ANALYTICAL REVIEW AND THE ANALYSIS OF EDUCATIONAL PROGRAMS WITH COMPUTER MODELLING AND SIMULATION ENGINEERING CONTENT

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ABSTRACT

The paper deals with outcomes of a working package in the InMotion ERASMUS+ project, in which European partners should help to establish improved programs with modelling and simulation content in Malaysia and Russian Federation. By the aid of a survey sent to partner universities and worldwide, the analytical review and the analysis of educational programs with computer modelling and simulation engineering content was done. The answers were analysed for bachelor, master and PhD programs with regard to the basic information (duration, contact hours and individual work, final work, practical orientation of the study and elective courses), with regard to curricula and competencies. The final part is devoted to the investigation whether there are some bachelor, master and PhD programs that are completely in the area of modelling and simulation. We were able to find only one example of such institution in US.

Keywords: education, curriculum, syllabus, computer modelling and simulation engineering

1. INTRODUCTION

Most of engineering higher education programs have Computer Modelling and Simulation Engineering (CMSE) content as important part inside several courses. InMotion (Innovative teaching and learning strategies in open modelling and simulation environment for student-centered engineering education) (Inmotion, 2017) is an ERASMUS+ project under Key Action 2 – Capacity Building in the field of higher education (EACEA, 2017) with the general aim to continue the reform of the system of engineering higher education in in partner countries (PC) Malaysia (MY) and Russian Federation (RU), to improve quality of education and teaching according to the priorities established in the Bucharest (Bucharest, 2012) and Yerevan Communiqués (Yerevan, 2015), and to meet the demands of Strategic Framework for European Cooperation in Education and Training (European Commission/EACEA/Eurydice, 2013). This has to be done by the aid of European partners (EU universities): University Bremen (UniHB), National Distance Education University, Madrid (UNED) and University of Ljubljana (UL).

The following aims were defined:

- to improve the level of competences and skills in CMSE by developing new and innovative education approaches and learning modules,
- to provide relevant learning activities in appropriate contexts for different types of learners, including lifelong learning,
- to ensure a quality higher education system in CMSE and enhance its relevance for the labour market and society,
- to promote a European dimension in higher education for the modernisation, accessibility and internationalisation of the higher education in CMSE in MY and RU and
- to contribute to the cooperation between the EU and PC universities.

The main objectives are:

- Updated Curricula in CMSE with new Syllabi and educational content as fundamental educational program for three level educational model and development of guidelines for Long Life Learning (LLL).
- Development of a common approach for student-centred learning in the use of modern computer simulation packages and tools for solving innovative engineering problems for various application areas.
- Introduction of eScience approach and research-based learning; development of eLearning modules based on innovative teaching strategies and creative learning approaches using workflow modelling tools and blended learning approaches based on the best information-communication technologies (ICT).
- Elaboration and implementation of Open Modelling and Simulation Environment platform (OMSE), and Massive Open Online Courses of the new generation (MOOC) for qualitative improvement of the engineering education process and academic workflow

support among universities and stakeholders across the PC and EU Member States.

When implemented it is supposed the project will change the situation in the following ways:

- Student-centred learning will make the educational process more flexible and more efficient by the choice of the desired studying areas.
- Graduates from MY and RU universities will obtain appropriate competences from the CMSE field.
- With OMSE a new paradigm with respect to integration, harmonization and aggregation of various types of quality-controlled eLearning components derived from internationally operated learning and research facilities will be created.
- The stakeholders will get access to the MOOCs for the LLL training of their professionals.
- Prospectively, other faculties of partner universities and universities outside the consortium may adopt the learning environment (OMSE) and use it for the teaching.

As much as possible the results from a previous TEMPUS project eMaris will be used (Wishnewsky et al., 2013, Gordeeva et al., 2014).

The focus of this paper is one working package - WP1.2, with the goal to make an analytical review of educational programs with CMSE content in EU and PC universities. The analysis should include bachelor, master and PhD level. The results will be used as a basis for new or updated curricula and Syllabi with CMSE content. University of Ljubljana, Faculty of Electrical Engineering (UL) was responsible for this action and for the report.

2. INITIAL ACTIVITIES

The first idea was to collect the current curricula and syllabi of all project partners. However some beginning activities showed that the huge volume of materials would be collected in quite different forms, so it would be later very difficult to extract any usable information. After some meetings within UL group and with some consultations with our partners, we decided to develop a survey with which each partner would be forced to develop a document which already analyses their programs in a way that synthetical results can efficiently be used for further developments in working package WP1 and further. So we decided to collect surveys for the programs, which have most modelling and simulation courses, but simultaneously also to collect curricula. All materials should be in English. One program means one survey. We expected from each partner several surveys, if possible for bachelor, master and PhD cycle.

Although the emphasis was given to CMSE it was rather clear that there are at least according to our knowledge no CMSE programs. We have in mind more general engineering programs, which hopefully contain several CMSE courses (e.g. electrical, computer, mechanical engineering …).

Simultaneously we also asked partners to send curricula.

3. SURVEY

3.1. Description of the survey

The first part of the survey collects general program information: institution, name of the program, duration, number of credit points (CP), information about the actual amount of 1 CP load for a student, the number of contact hours (CH), the number of hours of individual work (IW), then the information in CP for final work (diploma), practical work, and at the end the total amount of CP of compulsory and elective courses. Of course we did not know the situation in Russia and Malaysia with regard to the credit system. Therefore we explained in the instructions the European credit system and asked partners to recalculate their own credits into European in order to be able to better and easier compare programs.

The remaining part of the survey is more dedicated to the CMSE area. It consists of PART I and PART II.

In PART 1 we analyse the curriculum with regard to CMSE: three types of courses should be listed:

- Basic courses in engineering programs without direct CMSE contents but very important (essential) for CMSE (e.g. Mathematics).
- Courses, which parts are also important parts of CMSE courses (e.g. Numerical methods).
- Pure CMSE courses (e.g. Continuous systems modelling and simulation).

In this part the survey asks for syllabus outline. We wanted that important topics mostly from all (pure) CMSE courses are itemised. This means that the syllabi of several courses should be analysed and more important items included. The survey asks also for proposals for additional topics in case of reforms, possibilities for new courses, … and for some interesting CMSE applications.

PART II was included at the request of a Russian partner and deals with competencies. We ask to indicate three types of competencies:

- General (general outcomes that students must obtain in higher education programs, e.g. critical thinking on the basis of analysis and synthesis, …)
- Professional-general (these are competencies related to the particular engineering program, e.g. optimal use of ICT.
- Professional-specific (these are competencies devoted to modelling and simulation in

engineering programs, e.g. experimental modelling, …).

The PART II is followed by formation of competencies distribution. Namely we ask for the numbers of courses (among the listed ones) that give three types of competencies. We expected that basic engineering courses give mostly general competencies, the courses with CMSE content more professional-general competencies, and the pure CMSE courses mostly professional specific competencies. So we expected to obtain a matrix with bigger numbers at the diagonal.

The survey is concluded with appropriate web links, where more information about the programs can be found.

A detailed instructions for survey completion were also included.

3.2. Distribution of the survey

The survey was sent to 10 EU and PC partners. As we wanted to obtain more results we sent the survey also to 19 other European partners who do not participate in the project. We did not obtain responses from eight partners. All partners with appropriate acronyms, which are later used in the analysis, are presented in Table 1.

Table1: All partners to which the survey was sent.

	Partners in the project – EU and PC	**Country**	**Acronym**
1	University of Bremen	Germany	UniHB
2	St.Petersburg State Marine Technical University	Russia	SMTU
3	St.Petersburg State Politechnical University	Russia	SPBPU
4	Novosibirsk State Technical University	Russia	NSTU
5	Universiti Kuala Lumpur	Malaysia	UniKL
6	Universiti Teknologi Malaysia	Malaysia	UTM
7	Universidad Nacional de Educacion Adistancia (The National Distance Education University)	Spain	UNED
8	University of Ljubljana	Slovenia	UL
9	St. Petersburg Institute for Information of RAS	Russia	SPIIRAS
10	Universiti Teknologi PETRONAS	Malaysia	UTP
	Other universities which responded		
1	University of Ljubljana, FRI	Slovenia	UL FRI
2	Amsterdam University of Applied Sciences	Netherland	AUAS
3	Faculty of Information Studies in Novo mesto	Slovenia	FIS
4	Technical University Riga	Latvia	TUR
5	University of Maribor	Slovenia	UM
6	Wismar University of Applied Sciences	Germany	WU-M
7	University of Glasgow	Scotland	UG
8	Politecnico di Milano	Italy	PoliMi
9	Vienna University of Technology	Austria	TUW
10	University of La Rioja	Spain	UR
11	University of Zagreb	Croatia	UZG

3.3. Reception of surveys and curricula

From project partners we obtained surveys for 10 bachelor studies, for 7 master studies and for 4 PhD studies (Zupančič et. all. 2016, see Table I). From other European institutions we obtained surveys for 8 bachelor programs, 7 master programs and 1 PhD program. All together 37 surveys were completed.
From project partners we obtained curricula for 7 bachelor studies, for 5 master studies and for 4 PhD studies. We did not collect curricula from other European partners.

4. ANALYTICAL REVIEW

4.1. General program information

It is well known that European credit system specifies 25-30 hours (usually 25) of student work (CH+IW) for 1 CP. 1 semester has 30 CP. So 3 years program has 180 CP and 4 years program 240 CP. 1 semester normally contains 15 weeks. According to Slovenian rules the number of CH/week must be between 20 and 30. Russian system also operates with CP, which are even entitled ECTS. However 1 CP means 36 working hours. The max. no. of CH/week is 32. As one semester contains 17 weeks, it results in much higher number of contact hours in the program. In Malaysian system the credit system is also used. However they operate with 1 CP_{Mal}=40 hours of student work. As 4 years programs have app. 140 CP_{Mal}, then 1 semester means 17.5 CP_{Mal}. To compare programs more easily we asked partners for appropriate recalculations to European system. It seems that hours for 1 CP_{Mal} should be divided by 1.6 and Malaysian credits for courses and programs must be multiplied with 1.6 to obtain European credits.

4.1.1. Analysis of general information for bachelor programs

General program information is analysed in Zupančič et. al. 2016, see Table II.

Duration

The duration in Europe is usually 3 years (180 CP), sometimes 4 years (240 CP). In Russia and Malaysia all programs have 4 years (240 CP).

Contact hours and individual work

It was already commented that Russian programs have much more contact hours. The ratio CH/IW is very different: from 0.37 for UNED (what can be explained as this is an e-learning institution), app. 0.8 for Russian universities (2.6 for SPbPU is probably a misunderstanding) and 0.6-1 for EU universities.

Final work
The final work, which includes preparation, thesis, defence … has usually 5-15 CP with some exceptions (AUAS 30 CP, UL 0 CP). The difference between EU and PC partners is not observed.

Practical orientation of the study
It is very important for engineering studies to have a strong practical component. Therefore we introduced two questions in the survey: practical work, which includes lab. exercises, seminars, tutorials, … and practical work, which includes field internship (typically in industry). The percentage ratio between the sum of these two data and the CP of the program shows the value from 24% (UM) to 65% (UniKL).

Elective courses
Traditional European programs were based on compulsory units. Bologna reform required more elective courses. The percentage of elective CP against program CP shows for most programs the value 10-20%. According to Slovenian rules the minimal value is 10% (5 % of professional courses, 5% of general courses, also from any other institutions).

Although the instructions clearly explained that elective courses must be counted from a student point of view (i.e. how many can a student select) some partners included the sum of all elective courses credits.

4.1.2. Analysis of general information for master programs

General program information is analysed in Zupančič et. al. 2016, see Table III.

Duration
The duration is in most cases 2 years (120 CP). There are also shorter programs: UNED (Spain) with 2 e-learning programs - 1 and 1.5 years, WU-EM (Wismar) and UG (Glasgow) 1 year. UG (Glasgow) has also one integrated master program with duration of 5 years. The number of CP sometimes differs from expected values, as some 2 year programs are actually 3 semester programs and some programs have more intensive teaching – also the work during vacation period.

Contact hours and individual work
The ratio CH/IW is very different: from 0.2 for SPbPU to 0.9 for UG. Typical value is app. 0.5.

Final work
Final work which, includes preparation, thesis, defence … has very different amount of CP: from 6 CP (on SPbPU) to 30 CP (on UNIHB, GU, UL). In general the number of CP is higher compared to the bachelor level.

Practical orientation of the study
The percentage ratio between the sum of the practical work, which includes lab. exercises, seminars, tutorials, … and practical work, which includes field internship (typically in industry) and the CP of the program shows the value between 20% (UL, PoliMi) and 70% (SPbPU, NSTU, UNED1, UR).

Elective courses
The percentage of elective CP against program CP shows for most studies the value 10-80%. Typical value is app. 30%, which is more than on the bachelor level.

4.1.3. Analysis of general information for PhD programs

Unfortunately we received only 5 surveys for PhD programs (SMTU, NSTU, UL, SPIIRAS, UR). Although most institutions, which were included into investigation, answered that they have PhD programs but as there are no CMSE courses, they did not complete the survey. General program information is analysed in Zupančič et al. 2016, see Table IV.

Duration
The duration is in two European programs and SPIIRAS 3 years (as proposed by Bologna rules) and in two Russian programs (SMTU, NSTU) 4 years.

Contact hours and individual work
Of course in all programs there are much more individual (research) work as contact hours. The ratio CH/IW is 0.03-0.09.

Final work
Final work which includes preparation, thesis, defence … has on SMTU and NSTU 9 CP, on UL 30 CP and on SPIIRAS 4 CP.

Practical orientation of the study
The percentage ratio between the sum of the practical work, which includes lab. exercises, seminars, tutorials, … and practical work, which includes field internship (typically in industry) and the CP of the program shows the value between 3% (SMTU) and 8% (NSTU, SPIIRAS). Such small numbers are expected due to the fact that PhD study is based mainly on individual research work.

Elective courses
The percentage of elective CP against program CP shows for most studies the value 3-8%. This is also expected as the majority of CP is devoted to individual research work.

4.2. PART I. Analysis of the curriculum with regard to CMSE

In this part we collected three types of courses: basic courses in engineering programs without direct CMSE contents but very important (essential) for CMSE, courses, which parts are also important parts of CMSE courses and pure CMSE courses (see Section 3.1.). We collected the titles of courses, appropriate CP, CH and IW and the information whether courses are compulsory or elective. Later we learnt that according to educational standard (named 3+) there are even more categories in Russia:

- compulsory basic - units, that are obligatory to take place in the curriculum,
- compulsory variable - units a department should choose from some certain quantity and include them in the curriculum; all practices (after the 1, 2, 3 years),
- elective - units a student should choose from some certain quantity and include them in his own individual educational plan,
- facultative – units, a student may additionally choose; such disciplines are not marked in CP.

The analysis shows, how much a particular program is oriented into modelling and simulation. As expected usually engineering programs have only few courses, which can be treated as pure CMSE courses.

As partners completed this part with very different understanding, the results are rather questionable. It appeared that there are very different interpretations about the particular course types.

4.2.1. Analysis of bachelor programs
The results are analysed by Zupančič et al. 2016, Table V. We see that programs have 0-4 pure CMSE courses with 0-11 CP. In average there are 2-3 courses with app. 10 CP. There is no big difference between EU, Russian and Malaysian programs.

4.2.2. Analysis of master programs
The results are analysed by Zupančič et al. 2016, Table VI. We see that programs have 0-6 pure CMSE courses with 0-30 CP. In average there are 3 courses with app. 18 CP. There is no big difference between EU and Russian programs. UTM as the only Malaysian representative declared only 1 course with 5 CP.

4.2.3. Analysis of PhD programs
The results are analysed by Zupančič et al. 2016, Table VII. In this part the analysis is difficult as there are only 5 surveys. We see that programs have 0-2 pure CMSE courses with 0-20 CP. It seems that Russian partners have more CMSE contents as European partners. NSTU declared 2 courses with 21 CP. SMTU has even Mathematical modelling included in the name of the specialisation within the PhD program, but actually only 1 pure CMSE course with 5 CP.

4.3. Syllabus outline
As mentioned we asked partners and others to write in itemised form the most important topics, which are in their opinion typical for modelling and simulation. We expected that this items are mostly from pure CMSE courses, but can be also from other courses. The completed surveys show, that the thinking, what is actually important for modelling and simulation is very different. Some partners listed contents that are in our understanding important but not in the real focus of CMSE. Some surveys were in this part empty. We understand that such partners meant that they do not have real CMSE contents in the program.

The survey asked also for proposals for additional topics in case of future program updates or reforms.

Based on all the responses we made a selection of more important items for the current situation and for the future plans separately for bachelor, master and PhD level. As the programs are very different one can find same contents on different cycles.

Syllabus outline for bachelor programs
Current status

– Conventional mathematical modelling of dynamical systems.
– Theoretical, experimental and combined modelling.
– Simulation methods: from differential equations, transfer functions, state space description to simulation program.
– Multi-components models.
– Unified and universal modelling.
– Object-Oriented modelling.
– Tools: UML, Matlab, Simulink, Stateflow, Modelica, Maple, Mathematica, Rand Model Designer.
– Simulation with general purpose programming languages.
– Models based on partial differential equations.
– Numerical methods and problems: integration methods, numerical stability, the problem of discontinuities, the problem of algebraic loops.
– Analysis of simulation results.
– Experiment design and optimization.
– Verification and Validation.
– Experimental modelling – Identification.
– Finite element methods.
– Modelling and simulation of discrete-event systems (DEVS).
– Tools for DEVS: Matlab, SimEvents, Enterprise Dynamics, AnyLogic.
– Petri nets, coloured Petri nets.
– Agent-based modelling.
– Analysis of bottlenecks.
– Modelling, simulation and optimization of production systems.
– Monitoring and supervision of processes units.
– Logistics: Ports, airports, shopping centres...

- Operational Research.
- Queuing theory.
- Monte Carlo method.
- Probabilistic models, modelling of random inputs.
- Hybrid systems.

Future plans
- Numerical libraries.
- Planning and carrying out computer experiments.
- Real time, hardware in the loop simulation.
- Visualisation and animation.
- Artificial intelligence in modelling and simulation.
- Virtual-reality based simulation.
- Simulation of complex and distributed control systems.
- Modelling and simulation of hybrid systems.
- Agent-based modelling.
- Web and cloud computing based simulation.
- Industry 4.0 in modelling and simulation.

Syllabus outline for master programs
Current status
- Simulation of complex systems (discontinuous, variable structure, …).
- Hybrid systems. Event detection, software tools.
- Component models (variable structure, agent based modelling).
- Model simplification.
- Bond graphs.
- Evolutionary computation for modelling and simulation.
- Modelling and simulation with PDE.
- Dynamical model parameter estimation.
- Identification of non-parametric models.
- Multivariable and non-linear system identification.
- Paradigm of physical modelling.
- Object oriented modelling. Modelica. Rand designer.
- Computational causality. Overdetermined and underdetermined systems. DAE index. Index reduction. System initialization. Algebraic loops. Symbolic manipulations. Tearing.
- Finite automata and state charts.
- Modelling with partial differential equations. Initial and boundary conditions. Numerical methods for solving PDE.
- Fundamentals of solving partial differential equations using finite element method.
- Real time simulation, hardware in the loop, software in the loop, rapid prototyping.
- Discrete-event models, cellular automata, agent-based models.
- The basics of cellular automata and Monte Carlo methods.

Future plans
- The supply chain modelling.
- Parallel computing.
- Planning and carrying out computer experiments.
- Real time simulation.
- Web-based simulation.
- Co-simulation.
- Modelling with partial differential equations.
- Virtual reality based simulation.
- Integrated marine logistics optimization.
- Multi-body systems.
- Visual analysis and animation.

Syllabus outline for PhD programs
Current status
- Hybrid systems: discontinuous, variable structure, events and accurate detection, stiff systems, numerical integration methods.
- Hybrid automata. State diagrams. Block diagrams. Block-textual diagrams.
- Software for modelling and simulation of hybrid systems.
- Graphical modelling languages and visual computer models. Formal languages. Syntactic and semantic analysis.

Future plans
- Multi-agent models. Use of software for developing and analysis of agent-based models.
- Hybrid system simulation.
- Visual interactive simulation.

4.4. PART II. Competencies

As already mentioned, we introduced this part in the survey at the request of a Russian partner. It is still not clear whether the future analysis of this part can give some practical results. Many partners were unsatisfied to complete this part as they did not feel competent for it. This was also the reason why some surveys were not sent back or were empty in this part. The fact is that proper fulfilment of this part is complicated and time consuming.

Some countries (also Russia) have special catalogues for all types of competencies and then it is easier to fill out appropriate data. However in other countries they do not use catalogues and then one has to invent many answers, which are than quite different and cannot be compared. But it is clear that one should fill out this part from accredited program. Unfortunately competencies of accredited programs usually (at least in Ljubljana) do not include modelling and simulation items. These items can be found only in a document, which precisely specify the competencies and outcomes of particular courses. So some partners developed huge lists of competencies which are usually rather self-understanding but still very difficult for comparisons.

We know that we should develop programs starting with competencies. This is a systematic approach. However we do not plan to build new programs but to upgrade the existing ones. So we do not need to think about some general competencies but about very specific ones for the CMSE area. Going through all surveys we can find a useful information.

To conclude, many surveys came back also with competencies distribution table fulfilled. What we expected that basic engineering courses give mostly general competencies, the courses with CMSE content more professional-general competencies, and the pure CMSE courses mostly professional specific competencies, was proved.

5. OTHER MODELLING AND SIMULATION PROGRAMS

As mentioned several times all engineering programs have usually a small amount of modelling and simulation content. It would be really interesting to make an investigation whether there are some bachelor, master and PhD programs that are completely in the area of modelling and simulation. We found an example on Old Dominion University in Norfolk, US (Old Dominion University, 2017) which offers an undergraduate four-year degree program leading to the Bachelor of Science in Modelling and Simulation Engineering. The department also offers programs of graduate study leading to the degrees Master of Engineering, Master of Science, Doctor of Engineering, and Doctor of Philosophy with a major in Modelling and Simulation.
The institution offers many small courses usually for 3 CP. Details can be found on the WEB page
http://catalog.odu.edu/courses/msim/
This is the list with some courses titles:

- Introduction to Modeling and Simulation Engineering.
- Discrete Event Simulation.
- Continuous Simulation.
- Simulation Software Design.
- Continuous Simulation Laboratory.
- Simulation Software Design Laboratory.
- Topics in Modeling and Simulation Engineering.
- Introduction to Distributed Simulation.
- Introduction to Game Development.
- Secure and Trusted Operating Systems.
- Computer Graphics and Visualization.
- Introduction to Medical Image Analysis.
- Design and Modelling of Autonomous Robotic Systems.
- Introduction to Game Development.
- Machine Learning.
- Optimization Methods.
- Finite Element Analysis.
- High Performance Computing and Simulations.
- Cluster Parallel Computing.
- Advanced Analysis for Modelling and Simulation.
- Modelling Global Events.
- Computational Methods for Transportation Systems.
- Internship.
- Practicum.
- Doctor of Engineering Project.

6. CONCLUSION

In the report we briefly summarize some important facts, which were obtained from the surveys. We are aware that some results and comparisons are questionable also due to some misunderstandings, which also occur due to time limitations all partners had for completing surveys.

More information can be found in the surveys (Zupančič et al. 2016 – Appendix). The surveys are divided into classes for bachelor, master and PhD programs. In each class there are surveys of partner institutions (all partners in the project) and of other European universities.

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