MODELING AND SIMULATION TRAINING FOR UNDERGRADUATE STUDENTS

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Abstract

Education should be beyond simply offering content and asking learners to master it. Primarily, it should aim to create a critical view for the problems that exist and make individuals flexible, creative and open to different approaches towards potential solutions. Modeling and simulation deal with the real world issues through abstractions of its complexities and testing possible outcomes using "what if" analysis. Getting a deeper insight in the nuts and bolts of this area demands long training with a good start. Hence, developing an introductory course that will introduce undergraduate students to the art of modeling and various techniques in performing experiments using simulation is a demanding and daunting task. Many concerns need to be addressed. Inter alia, the conceptual syllabus, the scope of the coverage, the pedagogical approach, and the simulation software environment. The article argues that a course that spans over the three major approaches to simulation and does not require rigorous prerequisites and extensive background from the students, in addition of being a smooth introduction to modeling techniques, serves as a sound and fertile basis for their future education. Moreover, the latest developments of multi-paradigm software tools, which are user friendly and intuitive to use, further facilitate the process of course design, implementation, and acceptance by the students. The experience gained through the first two years in offering this kind of course proved most of the enumerated expectations.

Keywords: Modeling, Simulation, Multi-paradigm approach, Courses in M&S.

Presenting Author's biography

Iskra Popova has Ph.D. in Computer Science and has thought at Saints Cyril and Methodius University, European University, and Mid Sweden University. At present she works at Department of Computer and System Sciences at Stockholm University. Her research and educational interests are focused in the areas of Internet technologies, e-Learning modeling and simulation.

1 Introduction

According to [1] applications of simulation can be classified into two broad categories. The first one is usually called main-in-the loop simulation and is primarily used for training and/or entertainment, while the second one concentrates on the analysis of systems. The later is associated with modeling, a process of creating a simplified representation of a system while preserving the elements that characterize the changes of its behavior with respect to time. With simulation this behavior can be observed under different decision policies, changes and/or modifications introduced in any part of the original model.

Before the computers became a common tool, model building was considered as the act of developing a mathematical system that depicts a certain real situation where the simulation showed the essence of the system activity over time [2]. Nonlinear dynamic systems were subject of the most investigations. The first simulators were purely constructed in hardware [3]. Later, the decrease in the cost of computing power and the generation of new special purpose simulation languages contributed modeling and simulation to become a valid discipline focused upon difficult challenges in experimenting with complex real systems and offering solutions to hard and mostly multidisciplinary problems. However, competence in formulating the problem, designing the model, and performing the simulation, as well as in depth understanding of the system analyzed, are considerable requirements from the simulation professionals. Hence, many educational institutions developed numerous master degree programs to meet the needs and answer the market demands for advanced education in modeling and simulation [4], [5]. Undergraduate courses in the topic are usually offered within different departments and their content is related to the major field of study (Biology, Environmental Engineering, Physics, Geography, Computer Systems, etc.).

The emergence of various modeling and simulation tools with easy to use graphical user interface have compelled the educators to introduce modeling and simulation training to students without extended background in mathematics and programming. The text that follows gives a short overview of the different modeling and simulation paradigms and the respective software tools. The next section presents the influence of the emerging expressive simulation software on the new approach in creating modeling and simulation training at the undergraduate level, where the focus is on modeling social dynamic systems. The final section is dedicated to the approach in introducing modeling and simulation paradigms in the second year of the undergraduate studies at the Department for Computer and System Science at Stockholm University and the lessons learned during the first two years.

2 Three Different Paradigms in Modeling and Simulation

Three different types of modeling and simulation techniques for dynamic social systems, well known today are System Dynamics (SD), Discrete Event Simulation (DES) and Agent Based Simulation (ABS), also called Agent Based Modeling (ABM) or Multi Agent Based Simulation (ABMS). The first two are often a part of the curriculum in undergraduate programmes, while the third is rather new and is rarely taught at this level.

2.1 System Dynamics

SD takes a holistic view and implements a top down approach treating the system as a whole. The system variables, their causal relationships and feedback loops can be represented with differential equations using algebra and calculus. The aim is to determine which variables are crucial for the system and observe how they change with time. When modeling non trivial social systems, even complex mathematical apparatus is incapable in obtaining the desired output. Instead, the so called step-by-step simulation is used, [6], with the time step being constant throughout the whole period the system is observed. Applying numerical methods for solving the equations at each time step is necessary to obtain the value of the desired variable at a particular time.

System Dynamics modeling and simulation was developed as an approach to problem solving by Jay Forrester at MIT in the early 1960s. It is typically used, but not limited, in modeling population, ecological and economic systems, as well as regarding problems in business and government strategy development. The application of this approach to countless real life problems became popular with the appearance of user friendly programs that could be easily implemented by students without delving behind the mathematics used for producing graphical outputs. Several software packages with graphical-user interface that is simple to use have been developed to support this type of modeling and simulation. The most popular ones on the market and in academia are Dynamo, IThink/Stella, PowerSim, and Vensim .

2.2 Discrete Event Simulation

DES models a system as a set of entities being processed and evolving with time according to the availability of resources and the triggering of events. Unlike SD, it makes possible the analysis of the system dynamics and not just the average behavior of the system under observation. The system variables with this approach change instantaneously at the certain points in time. Randomness is involved into most DES models.

Traditionally manufacturing plants, inventory systems, communication and transportation networks, as well as many other systems are modeled using DES. Their performance is usually measured in terms of delays, buffer occupancy, throughput, and resource utilization [7]. Delay denotes time spent waiting for resources, buffer occupancy is represented by the number of entities waiting for resources, throughput is expressed through the number of elements that go through the system per time unit, and the percentage of time the resources are busy relative to the total time is referred to as resource utilization.

Discrete-event simulation is today widely used for decision support in manufacturing (batch and process industries) and service businesses that work with queues. Originally formulated to study problems in telephony, queuing models have been also implemented for studying sequencing of all kinds of jobs to be serviced and the scheduling of resources to perform services. Most queuing systems can be either open-loop or closed-loop systems. Queuing theory is a mathematical discipline to analyze both types of systems and solve them analytically.

Software used to develop models using the discrete event paradigm can be divided into three categories [8]. The first are the general-purpose programming languages, such as C and Java. The second includes classical simulation languages like GPSS/H, SIMAN V, SLAM II. All software packages with graphical user interface belong to the third category. Some of these simulation environments have built in a simulation language and some are equipped with graphical easy to use tools. Many are especially developed to support DES for developing models in a particular application area. There are software packages of both types; open source and proprietary like for example SimPy, Arena, AutoMod, WITNESS, and many others.

2.3 Agent-based Simulation

Social system models usually consist of networks of interacting entities and exhibit aggregate behavior that emerges from individual activities. Mathematical modeling has had little success for studying these kinds of systems. Expressing laws that regulate these phenomena is either very difficult or not possible. Hence, a new paradigm for modeling and simulation was needed. ABS or MABS is a novel approach to modeling systems that promises to have some distinct advantages over the other two methods. The system is modeled as a collection of autonomous decision-making entities called agents that can learn and adapt to the environment. The structure emerges at micro level as the result of actions of agents and their interactions with other agents and the environment [9]. Most agent-based environments are time driven with simulation time being advanced in constant time steps. Agents are scheduled to execute their autonomous actions in each time steps. More sophisticated attributes may be associated with the agents, such as desires, beliefs, intentions, space where they live, as well as learning abilities. Possible application fields for this modeling approach are social and political sciences, and the economics or ecology.

Depending on the area of application, ABS modeling tools are very diverse [10]. Modelers with a strong programming background usually prefer to use agent-oriented high level programming language that provides them with a possibility to code parts of their conceptual models for which support libraries do not exist. Those without such background implement some of the GUI-based languages. An agent-oriented visual language hides computational complexity to the modelers and facilitates building conceptual models using simulation toolkits. They actually directly program their system through simulation support libraries hidden behind the graphical tools. Some popular languages for ABS are NetLogo, Mason, Repast, and Swarm.

3 The First Modeling and Simulation Course

3.1 Impediments

Teaching any of the three simulation techniques to undergraduate students who have little or no background in pre-calculus mathematics, statistics or operation research may seem to be a daunting task. System dynamics requires understanding numerical methods for solving differential equations. The DES method presumes strong foundations in the areas of statistical analysis, stochastic modeling and system analysis, [11]. In addition modeling queuing systems require some background from queuing theory. Being a novelty, the agent based modeling is seldom taught as a first modeling technique. It often requires good programming skills and deep knowledge of the system modeled.

Choosing any of the three simulation methods would require selection of the appropriate software package to be applied in implementing the knowledge gained into solving practical problems. It should be easy to use and at the same time have a functionality that helps model real world problems. This is necessary in order to motivate the learners and raise their interest in the subject. When the course is taught in ten weeks students have problem grappling the terminology and concepts associated with the modeling paradigm taught, as well as learning how to use the new tool. Hence, picking a simple, yet powerful tool is crucial.

3.2 AnyLogic – Three Paradigms Simulation Tool

AnyLogic is developed by XJ Technologies in 2007, [12]. It is based on Java and Eclipse platform. The package has gone through several improvements and the current version is 6.5. The multi-paradigm approach brings together SD, DES and ABS within a single modeling language and development environment. It supports SD stock-and-flow diagrams in the same way as the specialized SD tools. The latest version also provides a possibility for importing models created with Vensim. Enterprise library is a component for creating discrete-event models using drag-and-drop blocks. It has a default animation for every block with the users being able to create their own 2D or 3D animations which allow parameters to be managed during the run time. AnyLogic provides a visual language that significantly simplifies development of agent based models. Users without strong knowledge of Java can use UML state-charts to define agent behaviors and action charts do define algorithms.

The existence of this multi-paradigm software package with simple yet powerful graphical tools offers incentive to include all three modeling and simulation paradigms into a single introductory course. Its main objective should be to develop skills for critical thinking and problem solving, introduce terminology, key concepts for all three paradigms, as well as provide opportunity for practical experience with real life situations.

4 Two Years of Experience

4.1 The First Year

The first attempt to introduce modeling and simulation into the curriculum of undergraduate studies was through designing two separate courses. The idea with the first one was to build the understanding of the relationship between mental and simulation models through system dynamics approach. Educational version of Vensim software [13] was the main vehicle for experimenting with SD models. The second course was supposed to follow immediately after, and the prerequisite for taking it was the system dynamics module. University edition of AnyLogic was used to deepen the insight in system dynamics and start with discrete event and agent based simulation.

The courses are elective for the students in the second year. The idea behind this strategy was to motivate individuals interested in modeling and simulation to take both of them; hence, the names System Analysis 1, and 2. The first course was offered in the fall, while the second in the spring semester.

The short description given to the students and the guest lecturers from environments where simulation of social systems intended to attract a large number of listeners for the first course. The curriculum was based on the similar open courseware offered online by MIT. Four real life problems were designed for the students and assigned to different groups as a collaborative work. We witnessed many different solutions for each of these four problems during the seminars at the end of the course. The main obstacle for the advanced learners was the old-fashioned interface of Vensim and the PLE version that is pretty closed and do not offer possibility of inserting code when necessary. Those with less background in programming complained about the discrepancy in the difficulty of the group work when compared with individual assignments.

55 out of 69, or about 80% of the students passed the course. 33 of them, or 60%, took the second course and only 14 fulfilled the requirements to complete it. The analysis of the results showed that the interest of the students has fallen down during the second course despite (1) using much more sophisticated software tool, and (2) having all three modeling paradigms.

Action research approach, [14] was instrumental to introduce changes, implement the, and evaluate the results. After long brainstorming the conclusion was to change the strategy regarding the prerequisites.

4.2 The Second Year

The new strategy was to offer both courses again without the first one being prerequisite for the second. Because of the continuity the name of the first course was kept, while the second was renamed into Modeling and Simulation.

The same hands-on-experience pedagogy was used this year to help students become comfortable in using the simulation software for creating different kinds of models, investigating various scenarios, collecting input data, and presenting the outputs in a multitude of forms. They learned how to formulate a problem, create conceptual model of the system under observation, design and perform experiments, implement sensitivity analysis, and finally interpret the results obtained. In addition, during the second course they could distinguish among the three different methods for simulation and choose the appropriate technique for a particular problem.

This year the popularity of the first course was lower. Only 44 students decided to take it, despite having the same enrollement as in the previous year. There were 23 or slightly over 50% who were actively involved and completed the requirements for getting the final grade. Almost 70% of them (16 students) who passed the first course continued with the Modeling and Simulation course. In addition 6 more students who were enrolled, but did not finished the first course decided to take the second course. Besides these 22 students having some idea about modeling, there were 14 more who took the course with no experience with any kind of simulation tools. Except with the first part dedicated to modeling with System Dynamics, where the first group had slight advantage, there was no difference in the progress they made throughout the course.

The curriculum for the Modeling and Simulation course consisted of four modules, the introduction and one for each modeling method. Students were getting enough practice with each type of simulation during individual assignments. In the final project they collaborated to analyze the system, choose appropriate modeling approach, create the model, make experiments and "what if" analysis and perform presentation and validation.

AnyLogic's visual environment and some experience in Java programming accelerated the process for developing models with any of the three paradigms. Possibility to use external libraries and write custom code provided limitless extensibility for experienced programmers. On the other hand, the extensive statistical distribution functions built in the software for simulating the uncertainty inherent in DES were of great help for the students to overcome the lack of background in probability and statistics. The animation features built into the tool served as motivation for creating visually rich and interactive simulation environments. Automatic applet creation allowed students to quickly build simulations and place them on a website.

The aim with the grading policy was to motivate students to work regularly throughout the course. The final exam contributed to the grade with 46% and practical work 54%, with the accent placed on the final assignment (37% for the individual ones and 54% for the group work). All three parts were compulsory for the passing grade. At the end of the course we had 23 students who completed the course, 6 from the group who had no experience with any tool before and 17 from the other group. 16 of them were the students who passed the first course.

Sometimes, the number of students who pass the course does not show the true success. In this case, the grades may show the real interest in the subject and the capability to master it. For instance, we had 8 students with highest grades (A or B), half being from the group with some experience in modeling and the other half from the other one.

4.3 Lessons Learned

The numbers of enrolled students and students who completed the courses in both school years are presented on Figure 1. Note that for 2008/09 the students in System Analysis 2 course are a part of those presented for System Analysis 1 course. This is not the case for courses System Analysis and Modeling and Simulation for the 2009/10 school year.

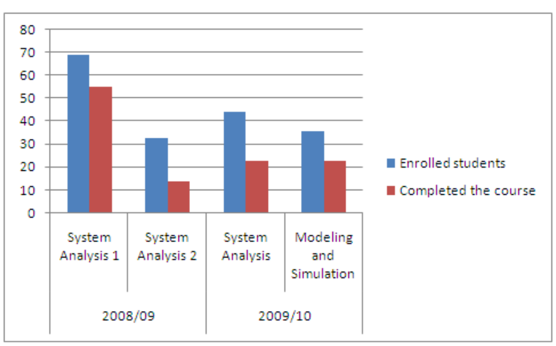

Figure 1: Number of students enrolled and completing courses in the two occasions

The comparison regarding the number of students trained in modeling is shown on Figure 2. The chart is showing the number of students who finished a particular course normalized to the total number of those who showed interest in taking courses. For the school year 2008/09 the number of students enrolled in the first course is used for normalization (69). In the next year, the number for normalization is the sum of students enrolled in the first course and those that were enrolled in the next one having no experience with modeling (44+14). 3P is the acronym for 3 modeling paradigms.

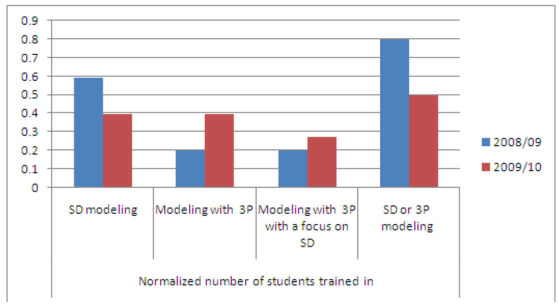

Figure 2: Normalized number of students trained in both school years

Finally, Figure 3 shows the pie chart for the students with highest grades in the Modeling and Simulation course.

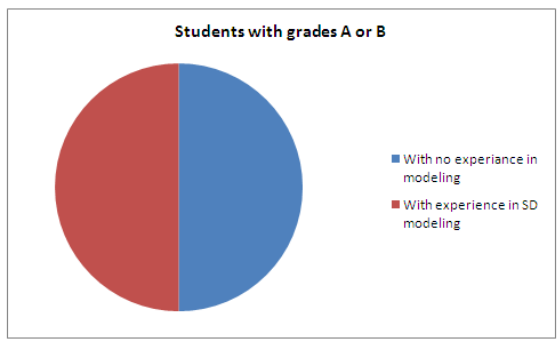

Figure 3: Distribution between students with highest grades in Modeling and Simulation course

After the analysis of the outcomes presented on the three graphs the following observations were made:

- The interest in students finishing the course that covers three modeling techniques is bigger in the second year.
- The experience with SD does not contribute significantly towards having advantage when grappling the three modeling paradigms.
- Larger number of students gets an overview of the existing approaches for modeling and simulation.
- There is no significant difference in the achievements of the students in both groups especially for those with highest grades.

Our main concern is to validate the positive results obtained with the new strategy in the years to come. The plan is to continue with the same courses and introduce some modifications to accommodate different learning styles of the learners. The step-by-step advancement of the criteria for completing all tasks and raising the expectations for the student work are among the few additional objectives to be achieved. The preparation phase for the next cycle of the action research should define precisely the development goals for the next cycle.

5 Conclusion

Modeling and simulation techniques are not always easy to understand and implement by individuals who have no previous training or background in the appropriate mathematical disciplines. Hence, it might seem almost impossible to successfully introduce the three main paradigms, SD, DES, and ABS to undergraduates in their starting years of college. The trepidations are usually associated with the overwhelming amount of new terms and concepts and lack of time. The study presented points out that carefully planned curriculum together with user-friendly software can help overcome most of the difficulties encountered by the learners and help teachers inspire and motivate their students for enhancement of their skills either through further education or via practical work.

The first cycle of the action research showed clear improvements with respect to the strategy implemented. In the next several years, we expect further validation of this pedagogical approach and even larger acceptance by the students within various study disciplines.

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