CONCEPT AND STRUCTURE OF A NEW MASTER-PROGRAMM "SYSTEMS ENGINEERING"

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Abstract

Nowadays engineered systems become more and more complex and more and more systems are complex due to the technological developments. At the same time there is a lack of good and systematically trained systems engineers who are able to guide, to coordinate and to manage the technical design, development, integration and implementation of those systems. One reason for this situation lies in the fact that the education and training of systems engineers is a quite difficult task. This is because systems engineering has also a lot to do with experience and with a certain way of thinking, the so called “systems thinking”. Therefore, the “art & science” of systems engineering cannot be taught only in a classical way but it must also be learned by applying the new knowledge continuously to practical problems and exercises. Due to this situation and the increasing importance of systems engineering capabilities for companies and future projects, a new Systems Engineering Master program is offered and will be explained in this paper.

Keywords: Design education, Systems engineering (SE), Desgin learning

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1 INTRODUCTION

Modern technical systems are distinguished by a continuous increasing complexity which results from the variety and the variability of technical functions and its integration. One example: Not only the car takes the centre of attention of the designer. New concepts like autonomous driving, safety brake systems or traffic jam assistance necessitate the inclusion of the environment of the automobile in the development context.
In addition, companies today operate in a complex and dynamic environment. Not only several stakeholders have to be considered, but also a number of boundary conditions for the development process like the market, the branch, competition or the social environment (see figure 1, [Blanchard]).

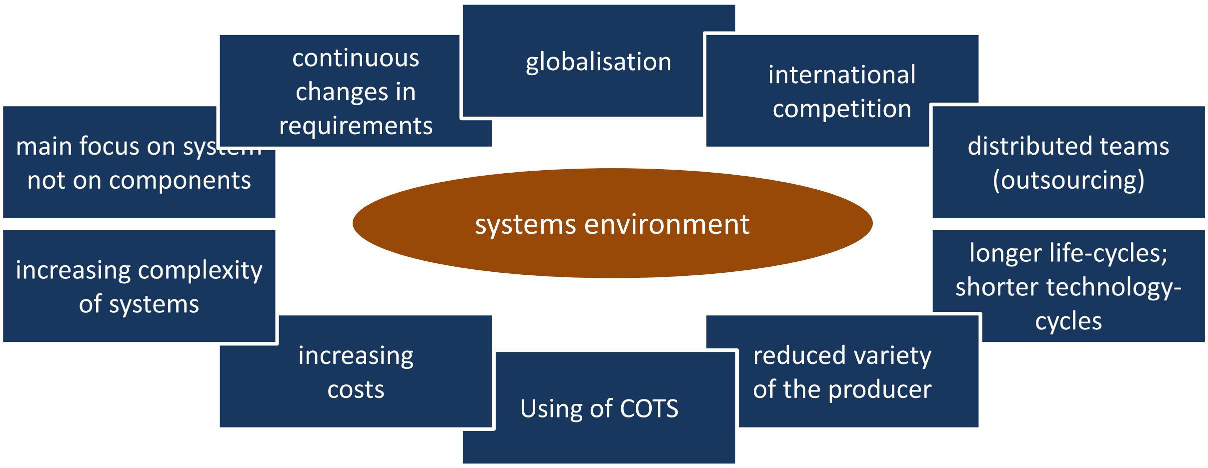

Figure 1: Prospective challenges for the product development

To transfer innovative ideas into technical systems with high quality and to position it on the market it needs the ability, to handle the technology in developing and detailing components. In a number of branches an increasing challenge in the system integration can be observed. Integration in this context not only means the integration of components or technical functions to an overall system. Integration today also refers to organisational processes and the cooperation between interdisciplinary teams in the development.
Such challenges, based on changes in the industry, have to be picked up in the concepts of education at the university. The objective of typical courses of study in engineering sciences is to build up strong basic knowledge of technical issues in principle, complemented with expert knowledge in specific fields. In the focus is not only to impart knowledge, but also to build up competences in the evaluation, analysis and the provision of knowledge. Especially in the consolidation it is important to link the several fields of knowledge as well as to establish the correlations between the "knowledge-islands". Difficulties in education lay in the fact, that professional competences connected to the managerial environment are often only procured in a limited way. Indeed, process-competences are also established, but these competences are coupled to engineering processes and technology competences. Processes in an organisation are much more heterogeneous, depending not only on the product structure, but also on the environment of the organisation, influenced by aspects of the market, competitions, etc. Decision making and responsibility can be trained only in a limited form. These competences are formed later in professional life.
Based on discussions with a number of business partners it has become apparent that the consideration of the overall-system, respectively the systems integration is more and more one of the most important challenges. Of course, the implementation of the overall-system is based on the knowledge of technologies and specific expert knowledge, but it also needs advanced competences to assess the effects of several components or functions for the systems behaviour. To support the integration in the organisation, knowledge about development processes is insufficient. It needs additional knowledge about associated processes like requirements management, configuration management or project management and the interrelations and dependencies between these processes.
These trends lead to new challenges in the design of technical systems, more and more methods of systems engineering are applied in product development. *Systems Engineering is an interdisciplinary*

approach and means to enable the realisation 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 [Incose]. In principle, Systems Engineering describes a top-down approach which receives the technical system as a holistic unit in the environment. Therefore, methods for an integrative development are provided [Weilkiens]. Systems Engineering must also be appreciate as a process for the goal-oriented development and operation of complex systems. Such a view includes the orientation on the product lifecycle as well as on requirements and needs of the user and requires an interdisciplinary cooperation. With such a holistic way of thinking the focus of design lays not only on the components or sub-systems, the holistic view on the technical system and questions of systems integration get more importance und are supported. Of course, a detailed consideration of the components is included; methods for systems integration are on an equal footing with component design.

The challenge in the handling of complex technical systems today is in many fields object of research and development. Alongside, the importance of systemic thinking is often recognized by a kind of psychological strain in the daily work and in the industrial environment. Therefore, the content of Systems Engineering shall be procured in an extra-occupational course of study. The concept of this course of study is explained in the paper.

2 EXPECTED COMPETENCES AND SKILLS FOR A SYSTEMS ENGINEER

Based on the explained challenges in design and operation of complex technical systems from specific properties and skills are expected from the designer. Beside skills like quick apprehension, eagerness of knowledge and creativity, openness for new ideas, which distinguishes a good engineer, other skills like willingness to think in larger correlations, to build broad links between sometimes very heterogeneous components and a broad and a comprehensive basic knowledge come along. Beside the technical-oriented competences it needs also organisational competences, soft skills and management competences. That needs the ability to deal with permanent modifications and with uncertainties, to engage in novel and unknown ideas, distinctive ability to communicate, leadership competences as well as appreciation for processes and its optimal organisation. In a number of projects it needs procedures with the right sense of proportion. It is dangerous to think too much in details, because the engineer wastes his energies, solutions often could be perfect in detail but incomplete in summary. Facile thinking holds the risk to forget respectively ignore important influence factors.

Systems Engineering requires an integrated thinking and acting. Solutions from different domains have to be included and assessed concerning their impact to the overall system. Such estimation is coupled to a reduction: the engineer has to reduce solutions for components or sub-systems to these aspects which characterise the component itself and such aspects which lead to important interfaces for the system behaviour. Normally, not only the main functions of a component are of interest, but also a number of auxiliary functions, which are not important for the component, the overall functionality respectively the systems behaviour may be significantly influenced. Such a view of a technical system is more than the classical description of interfaces, often described only by structural parameters.

With the technical integration in an overall system the necessity of an organisational integration and the process integration is connected. The required process-management and project-management comprises not only the several steps of designing a technical system, but also aspects like risk-management, requirements-management, configuration-management and so on. The systems engineer has to consider the resultant different views, and connected with this, the different stakeholders on the systems behaviour. The diversity in the task of a systems engineer requires his ability to completely include and to structure the situation in the development process as well as make decisions for further procedures from a holistic point of view. Another important task is to recognise and to describe interfaces between several participants and between components or sub-systems. The description of interfaces is a current task over the whole development process. The ability to a holistic and integral thinking can be supported by a number of methods and strategies. Knowledge about such methods is necessary for an efficient and effective work for the system design.

3 CONCEPT OF THE COURSE OF STUDY FOR SYSTEMS ENGINEERING

Based on the expected competences of a systems engineer a concept for an extra-occupational course of study was developed. The work-experiences of the students in handling complex technical systems is an essential element in this course of study and is expected. It is also assumed that knowledge about basic technologies for the technical systems is available and understood.

Fundamentally, it is supposed that in the bachelor-study the knowledge base will be built up, the principle physical, mathematical and engineering background is identified and understood. Based on the bachelor the master-study recesses this knowledge, relations between the basic knowledge will be built up to describe more complex circumstances. The students will learn more to think in processes and relations. The adaption of the understanding of processes in business environment, connected to a branch, the market situation, competitive position etc. will be firstly build up by occupational practice. Our modern course of studies in the field of product development is of course sensitising to such systemic challenges, a deep treatment does not take place. The meaning of systemic thinking and the influence of product quality and processes often results from the real confrontation. Young engineers get a “psychological strain” to manage complex situations.

The extra-occupational course of study procures - appropriate to the thoughts - no technological knowledge. In the focus is content which helps to include the complexity from all point of views in the development of technical systems. It is essential to analyse complex technical systems and complex decision situations to draw conclusions for the synthesis process and to manage the complexity. The content of the extra-occupational course of study is summarised in figure 2. In the figure three objectives are named:

- It needs to build up an understanding of the complexity of a technical system. Therefore, it needs not only to communicate knowledge about processes and methods, but also practical problems in the context of systems engineering.
- On the basis of a systems-understanding and process-understanding tasks of a systems engineering management will be carved out and solution approaches are discussed.
- The students have to be qualified, to transfer and to apply the fundamental knowledge in the field of systems engineering to real problems from their professional practice in the company, the branch, etc.

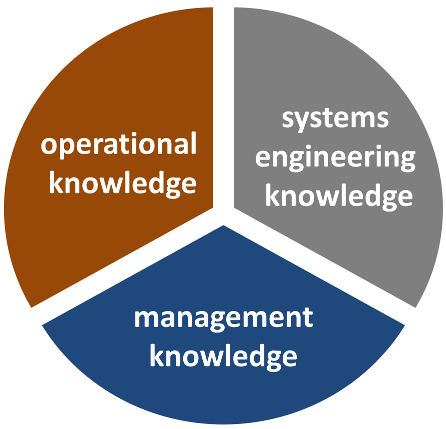

Figure 2: Objectives of the extra-occupational course of study systems-engineering

3.1 Structure and content of the course of study

Based on the knowledge of technical systems as a summary of high cross-linked sub-systems development and management approaches will be introduced, which support not only the project handling but also the process of problem solution in practice. The course of study is clustered in 3 main areas (figure 3), explained below.

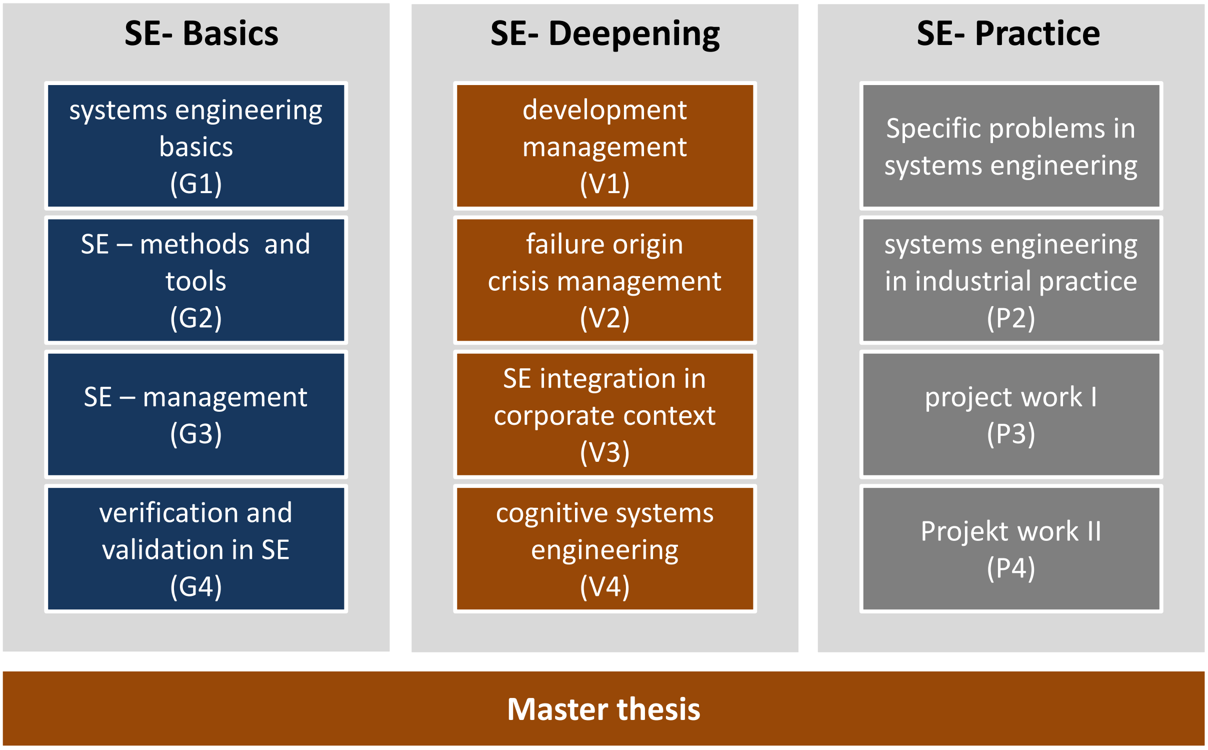

Figure 3: Content of the occupational course of study Systems Engineering

3.1.1 Basic Moduls:

Within the scope of the first cluster basics for a principle understanding of complex systems are explained. Beside system-theoretical fundamentals for technical systems and principle considerations for systemic thinking the description of available methods and tools and the integration into management-concepts is focused on.
In the context of the module "Systems Engineering – Basics" system-theoretical fundamentals are explained, terms are defined and the background will be explained. Typical problems in the handling of complex systems are carved out, with the goal to derive not only tasks but also a principle understanding for complex systems. Parallel in the module "Systems Engineering – Methods and Tools" known procedure models for the development, like for example the V-Model, are explained and adjusted with methods and procedures known from system engineering to deal with the complexity of the system in a project. Based on the main parts of the systems engineering process current methods and tools for specific tasks are explained with which the systems engineer is able to handle the complexity. Beside the knowledge about processes and product lifecycle to understand the process of technical development it is also necessary to involve boundary conditions of the development like budget, costs, disposable time and resources in the planning process. This is the reason why in the module "Systems Engineering – Management" typical tasks of a systems engineering manager are explained and concretised. The technical project management stands in the focus of the module. The foundations of Systems Engineering will be perfected with the module "Methods of Verification and Validation in Systems Engineering". Quality and functionality of complex technical systems are the main objectives in the development process; these properties have to be ensured process attended. Available methods from the field of simulation as well as tests are explained and attended to the development process. At the end, the students should be able to define concepts of verification and validation depending on available data and product maturity.

3.1.2 Moduls for Deepening

The second cluster provides possibilities for deepening of several areas of systems engineering. Beside subject specific problems in managing complex systems and processes are discussed. Additional competences in fields of crisis-management, organisational development and personal development can be built up.

Within the scope of the modules ”Development Management“ and ”Systems Engineering – Integration in business processes” the systems engineer gets the knowledge of the most important processes and their relationships in an organisation. Beside strategies for a long-term validation of the organisation, methods and approaches for single and multi-project management, the cross-link to systems engineering as well as the integration in the organisation is explained. Furthermore, process business processes like controlling, leadership and network creation, development of organisation and human resources in the context of systems engineering is picked up and explained. The systems engineer has to dispute with vendors and customers, strategies for a better understanding of these participants are included in the modules. Another module “Processes of failure genesis and crisis management” explains mechanisms for failure genesis based on the analysis of failures and failure propagation. In principle, the human being has often difficulties with complexity, to recognise the whole complexity of the technical system. Strategies are explained to overcome barriers in thinking for a better understanding of relations in technical systems and between several systems. Based on this, the discussion can start how to react in critical situations. Methods for decision making are explained as well as requirements to the systems engineering to handle critical situations. The module “Cognitive Systems Engineering” makes allowance to the challenge, that the human being more and more is not able to handle complex technical systems in their totality. To support the human being, strategies of automation are used in practice, more and more tasks are adopted by the technical system. In this context, human-machine-interfaces and human-machine-integration get more importance. Aspects, approaches and methods of the cooperation between human being and technical systems are content of this module.

3.1.3 Practical Modules

The third cluster focuses on the application of the obtained knowledge to special problems in the corporate environment and on domain specific questions. The objective is to depict challenges from the different fields of expertise of the engineers and to discuss solution approaches. Therefore, in the context of the module “Systems Engineering in the industrial practice” experiences practitioner and specialists from the industry are invited to explain the process of problem solving and best practices. Systems engineering is a discipline, where practical solutions depend on the branch, the product and the market. Together with the students examples are analysed, potentials and risks are carved out and solutions are derived. Last but not least, strategies have to be explained to realise the solutions found. The module “Specific Challenges in Systems Engineering” gives the opportunity for the students to discuss questions and problems resulting from their day-to-day business. Also for this module a speaker with specific background and knowledge is invited depending on the specific interests and questions of the students. Main topics are defined in a process together with the students and prepared by the students with specific talks and presentations using the acquired knowledge. The practical modules are completed by project works. In the context of the project work it is necessary to find solutions for a well-defined problem based on the acquired knowledge of systems engineering. This work can have a theoretical, experimental or design-character. Beside the solution-finding an exposition has to be prepared.
A master-thesis completes the extra-occupational course of study of systems engineering.

3.2 The Teaching Concept

For the teaching cluster adequate teaching methods have to be used, which include the former professional qualifications and which are qualified for the characteristic of the teaching cluster. The objective of the first cluster is to procure and to deepen basic knowledge. Therefore, classical learning methods with lectures and exercises adapted to a correspondence course are useful. The methods are completed by topics and tasks which have to be executed self-dependent by the students.
With this approach, the reference to practice is realised. An intensive dispute of the content by the students is expected. In the stage of presence several simulation tools and case studies may help in deepening the knowledge.
With the deepening modules several aspects of the basic knowledge are picked up and are considered in a deeper matter. Otherwise, further problems are taken up and are discussed. The objective is to establish the reference to practice. The content of teaching is adapted to occupational challenges in a discussion with the students. For the intermediation of the content problems from industrial practice

are used. This is needed for the principal motivation of classical teaching methods. The main focus lays on the self-contained editing of the content by the students. This is necessary to describe the relevance for the adaption in practice.

Tasks in the field of systems engineering are very heterogeneous. Solution approaches depend on branch, market, product spectrum, competitive environment and other aspects. With the practical modules the students get the opportunity to get to know solution approaches and best practices from several domains and to transfer these approaches to similar tasks and problems in other fields. At once, problems from the professional environment of the students are picked up and are analysed with the goal to derive concepts of handling the problems. The students are intensively involved in the preparation of the modules. Speeches and presentations are part of the examination. The presence-stage is organised as a workshop, not only to support the build-up of knowledge, but also to find solutions for actual problems. Speeches from referents from industrial partners complete these lectures. This principle structure allows to include wishes and needs of the participants in the module. Thereby, the modules have the character of elective courses.

4 DIDACTIC DESIGN OF DISTANCE TEACHING IN THE SYSTEMS ENGINEERING MASTER PROGRAM

Blended learning is a didactic concept, which varies methods, media and theoretical approach to learning and is characterized by a combination of e-learning and teaching in presence as well as learning support (Klimsa, 2011). Since 90% of the teaching in the Systems Engineering master program is performed as e-teaching, this text focuses on the methodological structure of e-teaching. Yet, the presented approach of activation, support and transmitting is applicable for the teaching on campus.

The didactic design in e-teaching in the master program is binary structured: Firstly, the structure of the modules, which clusters (the approximately) 12 weeks of a trimester to several topics and secondly, the internal structure of those topics, which consist of support, transmitting and activation (Reinmann, 2013). The structure of the e-teaching is displayed transparently: In order to provide orientation during the trimester, the chronology of the topics is presented to the students at the beginning of the trimester. To prevent overburdening with too much information, the inner structure of the topics is announced “just in time“ and always contains on overview of the topics of both modules.

Teachers provide online feedback regarding the results of activation (see below), answer precise questions via e-mail or mimic a certain role within case studies, for example a customer, and thus deliver support (brown in figure 4). Moreover, providing organizational information, assistance and encouragement when needed identify **support** by an e-tutor.

The term “**transmitting**” (blue in figure 4) sums up the content received by students. It generally consists of an introduction, further readings and in some circumstances an activation.

(dark gray in figure 4) describes assignments, which vary in between the different types of modules. Applying a theoretical concept to a case study, exemplifies a typical activation in basic modules. A virtual team of students works on such tasks and handed in the solution digitally on due date. In advanced and praxis modules, the students provide current and practical cases and link those to the content of the topic as well as to their own research. Students may present results of this kind of activation during a workshop on campus.

The topics within the modules take place within a time frame of one to four weeks. Depending on whether activation takes place and how complex the texts within are, the specific amount of content varies.

Figure 4 shows the prototypical structure of two modules, which simultaneously take place in one trimester (approximately 12 weeks). The weekends for teaching in presence on campus and certain needs of the students influence the chronology of the topics, which spans horizontally in the figure. The internal structure of the topics spans vertically in the figure and includes the transmitting in varying ranges and possibly activation.

The master program Systems Engineering usually performs two modules at the same time. Since a week lasts from Thursday (beginning of a topic) to a following Thursday (end of a topic, possibly with delivery of a solution to an assignment), weekends on campus are marked in the figure rather at the beginning of a week.

Important features of the e-teaching of the trimester in figure 4:

- Activation never take places in both modules at the same time;
- There is a phase within the trimester without activation;
- New topics begin with a broader spacing than weekly;
- Topics generally include introductions and further readings;
- Activation either results in an online feedback or feedback on campus;
- There is a period free of further topics for the preparation of the examination;
- The students are informed about the structure of the modules as well the topics (what needs to be done until when?);
- During weeks including teaching in presence on campus, there is no content from e-teaching to be worked on.

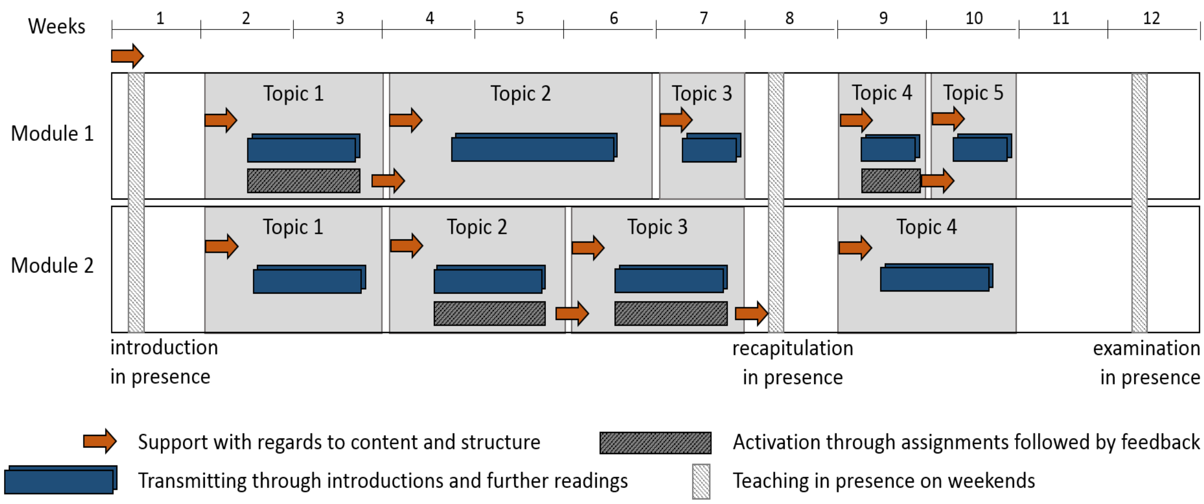

Figure 4: The prototypical structure of e-teaching (two modules during one trimester), containing the components of didactic design: support, transmitting and activation (Reinmann, 2013).

5 FIRST EVALUATION RESULTS

The first realization of the four basic modules was evaluated per questionnaire, consisting of questions concerning the overall impression of the modules and questions seeking insight into specific topics (for example the teaching material or workload). The results of the overall impression are reported here. At least 6 out of 7 students participated in the evaluation of each module.

“The modules instructional objectives were accomplished.”

On a 5-ary ordinale scale, ranging from „true“ (1) to „false“ (5), the students rated this statement with 1.475 on average, ranging from averaged 1.2 to 1.7 over the four modules.

“Were you satisfied with the module process and learning support?”

On a 5-ary ordinale scale, ranging from „very satisfied“ (1) to „very dissatisfied“ (5), the students rated this statement with 1.575 on average, ranging from averaged 1.3 to 1.8 over the four modules.

“What did you like most about the module?”

For analysis, the answers to this open question are structured into the parameters of the didactic design mentioned above:

The students state liking the “good support” in general, “the easy access to the teachers in case of questions“, “the encouragement of students’ participation during lectures on campus” and the “teamwork and discussions” (support). They appreciated the choice of topics, integration of case studies, providing control questions for preparing the oral examination, and the high quality of the material, particularly mentioned the short summaries with every topic (transmitting). The students’ remarks concerning activation include the teamwork online and on campus, assignments that are based on the one before and flexible timing (i.e. longer periods of time with larger assignment).

“What improvements would you suggest?”

The students suggest improvements concerning the organization of teaching, namely to provide short summaries and instructional objectives with every topic of every module and to reduce the workload if difficult material was used. Furthermore they provide suggestions for topics to be included in the curriculum of the specific modules and ask for increased orientation on practice by providing (even) more examples (transmitting). The latter is true also for activation: the students wish to work on practical assignments, preferentially based on each other. No improvements concerning support were suggested.

Repetitions of aspects within both types of open questions may occur because of this analysis being a summary of the evaluation of four modules (two performed at a time):

- Students directly compare the teaching performance and processes of the modules taken at the same time: aspects they like about one module are named as suggested improvements in the other.
- Suggestions concerning the first two modules were implemented during the following two modules and the students provide direct feedback: aspects, that were suggested after the first two modules had been completed, show in the “like”-section of the questionnaire after completion of the following two modules.

6 CONCLUSION

The Systems Engineering Master Program at the University of the Bundeswehr Munich is focused on the non-technical issues of systems engineering and aims at participants with a first working experience. In consequence it is based on the blended learning approach, which allows the participants to take the master program in parallel to their employment. This also strongly supports the transfer of the learned systems engineering methods, tools, processes, etc. to the praxis of day-to-day project life.

The program started in April 2014 and it became evident that, due to the practical experience of the participants in different fields, high quality dialogues developed, which helped considerably to transport the benefit of applied systems engineering. As not unusual in new programs, also some sub-optimal issues, like too high a work load, where identified, which will be improved in the future.

REFERENCES

Klimsa, P.: Online-Lernen. Handbuch für Wissenschaft und Praxis. Oldenbourg Verlag München; 2011.

Reinmann, G.: Studientext Didaktisches Design. München. URL: http://lernen-unibw.de/studientexte, 2013, last call: 04.12.2014.

Blanchard, S.B.; Fabrycky, J.W.: Systems Engineering and Analysis. Verlag Pearson New International Edition, 2012.

Kossiakoff, A.; Sweet, W.N.; Seymour, S.J.; Biemer, S.M.: Systems Engineering Principles and Practice. 2. Auflage; Wiley, 2010.

Haberfellner, R.; de Weck, O.; Fricke, E.; Vössner, S.: Systems Engineering – Grundlagen und Anwendung. Verlag Orell Füssli, 12. Edition, 2012.

INCOSE Systems Engineering Handbook v. 3.2; Incose-TP-2003-002-03.2; January 2010.

Weilkins, T. „Systems Engineering mit SysML/UML: Modellierung, Analyse, Design“, dpunkt Verlag, 2nd. Edition, 2008.