

INTRODUCING SYSTEM DYNAMICS AT CULS PRAGUE

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Abstract

The system thinking is the important component of study at the Faculty of Economics and Management, Czech University of Life Sciences Prague (CULS Prague) but the system dynamics is not the part of education there. Current effort is to focus on implementation of system dynamics into existing courses of Mathematical Methods in Economics.

The objective of the paper is to design and test flexible seminars' structure of system dynamics at the Czech University of Life Sciences Prague during the lessons and seminars on the courses of Mathematical Methods in Economics. The results are necessary for successful introduction of system dynamics courses at CULS Prague. First part of the paper describes the role of system dynamics in education and the registered benefits from its implementation into education at different schools and universities. Second part contains the sources that constitute the basis for the seminars' structure design. The proposed structure is tested in third part through the questionnaire and the opinions of students.

Key Words

System dynamics, simulation, education, system thinking

Introduction

The system dynamics as well as its teaching methods have developed since 1950, when J.W. Forrester wrote his first system dynamic works (Forrester, 1989). Significance of the system dynamics teaching led to a special issue of the System Dynamics Review in 1993 (Gould-Kreutzer, 1993) and papers with educational content are regular part of System Dynamics Society conferences. From the beginning, Forrester proposed an integrating role of the system dynamics in the management education (Gould-Kreutzer, 1993) and according to the wide range of schools where the system dynamics is being taught it looks like this goal is going to be slowly achieved.

In the lessons of 35 years Forrester (1993) describes the benefit of the system dynamics in management. The education of system dynamic provides "enterprise designer" which Forrester compare to airplane designer. Then the ordinary managers can be compared to pilots. Even a very good pilot (manager) cannot fly a plane (manage an organisation) that is badly designed.

In the middle of 1980s Clauset (1985) made a survey focused on system dynamics courses. There were a few of system dynamics courses, most of them located in the United States, Canada and northern Europe. Majority of them was for graduate students.

Davidson et. al. (1993) tested the benefits of teaching the system dynamics at the Nordic high schools (15 and 18 years old students). These tests did not focus on the knowledge of the system dynamics but on the impact of the system dynamics course on understanding of macroeconomics and questions from social and ecological sciences. Students who passed the system dynamics courses achieved 10% better results than those without such course; and the quality of their argumentation significantly increased.

Ossimitz (2000) summarized teaching of system dynamics at the high schools in Germany and Austria and tested the effectiveness of the courses. The teaching of system dynamics affected also the teachers thinking. Despite high impact of the teacher and the difficulties of measurement of the system thinking skills improved.

Sedehi et. al. (2008) compared approaches in the teaching of the system dynamics at various universities in Italy. Very different universities with different specialisation (from enterprise communication to statistics and engineering) needed to adjust the courses to their students' abilities. In spite of a difficult comparison it showed that all courses use business cases and introduction to the system thinking before the system dynamics methodology.

Wu and Onipede (2010) enhanced the system dynamics course at the Pennsylvania University by students' application presentation and experiments appropriate to the field of study. This led to the better evaluation of courses from the students and the significant increase of interest in the system dynamics.

Even younger students can study the system dynamics. The Creative Learning Exchange (2011) provides training of system dynamics and system thinking in K-12 education (K-12 means from kindergarten to 12th grade which means primary and secondary education in USA and Canada).

The system dynamics is relatively young in Czech environment; development of this field at universities could improve understanding the complex problems and thus it could improve the decision making in companies and public institutions (Mildeova and Vojtko, 2005). Such improvement is covetable especially in new EU countries (Mildeová and Němcová, 2009).

Even though the system thinking is an important component of study at the Faculty of Economics and Management, Czech University of Life Sciences Prague, the system dynamics itself is not a part of it. The current effort is to implement the system dynamics into existing courses of Mathematical Methods in Economics. The time donation in the different courses varies. The level of mathematical and system thinking skills depends usually on the study programme. The previously cited system dynamics courses' cases consisted of, at least, tens of hours; the basic (smallest) time donation at the CULS Prague is two lectures and two seminars (one lecture or seminar lasts 1.5 hour).

The objective of the paper is to suggest flexible seminars' structure of system dynamics at the CULS Prague. The flexibility consists of two characteristics. Firstly, the time flexibility that means the themes organisation of seminars adjusts to the time donation. Secondly, the theme flexibility that stands for the capability of the seminars' structure to reflect the knowledge base of students. Then the impact of the suggested seminars and lectures was tested. The students evaluated short introduction to the system dynamics that consist of two seminars and two lectures. The lectures were composed as the brief introduction into following topics:

- Simulations
- System dynamics theory
- System representation:
 - Diagramming
 - Numerical integration
 - Delays
 - Dimensional consistency
 - System archetypes

Students' answers will be used for further development of system dynamics courses at CULS Prague.

Material and Methods

The System dynamics deals with behaviour of complex systems over time. It focuses on a system description and understanding aiming at the policy analysis and design. Computer simulation supports the understanding of complex dynamic systems. The system dynamics core lies in feedback thinking with stress on delayed effects, stock and flow structure and nonlinear behaviour. The endogenous point of view is crucial for the system dynamics approach. See e.g. Meadows (2008), Sterman (2000) or System Dynamics Society (2011) for exhaustive definitions. The proposed organisation of the system dynamics seminars at the CULS Prague is based on the integration of the good experience of the other authors.

The theme arrangement arises from the principles of a system zoo (Bossel, 2007a, 2007b) and system archetypes (Senge, 2009). Whereas archetypes represent typical structures that conduct some characteristic performance, the animals from the system zoo consist of fundamental modelling structures with aim at the diagramming practice (stock and flow diagrams) and quantitative point of view. Even though the system archetypes are too simple for practical models (Lyneis, 1999) they still have great pedagogical value.

Concerning organisation of seminars' themes we mainly focus on the second and third step from the system dynamics process (fig. 1) by Forrester (1994) that create the hard operational research part of the process. The fourth step is also integrated especially for the longer courses.

System archetypes are assumed to be explained during lectures, the special theme of system archetypes in seminars consists of mathematical modelling of chosen archetype and archetypes identification in study cases.

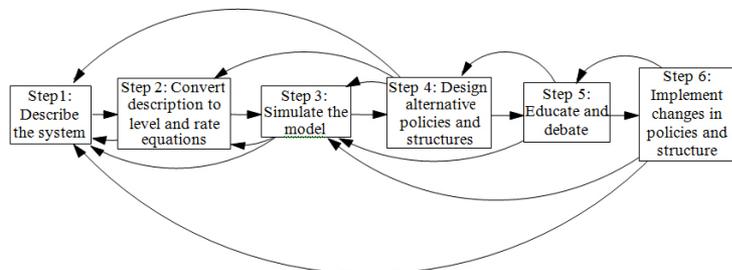


Fig. 1: System dynamics process, from Forrester (1994)

The system dynamics computer simulation is based on continuous behaviour, which leads to system of differential equations – this contains lot of differences to other topics from the Mathematical Methods in Economics courses. Fundamental tool that works as a bridge between mental models and mathematical expression of the complex dynamic system is diagramming – causal loop diagrams and stock and flow diagrams (Coyle, 1996, Sterman, 2000).

Coyle (1996) provides teaching time table that helps with time estimations of not already tested teaching examples and models. Similarly to Wu and Onipede (2010) or Sedehi et. al. (2008) Coyle stresses the differentiation of the courses on the basis of students' specialisation. Such differentiation is grounded on the cases variation and also on the emphasis topics corresponding to student abilities and knowledge.

Nearly from the beginning of the system dynamics the one classical tool is used: The Beer Distribution Game. This non-computer simulation is widely used for explaining the basics of

the system dynamics and system thinking (Senge, 2009, Sterman, 2000). A small simplified model of distribution problem helps to introduce system thinking, system dynamics, counterintuitive behaviour of systems, the effect of delays, etc.

Pruyt (2009, 2010) successfully uses “hot” actual case for teaching support. Actual real-world problems like Soft drugs case or Mexican flu model are used to increase students' interest. It is clear that such models are difficult to prepare but this disadvantage can be reduced by hot cases sharing (Pruyt, 2010).

Vensim PLE (Personal Learning Edition) Plus was chosen as a software used for the seminars because of student friendly policy of Ventana Systems (2011). The version Vensim PLE for non-commercial use is downloadable for free that allows efficient home preparation of students. The cases must correspond to the fewer number of Vensim PLE functions in comparison with higher versions of the Vensim.

Questionnaire survey

We used a questionnaire to evaluate impact of first two levels of the proposed seminars structure. Questionnaire contained binary comparison of themes in the specific course students with the possibilities to explain their views. The questionnaire is divided to seven parts and its anonymous, questions are following:

Man/Woman

a) Binary comparison of topics – tick the topic that you find *interesting*.

- 1) System dynamics (SD) x Nonlinear programming (NP)
- 2) System dynamics (SD) x Inventory theory (IT)
- 3) System dynamics (SD) x Input/output table (I/O)

- 4) System dynamics (SD) x Queuing theory (QT)
 - 5) Input/output table (I/O) x Nonlinear programming (NP)
 - 6) Input/output table (I/O) x Queuing theory (QT)
 - 7) Input/output table (I/O) x Inventory theory (IT)
 - 8) Queuing theory (QT)xInventory theory (IT)
 - 9) Queuing theory (QT) x Nonlinear programming (NP)
 - 10) Inventory theory (IT) x Nonlinear programming (NP)
- b) Would you find the System Dynamics as a practically discipline??
- c) Describe three cases of problems which can be solving through the System dynamics.
- d) Which part (topics) of lectures and practice you find more interesting?
- e) Which one (or more) of the discussed topics would you suggest to spend more time?
- f) Would you be more interested in learning the system dynamics??
- g) Which part(s) from the lectures and exercise(s) of system dynamics will come the least interesting??

This questionnaire was used for the students of system engineering in the second year of their study as two lessons in the subject of Mathematical methods of Economics. These students are highly qualified in the mathematical methods. The classes are small and count between 15 to 20 students, and most of them are interesting in this kind of topic.

Results

The purpose of seminar's structure

The organisation of seminars' themes is proposed in the graph form that shows links between the particular topics (fig. 2). Each node represents the theme accomplished. The arcs represent the recommended or estimated time for the theme.

Using spiral teaching approach like e.g. Road Maps at Creative Learning Exchange (2011) the explained problems are repeated and extended in subsequent problems. If the problem appears first time it must be explained and the corresponding theory from lectures must be briefly repeated. It is why the cases time can vary. Note that, the seminars' structure is not the project management graph and it is not necessary to use all the arcs to finish the theme but only just one.

Currently, times are rough estimations based on other authors' papers and will be improved with growing experience. Some topics lengths are not only estimations but also recommended time. The seminars are divided into 5 levels based on increasing complexity and difficulty, first of them focuses on the basic skills in systems dynamics and students must go thru these basic levels.

The level V can be reached in fifth seminar. Going shorter way (avoiding some themes) to level V must result in easier and/or longer hot or student case. It is obvious that levels do not represent the difficulty in absolute terms but only relative difficult to lower levels.

The backward arrows from level IV to Level III do not mean that the cycle is allowed, they present just the logical consequence of topics. Arrows to level V denote it is possible to start students' or hot cases after finishing any of the level IV themes. Students'

case means the hot case connected to chosen diploma thesis or project for another subject of actual semester.

The chronological succession of themes is pretty clear but the beginning of the course needn't to be the beer distribution game. Focusing on the courses with very small time donation the critical issues are in level I, which is assumed to take one seminar. Two or more seminars donation can start with beer distribution game and continue with level I or start with level I and continue with part of level II.

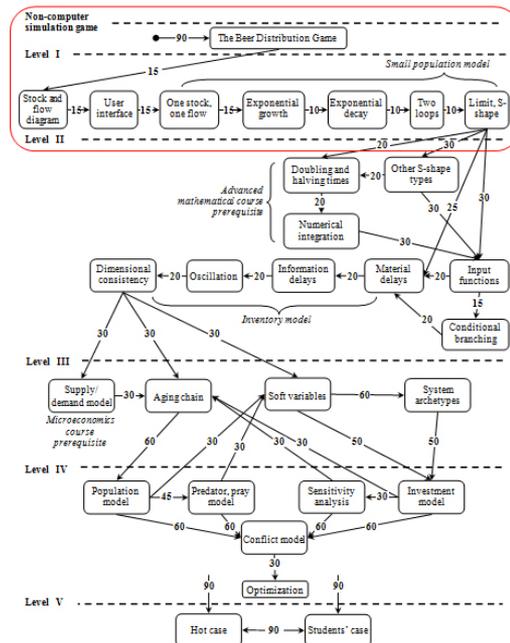


Fig. 2: The introduction seminar in graph of the seminars' structure (Krejčí et al., 2011)

Firstly, the theme flexibility is represented by parts connected to another courses. Such connection can make both courses more comprehensible and interesting for students. Also levels 3 – 5 contain very different topics thus the seminars can be tailored to the students' group demands.

To bring the organisation of seminars' themes to life we use the environment of LMS Moodle (fig. 3). Among other functions this learning system allows highlighting and hiding of some course parts what corresponds to the changing structure of the seminars. Moreover, in the case of the course structure with two lectures to one seminar, the themes are assumed to serve for the home preparation. The use of LMS Moodle can also help with this problem

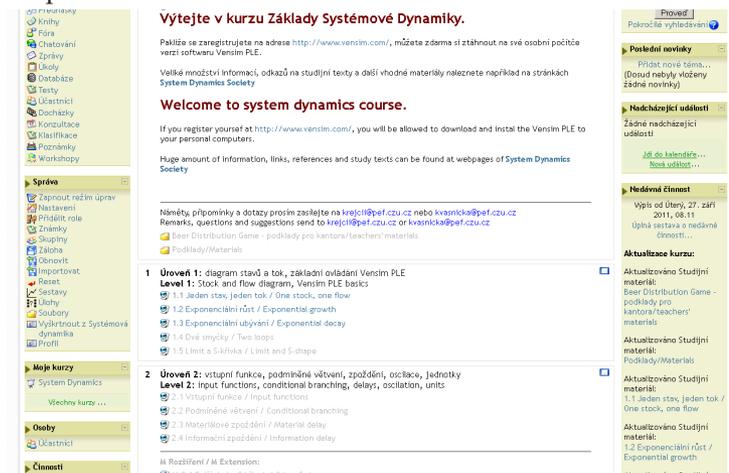


Fig. 3: SD course in LMS Moodle

The necessary theory including the simulations and system dynamics theory was introduced during the Lessons. The theoretical part precedes the main part of the practical

applications where the students have to go through the two practical seminars, with subject of:

- Beer distribution game,
- Vensim – Level I.

The marked part of the system dynamics has been taught as the last part of the study. The whole seminar structure of the whole course is in following table, the system dynamics was a part of Mathematical Methods.

| | Topic | Practical seminars |
|----|--|--|
| 1 | Structural analysis | Matching task |
| 2 | Mathematical programming | The counts in structural analysis |
| 3 | Gradient methods | Free extremes solving problem Solving of nonlinear tasks in EXCEL |
| 4 | Lagrange multipliers Quadratic programming Wolfe's algorithm | The short-and long-step method Zoutendijk's algorithm |
| 5 | Stochastic processes Markov chain | Wolfe's algorithm |
| 6 | Test | Nonlinear programming |
| 7 | Queuing theory | Markov chain |
| 8 | Inventory models - deterministic | Queuing theory |
| 10 | simulation models | Inventory models - deterministic |
| 11 | Basics of System Dynamics | The Beer Distribution Game |
| 12 | System Dynamics - Vensim | Vensim |

After these topics, the students filled the questionnaire, the questionnaire was completed by 15 students of System engineering the five of them doesn't visited the whole seminar so they have been removed. After that there were 10 regular questionnaires with 4 females and 6 males.

First part of results was **binary comparisons of topics**, sorted by weights, which are calculated through the method called Fuller's triangle (see: Anderson et al., 1991). The weights help us to order the main topics of all lessons in the subject of Mathematical methods in Economics according to the attractiveness:

| All students | |
|-------------------------|-----------------|
| System dynamics | 0,19 (3) |
| I/O | 0,16 (5) |
| Queuing theory | 0,22 (2) |
| Inventory theory | 0,26 (1) |
| Nonlinear programming | 0,17 (4) |

Tab. 1: The order of topic for all students

If we divide the results by gender, the order is totally changed, see in table:

| | males | females |
|-----------------------|------------------|-----------------|
| System dynamics | 0,283 (1) | 0,05 (5) |
| I/O | 0,133 (4) | 0,2 (3) |
| Queuing theory | 0,250 (2) | 0,175 (4) |
| Inventory theory | 0,217 (3) | 0,325 (1) |
| Nonlinear programming | 0,117 (5) | 0,25 (2) |

Tab. 2: The order of topic for males and females

The males' students prefer the systems dynamics as most interesting topic but females perceive the system dynamics as less topics.

From the second part of survey students answered the **open questions**; the results can be summarizing in these conclusions:

- All students find system dynamics as practical discipline
 - Six of them were able to write examples of problems relevant to system dynamics
- The most interesting
 - Vensim
 - Beer distribution game
- Which theme should be granted more time
 - Vensim
- The less interesting
 - Theory (lectures)
 - Numerical integration.

Discussion

Results from the questionnaire indicate the direction of further development. The result of such short introduction should be the students' awareness of system dynamics. They will not be system dynamists, but they should know the system dynamics is useful and practical discipline, they should understand the basic system dynamics principles and they should be able to identify the problem that is relevant to system dynamics. That is why we consider result six answers on question c as insufficient and as indicator for further improvement.

Similarly to Wu and Onipede (2010) we should stress the application presentation and experiments appropriate to the field of study. This should improve the students' orientation in them and their evaluation of course as well. .

This is also connected to hot cases. As Pruyt (2009, 2010) stressed these models are difficult to prepare and it is impossible to solve such problems in two seminars courses. But implementation of such cases into lectures, their presentation and explanation of the impact of such model should improve the students' knowledge of field of system dynamics study and also increase the attractiveness of that theme.

The proposed seminars structure can be compared to Coyle's system dynamics course time table. Even though the time table focus on one week seminar, its author suggests its modification for two weeks or whole semester. Length of the Coyle's seminar is about 30 hours that correspond to one semester course with one lecture and one seminar per week. It also contains optimisation and practical examples. Coyle's course does not include beer distribution game. The beer distribution game should be included only in case of long course at CULS Prague. This change will lead to increase of time donation to practical seminars with simulation soft ware.

Conclusion

The time schedules for single themes must be methodically improved to adjust the whole usefulness of the proposal. At present, the longest configuration gives the length of nearly 11 seminars. The proposal does not contain the tests. Addition of two tests and time reserve for differences in the time lengths of the topics gives full semester subject. Nevertheless, the longest configuration loses both time and theme flexibility. Thus, such configuration requires completed micro economic course

and advanced mathematical course as well. But even the full semester course can introduce only the most basic principles of the system dynamics.

Whole flexible course structure is based on a good experience of referenced authors. The practice show more possible connections between the themes. Also some new themes can appear as valuable to be implemented into the course.

For the successful implementation of the system dynamics courses the seminars' the organisation and study models are not sufficient. Many supporting materials will be prepared. We have already assisted making the system dynamics video lecture, which is the part of successful multimedia lectures project running at the CULS Prague (Houška and Houšková Beránková, 2010).

In the paper we purposed the whole seminars' structure, which is divided to the levels. These levels are possibility which will put some system dynamics topics in the course. The seminars' structure is way how to start with systems dynamics as a part of teaching subjects.

We are at the beginning of long process. The long term goal is full semester system dynamics course. According to literature implementation of system dynamics courses at CULS Prague can be considered as way how to improve students' system thinking and understanding of complex problems. Successful implementation of the courses should result in improvement in other subjects at university like e.g. economics or sociology but it should also improve the decision making in practice. Such results are hard to measure (especially the impact on practice) but highly desirable.

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