting!"

RT5: *The use of computer models and simulation facilitated learning.*

One student stressed the importance of using computer models:

“The computer models facilitate understanding that the system's structures are responsible for the system's behavior. The use of the software VensimPle© was very useful to me. It allowed me to test hypotheses and run different scenarios. The graphs generated by means simulations facilitated the learning.”

Another student commented:

“The computer models allowed us to learn more about real-life systems; we were able to run different simulations and understand future scenarios.”

RT6: *The comic strips brought humor to the classroom, facilitating learning complex issues, and helping to fix the concepts in their minds.*

The students enjoyed the use of comic strips. One student commented on the role of humor in classroom environment:

“The use of comics makes the class enjoyable, light, and very fun.”

Another student pointed out that it helped to understand the concepts in an easy way: "Comics facilitate the learning. In a concise way, the comics explain several concepts that otherwise would take several minutes of reading.”

Another student pointed out that comics helped to fix concept in his mind:

“Learning by comics is very interesting. It facilitates the understanding of the concepts, it helped me to fix concepts (as I remember the stories and examples told by the character).”

DISCUSSION

We used short-videos with real-life problems to enhance motivation and long-lasting learning. RT1 showed that the use of short videos allowed the students to learn from real-life problems. The more the students watch different short videos of different systemic problems, the more easily they develop causal loop diagrams representing the problems (individually and in group), thus the more they develop their modeling skills (Figure 1, feedback loop “Learning from making models based on short videos”). This finding is aligned with other researchers' findings that have described the benefits of using short videos to teach systems thinking concepts (Sweeney & Meadows, 2010) and foster students' participation in classroom activities (Sexton, 2006; Courts &Tucker, 2012). In addition, real-life examples help to retrieve this information in the future when applying this knowledge.

Collaborative learning was another important component of our program. RT2 helped to understand the importance of group-modeling activities: the more the students work with their peers, the more they share knowledge, therefore improving their systems thinking skills (Figure 1, feedback loop “Learning from peers”). Other researchers have also stressed that group modeling activities promote knowledge sharing (Peck, 1998) and critical thinking (Vennix, 1999; Hovmand, 2014). Also, collaborative learning enhances peer support and responsibility for learning (Williamson et al., 2020)

Documentaries were used as another learning material. RT3 facilitated to understand that watching documentaries helped develop modeling skills and contributed to students' comprehension of the structure of real-world problems (Figure 1, feedback loop "Learning from analyzing complex real-world problems"). This finding is in consonance with the discoveries of other scholars (Leet & Houser, 2003), pointing out that documentaries can help to exemplify complex problems.

This led to a valuable insight: *Creating models (first individually, then in groups of three students) of situations portrayed in short-video and documentaries sped up the learning of qualitative modeling tools (causal loop diagrams) to represent systems and systemic problem. Creating models also motivated the students and promoted intense knowledge sharing.*

We requested students to be exposed to an assignment from MIT. RT4 let to figure out that the MIT assignment was very effective. The assignments also led to individual and group-modeling activities that helped the students to develop modeling skills. (Figure 1, feedback loop “Learning from the assignments”). Other researchers have also pointed the benefits of using MIT Opencourseware materials in their courses (Yue et al., 2004; d'Oliveira et al., 2010). One potential mechanism here is to increase motivation as students feel that they could do it similarly as an MIT student.

RT5 let to understand that the more the students developed their modeling skills, the more they were able to learn from computer simulations (Figure 1, feedback loop “Learning from the computer simulation"). These findings are aligned with results from other scholars that point out that computer programs help to compress time and space (Sterman, 2010), allowing the simulation of different scenarios (Graham & Senge, 1990), therefore enhancing the student's mental models (Senge, 2014).

This led to the second insight: *Computer simulation improved the learning of quantitative modeling tools (stock and flows computer models), fostered the development of critical thinking and the understanding of systems’ structures and patterns of behavior*.

The final novel material in this program was the use of comics developed for this program. RT6 helped to understand that the use of comics was a good choice: it facilitated the comprehension of complex issues, helped to fix the contents in the students’ minds, and improved their motivation to learn. (Figure 1, feedback loop “Learning from comic strips”). Other researchers have already stressed the role of comics in stimulating critical thinking (Cheesman, 2006) and motivation to learn (Williams, 2008).

This led to our third insight: *The use of comics bought enjoyment to the classroom, helped the students comprehend complex issues, and improved the motivation to learn.*

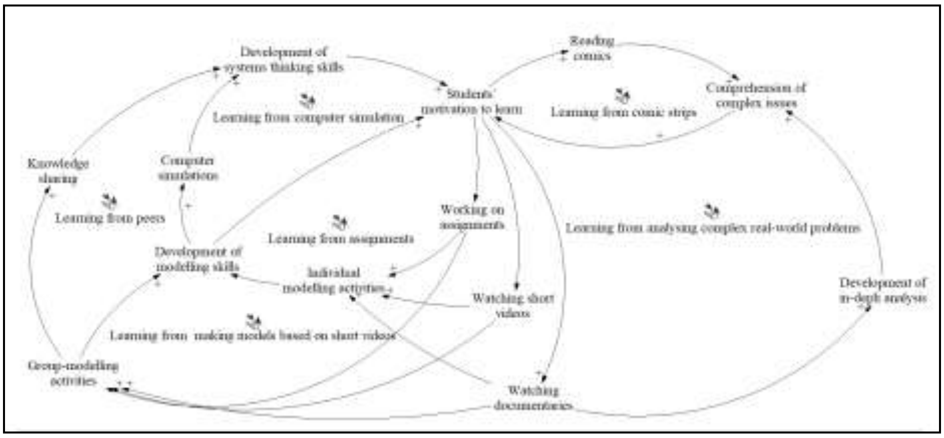

Figure 1
The course dynamics: the six feedback loops identified.

CONCLUSIONS

What was learned from this experience?

Returning to the research question, it can be affirmed that the combination of short-video and documentaries modeling exercises, written assignments, and computer simulation was very effective in teaching systems thinking. It is also possible to conclude that comics' use facilitated the learning and brought humor to the classroom. The students learned more when they were relaxed.

The short-videos helped the students to put immediately into practice the theory presented in class. The challenge of modeling a variety of situations portraited in videos facilitated learning on how to develop causal loop diagrams. The students learned while developing the model individually and learned, even more, when they improved their models in group modeling activities. The group modeling activities promoted intense knowledge sharing. Working in groups was not only instructional but fun.

It is also reasonable to affirm that the written modeling assignments promote a deep understanding of the modeling process; the students had to follow a well-defined step-by-step modeling approach. It brought discipline and confidence to the students. The students also benefit from working initially alone in these assignments and then in groups. Working in groups alleviates the stress that students face when doing the exercise alone and promotes knowledge sharing.

The assignments to model the dynamics presented in the documentaries promoted a deeper understanding of complex real-life problems. The students watched the films more than once in their homes, stopping the videos when necessary and creating the models gradually, at their own pace.

The computer simulations facilitated a full understanding of the structure of systems and their patterns of behavior. The students were able to challenge their mental models by analyzing different scenarios.

Based on the evidences here presented, we may suggest that professors of system thinking courses should make use of multiple resources (computer simulation, short-videos, documentaries, comics and written assignments), different modelling activities (group and individual modelling activities) and complementary educational approaches (problem-based learning and simulation-based learning) to engage the students, as we did here. By doing so, the course may become more interesting and meaningful to the students. It is a challenge since it involves a heavy workload to the professor: however, the educational benefits worth the effort.

We also understand the limitations of our study: the conclusions we presented here were based on a single course delivered to eleven students. However, we may speculate that lessons learned here can be useful to scholars that teach systems thinking in different contexts.

REFERENCES

Adamson, J., Gooberman-Hill, R., Woolhead, G., & Donovan, J. (2004). 'Questerviews': Using questionnaires in qualitative interviews as a method of integrating qualitative and quantitative health services research. *Journal of Health Services Research & Policy*, *9*(3), 139-145.

Arantes do Amaral, J. A., & Frazão, C. H. (2016). The Systemic Impacts of An Educational Project Conducted by One University in Partnership with Fifteen Organizations. *Science Education International*, *27*(3), 391-418.

Arantes do Amaral, J. A. (2019). Combining community-based learning and project-based learning: A qualitative systemic analysis of the experiences and perceptions of students and community partners. *Partnerships: a journal of service-learning and civic engagement*, *10*(1), 129-145.

Boleng, D. T., Maasawet, E. T., & Candra, K. P. (2020). Empowering critical thinking skills by implementing scientific approach-based models among various students' ethnics. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *6*(2), 199-208.

Bosse, H. M., Huwendiek, S., Skelin, S., Kirschfink, M., & Nikendei, C. (2010). Interactive film scenes for tutor training in problem-based learning (PBL): dealing with difficult situations. *BMC medical education*, *10*(1), 52.

Bossel, H. (2007). *Systems and models: complexity, dynamics, evolution, sustainability*. Nordersted, Germany: BoD–Books on Demand.

Bradley, E. H., Curry, L. A., & Devers, K. J. (2007). Qualitative data analysis for health services research: developing taxonomy, themes, and theory. *Health services research*, *42*(4), 1758-1772.

Burck, C. (2005). Comparing qualitative research methodologies for systemic research: The use of grounded theory, discourse analysis and narrative analysis. *Journal of family therapy*, *27*(3), 237-262.

Chauvet, S., & Hofmeyer, A. (2007). Humor as a facilitative style in problem-based learning environments for nursing students. *Nurse education today*, 27(4), 286-292.

Cheesman, K. (2006). Using comics in the science classroom. *Journal of College Science Teaching*, *35*(4), 48.

Cook, C., & Wind, Y. J. R. (2006). *The power of impossible thinking: Transform the business of your life and the life of your business*. Upper Saddle River, NJ: Pearson Prentice Hall.

Courts, B., & Tucker, J. (2012). Using technology to create a dynamic classroom experience. *Journal of College Teaching & Learning (TLC)*, *9*(2), 121-128.

Craik, K. J. W. (1952). *The nature of explanation*. Boston: MA, Cambridge University Press.

Creswell, J. W., & Miller, D. L. (2000). Determining validity in qualitative inquiry. *Theory into practice*, *39*(3), 124-130.

d'Oliveira, C., Carson, S., James, K., & Lazarus, J. (2010). MIT OpenCourseWare: Unlocking knowledge, empowering minds. *Science*, *329*(5991), 525-526.

Denzau, A. T., & North, D. C. (2000). Shared mental models: ideologies and institutions. In A. Lupia, M.D. McCubbins, S.L. Popkin (EdS.) *Elements of reason: Cognition, choice, and the bounds of rationality*, (pp. 23-46). Cambridge, MA: University Press

Forrester, J. W. (1997). Industrial dynamics. *Journal of the Operational Research Society*, *48*(10), 1037-1041.

Fregni, F. (2019). *Critical thinking in teaching and learning: the nonintuitive new science of effective learning*. Massachusetts: Lumini LCC.

Fregni, F., Jimenez, A. S. (2020). *Evidence-based analysis in of technology in teaching and learning: The real effect of technology-based methods in educational programs*. Boston, Massachusetts: Kindle Direct Publishing.

Gijselaers, W. H. (1996). Connecting problem-based practices with educational theory. In L. Wilkerson, W.H. Gijelaers (Eds). *New directions for teaching and learning*, (pp. 13-22).

Gini-Newman, G., & Case, R. (2018). *Creating thinking classrooms: Leading educational change for this century*. Thousand Oaks, California: Corwin Press.

Glaser, R. (1991). The maturing of the relationship between the science of learning and cognition and educational practice. *Learning and instruction*, *1*(2), 129-144.

Golafshani, N. (2003). Understanding reliability and validity in qualitative research. *The qualitative report*, *8*(4), 597-607.

Graham, A., Shiba, S., & Walden, D. (2001). *Four practical revolutions in management: Systems for creating unique organizational capability*. Boston, MA: CRC Press.

Graham, A. K., & Senge, P. M. (1990). Computer-based case studies and learning laboratory projects. *System Dynamics Review*, *6*(1), 100-105.

Guzdial, M., Kolodner, J., Hmelo, C., Narayanan, H., Carlson, D., Rappin, N., . . . Newstetter, W. (1996). Computer support for learning through complex problem solving. *Communications of the ACM*, *39*(4), 43-45.

Hovmand, P. S. (2014). *Community based system dynamics*. New York, NY: Springer.

Hung, C. M., Hwang, G. J., & Huang, I. (2012). A project-based digital storytelling approach for improving students' learning motivation, problem-solving competence and learning achievement. *Journal of Educational Technology & Society*, *15*(4), 368-379.

Langley, A. (2004). Using questionnaires in qualitative interviews. *Journal of Health Services Research & Policy*, *9*(3), 130.

Larmer, J., Mergendoller, J., & Boss, S. (2015). *Setting the standard for project-based learning*. Alexandria,VA: ASCD.

Leet, D., & Houser, S. (2003). Economics goes to Hollywood: Using classic films and documentaries to create an undergraduate economics course. *The Journal of Economic Education*, *34*(4), 326-332.

Lestari, N., Basri, K. I., Suciati, S., & Masykuri, M. (2020). The presence of the Problem-based Learning syntax in junior high school biology textbooks. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *6*(1), 9-14.

Lukitasari, M., Purnamasari, I., Utami, S., & Sukri, A. (2019). Blended-Problem-Based Learning: How its impact on students' critical thinking skills? *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *5*(3), 425-434.

Mann, D., Reardon, R. M., Becker, J. D., Shakeshaft, C., & Bacon, N. (2011). Immersive, interactive, web-enabled computer simulation as a trigger for learning: The next generation of problem-based learning in educational leadership. *Journal of Research on Leadership Education*, *6*(5), 272-287.

Meadows, D., Richardson, J., & Bruckmann, G. (1982). *Groping in the dark: the first decade of global modelling*. Boston, MA: John Wiley & Sons.

Meadows, D. H. (2008). *Thinking in systems: A primer*. White River Junction, VE: Chelsea Green Publishing.

Murphy, S., Hartigan, I., Walshe, N., Flynn, A. V., & O'Brien, S. (2011). Merging problem-based learning and simulation as an innovative pedagogy in nurse education. *Clinical Simulation in Nursing*, *7*(4), e141-e148.

National Research Council (2000). *How people learn: Brain, mind, experience, and school: Expanded edition*. Washington, D.C: National Academies Press.

Noble, H., & Smith, J. (2015). Issues of validity and reliability in qualitative research. *Evidence-based nursing*, *18*(2), 34-35.

Norman, D. (1983). Some observations on mental models, In D. Gentner, D., A.L. Stevens (Eds.). *Mental Models*. New York, NY: Psychology Press.

Nursa'ban, E., Masykuri, M., & Yamtinah, S. (2019). Improving student learning outcomes in science subjects through the implementation of PBL-based module. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *5*(2), 269-276.

Peck, S. (1998). Group model building: facilitating team learning using system dynamics. *Journal of the Operational Research Society*, *49*(7), 766-767.

Ramdiah, S., Abidinsyah, H., & Mayasari, R. (2018). Problem-based learning: Generates higher-order thinking skills of tenth graders in ecosystem concept. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *4*(1), 29-34

Richardson, G. P., & Andersen, D. F. (1995). Teamwork in group model building. *System Dynamics Review*, *11*(2), 113-137.

Roh, Y. S., Kim, S. S., & Kim, S. H. (2014). Effects of an integrated problem-based learning and simulation course for nursing students. *Nursing & health sciences*, *16*(1), 91-96.

Senge, P. M., Cambron-McCabe, N., Lucas, T., Smith, B., & Dutton, J. (2012). *Schools that learn (updated and revised): A fifth discipline fieldbook for educators, parents, and everyone who cares about education*. New York, NY: Crow Business.

Senge, P. M. (2014). *The fifth discipline fieldbook: Strategies and tools for building a learning organization*. New York, NY: Currency.

Sexton, R. L. (2006). Using short movie and television clips in the economics principles class. *The Journal of Economic Education*, *37*(4), 406-417.

Soderberg, P., & Price, F. (2003). An examination of problem-based teaching and learning in population genetics and evolution using EVOLVE, a computer simulation. *International Journal of Science Education*, *25*(1), 35-55.

Spinello, E., & Fischbach, R. (2004). Problem-based learning in public health instruction: A pilot study of an online simulation as a problem-based learning approach. *Education for Health*, *17*(3), 365-373.

Sterman, J. D. (2001). System dynamics modeling: tools for learning in a complex world. *California management review*, *43*(4), 8-25.

Sterman, J. D. (2006). Learning from evidence in a complex world. *American journal of public health*, *96*(3), 505-514.

Sterman, J. D. (2010). *Business dynamics*. Boston, MA: Irwin/McGraw-Hill.

Sterman, J. D. (1994). Learning in and about complex systems. *System Dynamics Review*, *10*(2-3), 291-330.

Sterman, J. D., & Sweeney, L. B. (2007). Understanding public complacency about climate change: Adults' mental models of climate change violate conservation of matter. *Climatic Change*, 80(3-4), 213-238. Suwarno, S., Wahidin, W., & Nur, S. H. (2020). Project-based learning model assisted by worksheet: It's effect on students' creativity and learning outcomes. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *6*(1), 113-122.

Sweeney, L. B., & Meadows, D. (2010). *The systems thinking playbook: Exercises to stretch and build learning and systems thinking capabilities*. White River Junction, VE: Chelsea Green Publishing.

Vennix, J. A. (1999). Group model-building: tackling messy problems. *System Dynamics Review*, 15(4), 379-401.

Walshe, N., O'Brien, S., Murphy, S., & Hartigan, I. (2013). Integrative learning through simulation and problem-based learning. *Clinical Simulation in Nursing*, *9*(2), e47-e54.

Watkins, K. E., & Marsick, V. J. (1992). Towards a theory of informal and incidental learning in organizations. *International Journal of Lifelong Education*, *11*(4), 287-300.

Williams, R. M.C. (2008). Image, text, and story: Comics and graphic novels in the classroom. *Art education*, *61*(6), 13-19.

Williamson, G. R., Kane, A., Plowright, H., Bunce, J., Clarke, D., & Jamison, C. (2020). 'Thinking like a nurse'. Changing the culture of nursing students′ clinical learning: Implementing collaborative learning in practice. *Nurse Education in Practice*, 43, 102742.

Wilson, B. G. (1996). *Constructivist learning environments: Case studies in instructional design*. Jersey City, NJ: Educational Technology.

Yearworth, M., & White, L. (2013). The uses of qualitative data in multimethodology: Developing causal loop diagrams during the coding process. European Journal of Operational Research, *231*(1), 151-161.

Yin, R. K. (2015). *Qualitative research from start to finish*. New York, NY: Guilford publications.

Yue, K.-B., Yang, T. A., Ding, W., & Chen, P. (2004). Open courseware and computer science education. *Journal of Computing Sciences in Colleges*, *20*(1), 178-186.

APPENDIX 1

The number of students attending Culture Courses

Lecture	Lecture Goal	Classroom activities
01	Present the concepts of systems thinking. Discuss the importance of system dynamics modeling tools.	Short-video modelling. Individual and group modelling activities. Critical reflection about the models developed
02	Present the concepts of system components and system structures. Discuss the concepts of patterns of behavior and feedback loops	Individual and group modelling activities, creation of causal loop diagrams using the software Vensim.
03	Review the theory and examples presented in the textbook by referring to the comic strips. Provide an overview of next assignment (MIT opencourseware assignment).	Discussion of situations portraited in the comic strips. Short-video modelling. Individual and group modelling activities, creation of causal loop diagrams using the software Vensim Ple©. Critical reflection about the models developed.
04	Discuss the students' answers to the MIT assignment. Foster the development of students' modeling skills, by means of exercises based on short-videos. Provide an overview of next assignment (model the dynamics portraited in the documentary 'Food Inc.').	Discussion of the MIT assignment (individual modeling assignment). Short-video modelling. Individual and group modelling activities. Critical reflection about the models developed.
05	Review the theory and examples presented in the textbook by referring to the comic strips. Foster the development of students' modeling skills by means of exercises based on short-videos.	Discussion of the models created to represent the dynamics portraited in the documentary 'Food Inc'. Short-video modelling. Individual and group modelling activities. Critical reflection about the models developed.
06	Present the concepts of systems' mental models. Review the theory and the examples presented in the textbook by referring to comic strips. Provide an overview of next assignment (model the dynamics portraited in the documentary 'Cowspiracy').	Short-video modelling. Individual and group modelling activities. Critical reflection about the models developed.
07	Review the theory and examples presented in the textbook by referring to comic strips. Present the concepts of positive and negative feedback loops. Discuss the dynamics of negative feedback loops with delays.	Discussion of the models created to represent the dynamics portraited in the documentary 'Cowspiracy'. Short-video modelling. Individual and group modelling activities. Critical reflection about the models developed.
08	Review the theory and examples presented in the textbook by referring to comic strips. Present the concepts of stock and flows. Help the students become familiar with VensimPle© simulation environment.	Short-video modelling and simulation. Individual and group modelling and simulation activities. Critical reflection about the models developed.
09	Review the theory and examples presented in the textbook by referring to comic strips. Teach the students how to create and run simple stock and flow computer models.	Short-video modelling and simulation. Individual and group modelling and simulation activities. Critical reflection about the models developed.
10	Review the theory and examples presented in the textbook by referring to comic strips. To help the students become familiar with the concept of table functions.	Short-video modelling and simulation. Individual and group modelling and simulation activities. Critical reflection about the models developed.
11	Review the theory and examples presented in the textbook by referring to comic strips. Present the students several computer models that address real-life problems. Provide an overview of final assignment, a student's self-assessment questionnaire.	Individual and group modelling and simulation activities. Critical reflection about the models used in simulations.
12	Present the students' perspectives about the course, based on the questionnaires. Interview the students, in order to understand what was not clear in their answers.	Individual interviews, reviewing the topics learned.

APPENDIX 2

Documentaries, short-movies and comic-book used

	Learning resources
Documentaries	(Movies from Netflix) 1. Food Inc 2. Cowspiracy
Short-movies	(Videos from World Economic Forum) 1. How wolves change the rivers 2. What would happen if the insects disappear? 3. Systems thinking: a cautionary tale about cats in Borneo 4. This is how Iceland transformed teenagers from heavy drinkers to model citizens 5. This is how to eat save the planet, according to scientists 6. Children need microbes not antibiotics
Comic-strips	From the website: "The cartoon guide to system dynamics"
Textbook	Thinking in Systems: a primer
MIT Assignment	MIT Opencourseware Assignment 01

APPENDIX 3 SURVEY QUESTIONS

Question 1. Throughout the course, we watched several short films and created models for the dynamics portrayed in each movie. Please tell me what you learned from this experience.

Question 2: In the classroom, after asking you to create, individually, causal loop diagrams for the dynamics portrayed in short films alone, I divided you into small groups of students and asked you to work together in order to improve the models. Please tell me about your experience working with your colleagues.

Question 3. You did a long assignment, a modeling exercise (MIT homework). Please tell me about your experience (initially working alone and then with the support of the other students) in performing this exercise.

Question 4: Please tell me what you have learned by creating computer models and running simulations using VensimPle© software.

Question 5: Please tell me about your experience in identifying and modeling the dynamics portrayed in long documentaries (Food Inc, Cowspiracy).

Question 6: Please tell me about your experience of learning through comics.