

A Project-Orientated Training Concept to Prepare Students for Systems Engineering Activities

Elke Mackensen

Abstract—Systems Engineering plays a key role during industrial product development of complex technical systems. The need for systems engineers in industry is growing. But there is a gap between the industrial need and the academic education. Normally the academic education is focused on the domain specific design, implementation and testing of technical systems. Necessary systems engineering expertise like knowledge about requirements analysis, product cost estimation, management or social skills are poorly taught. Thus there is the need of new academic concepts for teaching systems engineering skills. This paper presents a project-orientated training concept to prepare students from different technical degree programs for systems engineering activities. The training concept has been initially implemented and applied in the industrial engineering master program of the University of Applied Sciences Offenburg.

Keywords—Educational systems engineering training, requirements analysis, system modelling, SysML.

I. INTRODUCTION

TODAY many technical systems are characterized by a high complexity and a very large scale integration of electronic, mechanical and information-processing subsystems and components. There are many challenging constraints during the development of such technical systems: fast technology changes, ever shorter product lifecycles and development times and increasing customer expectations towards performance, quality and price. The development and operation of such complex systems requires a highly interdisciplinary knowledge in different engineering domains, but also in other domains like management, social or human domains. Systems Engineering is an engineering discipline which gives an answer to the question how to develop and operate such complex technical systems [1], [2]. Many related definitions about Systems Engineering can be found. INCOSE (International Council on Systems Engineering) defines Systems Engineering as “an interdisciplinary approach and a means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem.” [3]. Another good characterization of Systems Engineering is given by the NASA (National Aeronautics and Space Administration): “Systems Engineering a robust approach to the design, creation, and operation of systems. In simple terms, the

Elke Mackensen is a professor in the Department of Electrical Engineering and Information Technology at the University of Applied Sciences in Offenburg, Badstraße. 24, 777652 Offenburg, Germany (phone: 0049 781 205 4770; e-mail: elke.mackensen@hs-offenburg.de).

approach consists of identification and quantification of system goals, creation of alternative system design concepts, performance of design trades, selection and implementation of the best design, verification that the design is properly built and integrated, and post-implementation assessment of how well the system meets (or met) the goals.” [4]. Systems Engineering plays a key role during industrial product development. Fig. 1 depicts in summary the necessary expertise for working as a system engineer.

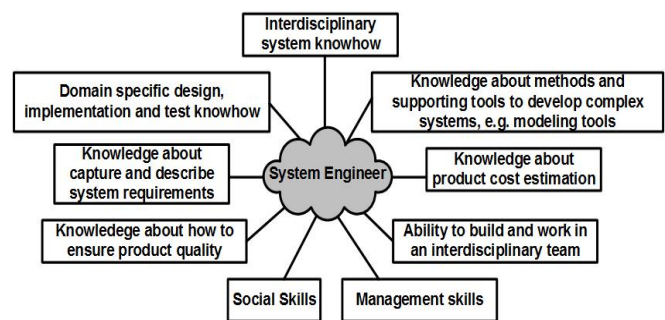


Fig. 1 Necessary expertise for working as a system engineer

The need for systems engineers in industry is growing. But there is a gap between the industrial need and the academic education [5]. Normally the academic education is focused on the domain specific design, implementation and testing of technical systems. All other systems engineering expertise, especially the establishment of superior relationships during a system development are poorly taught. Thus there is the need of new academic concepts for teaching systems engineering skills. This paper presents a project-orientated training concept to prepare students from different technical degree programs for systems engineering activities. The training concept has been initially implemented in the industrial engineering master program of the University of Applied Sciences Offenburg. In Section II of this paper the training concept will be described in detail. Results and further experiences from the applied project-orientated training will be given in Section III. A short conclusion in Section IV completes the paper.

II. DETAILED TRAINING CONCEPT

A. Objectives and Fundamentals of the Training Concept

The concept of the project-orientated systems engineering training has the following objectives:

- The final course must be project oriented. The project shall be similar to an industrial project and it shall be possible, that the students make usage of their existing

domain specific knowhow.

- The project-orientated course shall be transferable to different engineering degree programs.
- Key skills (system requirements analysis, interdisciplinary system design and system verification/validation) according to the INCOSE's systems engineering definition shall be taught and applied.
- The students shall become the knowledge about methods and supporting tools which will be applied during the system development process.
- The students shall learn a system orientated and interdisciplinary way of thinking.
- The students shall understand the system development process which is applied in industry.
- The students shall obtain a better understanding for the other engineering disciplines.
- The students shall learn other important systems engineering skills like management and social skills.

Fig. 2 depicts the fundamental concept and flow of the systems engineering training. The flow of the systems engineering training is based on the industrial system development flow. Over the total training runtime the students shall develop a complex technical system. The yellow colored parts of the flow are mainly processed by the student teams. The white colored parts of the flow are tasks for the lecturer.

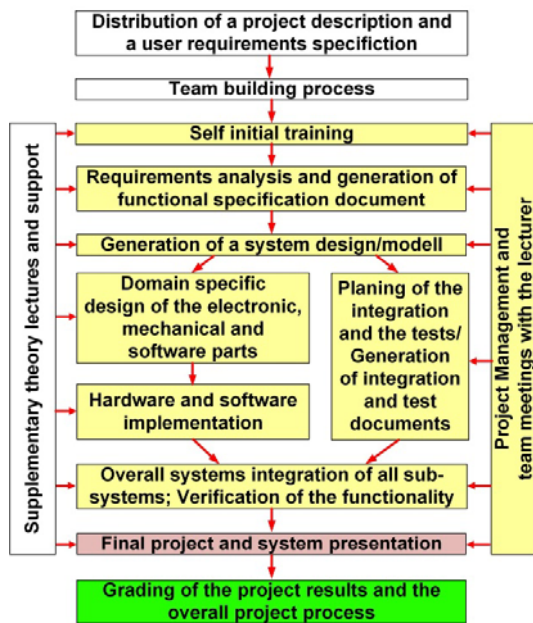


Fig. 2 Concept and flow of the project-orientated systems engineering training

The systems engineering training is designed for students of master degree programs and for a time frame of one semester. A final written examination is not designated. At the end of the training the student teams must deliver the developed system and various types of customized documents (e.g. the functional specification document or a system design document). The project results and especially the overall project process of the student teams will then finally graded by

the lecturer.

B. Content details of the Training Flow

The training is starting by **distributing a detailed project description** to the participating students. The project description encloses a detailed description of the training flow, information about additional teaching materials like software manuals etc. and information about items which must be delivered by students at the end of the training (e.g. the developed system). Furthermore a **user requirements specification** will be distributed to the students. The user requirements specification describes the system which shall be developed by the students. This system contains development tasks of electrical, mechanical and software units.

The development shall be done by a team of students in order that every student can play its individual role in the team. Fig. 3 shows the kind of roles in a student development team. Thus in a next step a **team building process** is performed by the lecturer. The team building process takes place in such a manner that every student will be interviewed by the lecturer. The students must give information about their previous experiences and activities. Due to the information the lecturer can divide the students in teams and can assign every student its particular role in the team. The required role activities will be communicated to each student.

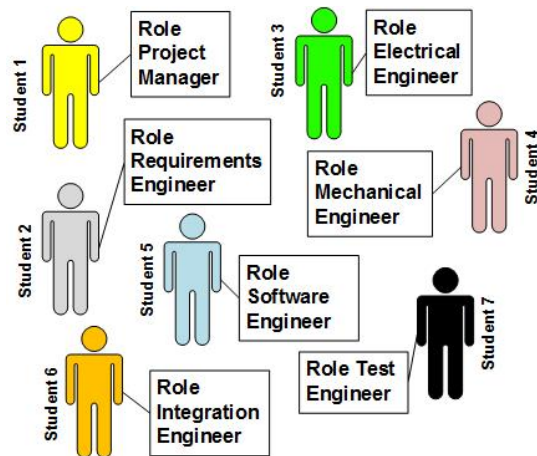


Fig. 3 Kind of roles in a student team for developing a complex system during the training runtime

After team building important **steps of systems engineering process** are following (yellow colored in Fig. 2), especially the requirements analysis, the system design and the verification/validation of the system but also the domain specific subsystem design and the hardware/software implementation.

Parallel to these important systems engineering process steps **supplementary theory will be taught** by the lecturer because most of students do not know

- how to make an requirements analysis and how to write a functional specification,
- how to modelling a system and how to generate a system design,
- how to plan and execute the system integration,

- and how to plan and execute the test (verification/validation) of the system.

Today one important method during the system development process is the modelling of the overall system with SysML (Systems Modeling Language) [6]-[8]. System modelling with SysML is in detail explained and applied during the systems engineering training.

Furthermore during the runtime of the training the **student teams have regular meetings with the lecturer**. In such a meeting the student can exchange the project status and they can become feedback from the lecturer. Additionally a **research assistant supports the students** in technical problems during the development process, e.g. in handling of development software.

A **project presentation** does finishing the systems engineering training. All student teams do demonstrate the developed systems and do explain it.

After the project presentation the teams does deliver the developed system and a set of documents to the lecturer. The lecturer can then grade the project results. Documents which must delivered by the students are for example, an Enterprise Architect SysML system model, a functional specification document, a circuit diagram of the electronic, software code, a mechanical design document, an integration and test plan etc.

III. RESULTS AND EXPERIENCES

The training concept has been initially implemented in the industrial engineering master program of the University of Applied Sciences Offenburg. Industrial Engineers have a very interdisciplinary technical knowhow. Thus industrial engineers will be more and more deployed as project manager or requirements engineers during industrial product and system development. Especially for project manager the knowledge about the systems engineering activities is very important.

A. The Project Assignment

The project assignment for the student teams is the technical expansion of an existing robot system. The existing robot system is a low cost system from Arexx Engineering [9]. The robot system is equipped with some sensors, a powerful ATMEGA32 8-bit RISC microcontroller, which is programmable in C and some software libraries so that the robot system can autonomous drive. The Arexx robot system offers good expansion and customization possibilities. A picture of the existing robot system is shown in Fig. 4.

The students shall expand the existing robot system by a mechanical protection. The mechanical protection shall be easy to manufacture, easy to remove from the robot system and protect the robot system against environmental impacts. Furthermore the students shall expand the functionality of the robot system. The robot system shall detect and bypass obstacles and steps during autonomous drive. Slopes shall be drivable, the whole system shall be energy optimized. These user requirements shall be achieved by a good combination of sensors, electronics, software and mechanics.

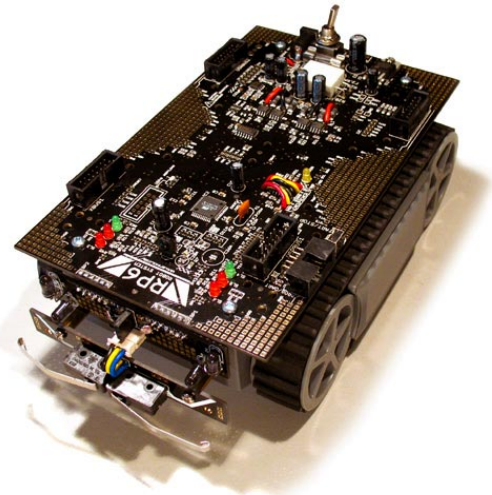


Fig. 4 Robot system RP6 from Arexx Engineering [9]

B. Applied Methods and Software Tools

One objective of the training was that the students shall become knowledge about development methods and supporting tools. Fig. 5 depicts the large number of methods and software tools which will be applied during the training. Especially the system-level development methods (e.g. system modelling with SysML or requirements analysis) and the handling of tools like Enterprise Architect [10] are new and unfamiliar for the students.

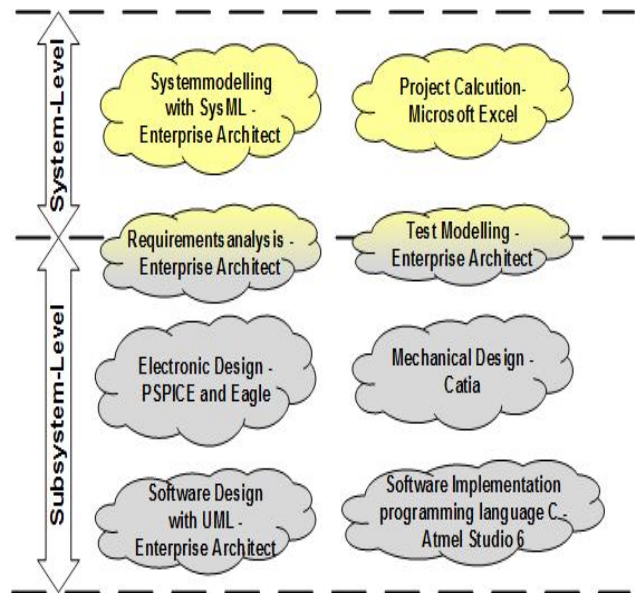


Fig. 5 Applied development methods and software tools

C. System Development Results

Despite the very short time of one semester all teams achieve the goal to expand the robot system and to deliver all demanded documents at the end of the training. Fig 6 shows some pictures from the finished robot systems and the project presentation. Interestingly all developed systems expansions shows different solutions. The resulting varieties of technical

solutions within the training are very large. Up to details the user requirements will be fulfilled from the student teams.

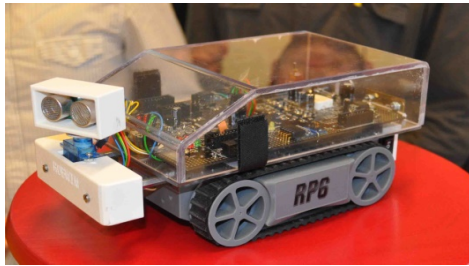


Fig. 6 Example of a finished robot system and a robot system during the project presentation

D. Results and Experiences from Students' Point of View

From students point of view there are the following results and experiences:

- The training has a very high educational level.
- The practical relevance for the future occupation is very good.
- The learning curve is increasing during the training. The overall knowledge/experiences will be improved.
- Technical knowledge from recent lectures during the bachelor or master degree program must be combined.
- Although there is no written examination required the students perceive the amount of work as too much.
- Many students realize that some operational activities not suitable for them. For example the project management of such a large team (seven students per team) was for many students too much. But also there are students which realize the best operational activities for them.

E. Results and Experiences from Lectures' Point of View

From the lectures point of view there are also many experiences and results:

- The elaboration of such a project-orientated training is very time expensive. It has taken two years until the training could be taking place as described in this paper.

- The support and maintenance of the students during the training is also very time expensive. Without a research assistant the training could not be performed.
- The number of students/number of student teams must be limited for such a training approach. Last year the training has been performed with five student teams (35 students). That was the upper limit for such a lecture. The support of the students is then very difficult. Better will be a maximum of three student groups (21 students).
- During the training it is possible, that the student teams get problems like bad team collaboration, bad timing, personal conflicts etc. In this case the lecturer must interfere and mediate between the students.
- The grading of the project results/project process is very difficult. It requires defined evaluation criteria. Otherwise the students don't understand the grading.

In summary it can be noticed, that the objectives of the training concept could be fulfilled. The author itself is amazed about the very good system development results from the different teams during such a systems engineering training. The author is absolutely convinced that this project-orientated training concept is a good possibility to prepare students for systems engineering activities.

IV. CONCLUSION

In this paper a project-orientated training concept to prepare students for systems engineering activities has been presented. The training concept has been initially implemented and applied in the industrial engineering master program of the University of Applied Sciences Offenburg. The training concept is very universal and can be transferred to other technical degree programs.

The outstanding features of the presented systems engineering training are listed below:

- Students process a system development project similar to industrial projects.
- Students train key skills (system requirements analysis, interdisciplinary system design and system verification/validation) according to the INCOSE's systems engineering definition. Furthermore they train other important systems engineering skills like management and social skills.
- Students obtain knowledge about methods and supporting tools which will be applied during system development.
- Students learn a system orientated and interdisciplinary way of thinking and they obtain a better understanding for other engineering disciplines.

REFERENCES

- [1] A. Kossiakoff, W. N. Sweet, S. J. Seymour, S. M. Biemer: Systems Engineering Principles and Practice, Second Edition. Hoboken, New Jersey: John Wiley and Sons, 2011.
- [2] A. P. Sage; J. E. Armstrong Jr. Introduction to System Engineering. John Wiley and Sons, Inc., New York, 2000
- [3] INCOSE: What is Systems Engineering? <http://www.incose.org/practice/whatisystemseng.aspx>
- [4] NASA (Pub.): Systems Engineering Handbook. Washington, December SP-2007-6105 Rev1, 2007

- [5] S. J. Seymour and Ronald R. Luman: Academic Perspectives of Systems. Johns Hopkins APL Technical Digest. Vol, 29, No. 4. 2011: 377 –386.
- [6] Holt, J.; Perry, S.: SysML for Systems Engineering. The Institution of Engineering and Technology, 2008. ISBN 978-0-86341-825
- [7] S. Friedenthal.; A.M. Moore; R. Steiner: A Practical Guide to SysML. Elsevier, 2009. ISBN 978-0-12-3378607-4
- [8] T. Weikens: Systems Engineering mit SysML/UML – Modellierung, Analyse, Design. dpunkt.Verlag, 2008. ISBN 978-3-89864-577-5
- [9] AREXX Engineering: RPG Robot System Website: <http://www.arexx.com/rp6/html/en/index.htm>
- [10] Sparx Systems: Enterprise Architect Overview and Features: <http://www.sparxsystems.eu/enterprisearchitect/ea-purchase/>



Dr.-Ing. Elke Mackensen, born in Freiburg/Germany, is a professor in the Department of Electrical Engineering and Information Technology at the University of Applied Sciences in Offenburg. She got her PhD in microsystems technology from the Albert-Ludwigs-University in Freiburg/Germany. Her areas of expertise are wireless embedded systems, VLSI and ASIC design, systems engineering, project-orientated education.

She has worked for many years as a research assistant at the Institute of Microsystem Technology/Albert-Ludwigs-University Freiburg/Germany and systems engineer and project manager for smart embedded systems at NewTec System Development GmbH. She has published many papers in different international conference proceedings.