SYSKIT 2.0 – IMPLEMENTATION OF A SYSML TEACHING APPROACH AND OBSERVATIONS ON SYSTEMS MODELLING BY MECHATRONIC TEAMS

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ABSTRACT
To fulfil the demands of modern product development processes, nowadays engineers have to interact with the domains of mechanical, electrical and software engineering. Due to this, their day-to-day business in practice is strongly characterized by working with different departments and stakeholders out of different disciplines. For improving their communication and to build up a common understanding, an interdisciplinary model language is needed. The Systems Modelling Language (SysML) is a language for modelling these interdisciplinary technical aspects of a system. This paper introduces the revise of an educational teaching approach for SysML presented in 2014 [1]. It is called SysKIT 2.0. First findings on the learning experience and the modelling results will be presented in this paper. The current approach was taught for the first time in a multidisciplinary course, where the students have lectures, exercises and a development project. In their development project the students have to use SysML for modelling – concepts, prototypes, validation and optimization. This paper presents the revised concept of SysKIT. The modifications compared to the first published concept are pointed out and explained.
Further the paper analyzes the modelling techniques of different students groups and summarizes statements about the benefits. These findings were made by interviewing and observing the SysML-trained teams using SysML during the development project.

Keywords: Mechatronics, SysML teaching approach, systems engineering, modelling method, project based learning.

1 INTRODUCTION - JOB PROFILE OF MECHATRONIC ENGINEERS

The innovative capacity and highly developed systems and products are a key factor for Europe's leading economic position. The demands on today's product developers are rising and it is getting harder for an individual to keep an overview on the whole product development process. For success in today's development projects, engineers have to apply knowledge of the fields of mechanics, electronics and information technologies. Their daily business is strongly affected by working in interdisciplinary teams of different departments. Thus joined-up thinking and interdisciplinary comprehension are required [2]. Students in mechatronics are setup to educate engineers to fulfil these demands. It is expected from mechatronic engineers to have a broad general knowledge and detailed knowledge, in a field of specialization. This knowledge should be applied together with methodological expertise to solve complex problems by finding innovative solutions. New processes, systems and products should be designed by using mechatronic synergy potentials. The survey 'Faszination Konstruktion' (engl. fascination engineering design) - from the national academy of science and engineering Germany - points out the need for so called system engineers that possess knowledge in the fields of mechanical, electrical and information engineering, manufacturing and assembly techniques, project management and creativity techniques [2]. As published by Matthiesen et al [3] a curriculum for mechatronic engineers has been developed at the KIT. Within the fifth semester the students will attend a course *development of mechatronic systems and products*, that consist of lectures, exercises and a development project (see chapter 2). In the lectures and exercises the students learn the SysML basics and apply them during their development project. SysML is used as a common modelling language to support the system design and communication. The graphical

modelling language SysML is for general purpose and supports the analysis, specification, design and validation of complex systems. [4] The visual modelling during the development process helps to build up a better communication and increased system knowledge of all project team members. Diagrams could also be used to communicate with stakeholders and customers. [1]

2 THE SYSKIT TEACHING APPROACH 2.0

This paper introduces the revise of the educational teaching approach for SysML presented in 2014 [1]. The new version is called SysKIT 2.0. The modifications compared to the first published concept are pointed out and explained in chapter 3. The approach was first tested in a pilot study (1 day workshop with 15 participants), modified based on feedback and findings out of the study. It was taught for the first time in the multidisciplinary mechatronic course (*development of mechatronic systems and products*) in 2014 at KIT. The revised SysML teaching approach consists of two levels (Figure 1) and is structured according the Bloom taxonomy levels [5]. In the course the students have SysML lectures with integrated active exercises. During the lectures the difficulty of the exercises, is increased from lesson to lesson adequate to the students' level of knowledge.
In the same course they work on a development project to develop mechatronic systems under realistic industrial conditions and use SysML for modelling [10].

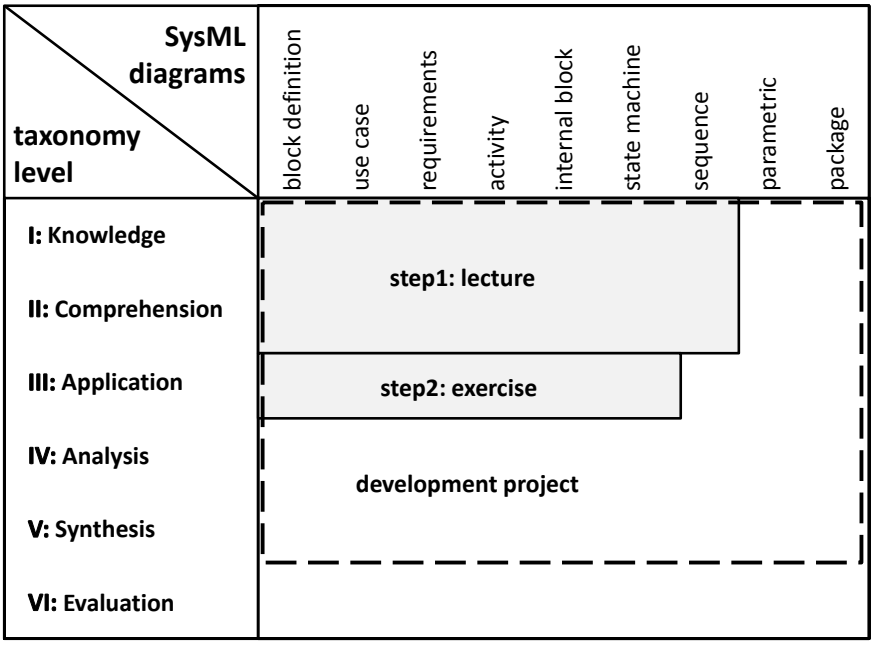

Figure 1. SysKIT 2.0 - a two step SysML teaching approach

Introducing lecture: This phase introduces SysML and model based system engineering to the students. During the introduction the participants are taught on knowledge and comprehension of most important SysML diagrams and the basic elements for each diagram type.
Exercises: After introducing one diagram and the possible elements, there is an exercise for each diagram type with worksheets. To reduce the complexity in this very early stage (application, not analysis or synthesis), most of the model contents are given. By doing so the students apply the new elements. After 10 minutes of partner work a possible solution of the exercise is presented. They focus on modelling SysML and are not distracted by technical complexity.
The lecture hall sessions (introducing lecture & exercises) prepare the students to use SysML in their development project. The goal is to reach the taxonomy level III – application of SysML (see Figure 1). In the development project the students have to develop under nearly industrial conditions. SysML supports the teams to get a common understanding and a better structured development process. A correction and discussion of their models is conducted in three workshops with supervisors during the semester. As shown in [1] the SysKIT-approach is designed to resolve the deficiencies of other SysML trainings: (1) overstraining caused by too many new elements at the same time, (2) overstraining caused by unknown tool, (3) dissatisfaction caused by missing a sample solution (4) frustration caused by not recognizing the benefit of using SysML.
How these dissatisfactions will be handled in this approach will be discussed in the next sections.

Sequential modelling in lecture hall sessions: To resolve deficiency (1) the SysKIT lecture introduces new diagrams & elements step-by-step (sequential) and the newly introduced diagrams are practiced in an exercise session before introducing the next diagram. This step-by-step-modelling is very uncommon for industrial projects, but it is a very effective way to get students familiar with SysML. Teaching assistants support the students by answering questions and discussing modelling options during the exercise sessions. Usually in industrial projects a designer adds contents to the different diagrams iteratively as the information (requirements, behaviour, structure, etc.) occurs. Figure 2 illustrates the differences between sequential (lecture hall sessions) and iterative (project work) modelling. The differences between this two modelling techniques are discussed with the students.

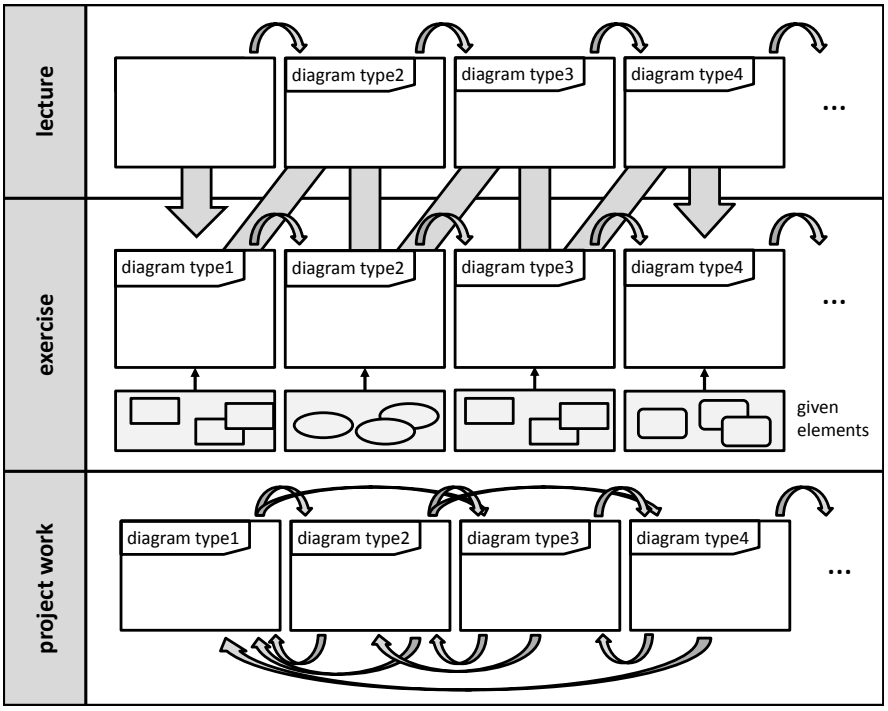

Figure 2. Process of the SysKIT 2.0 teaching approach

No SysML software modelling tool: During the exercise the students start with individual pen and paper modelling. This reduces the difficulty compared to learning a software modelling tool at the same time (2). To support modelling during the development project the teams can use whiteboards and memox©-cards. These cards are made to develop together in a team as shown in Boes [7]. The main benefit is, that cards can be rearranged easily to create clusters or describe dependencies. Furthermore, the content written on the card can be added, changed, or erased during the usage. For a better documentation and presentation the students can redraw their models in MS Visio with the SysML shapes of Pavel Hruby [8].

Discuss an example solution: A very common problem of modelling with SysML is that there is more than just one correct model. With regard to a given objective, one model appears more appropriate than others. This can lead to confusion (3) and dissatisfaction of the students. To resolve this deficiency, at the end of each exercise phase a given example solution helps to reflect and discuss the exercise together.

Point out benefits: During the lecture the benefits (4) of SysML such as a better system knowledge by interconnected model elements are pointed several times. Further on the methodical importance of generating and tracing requirements during different development steps are discussed.

Given elements: In many other SysML teachings the participants have to analyze a technical system e.g. a coffee machine and model it. It was observed that modelling beginners focus more on the (interesting) technical content than on the modelling itself. Thus time consuming discussions about the system instead of discussions on modelling took place in other SysML courses. When model content is given these discussions are obsolete and the students can focus on the modelling itself. This is another important aspect to speed up the learning during the very time limited lecture sessions.

3 SUMMARY OF CHANGES FROM SYSKIT TO SYSKIT 2.0

There are several changes and improvements made since SysKIT was published. These changes were made based on findings of the pilot study and findings made during the final preparation of lesson material (power point slides, worksheets, handouts). The most relevant changes are:

Steps: As part of the course *development of mechatronic systems and products* the SysKIT approach is reduced from a three step into a two step approach. The study made clear that the abstract modelling is even more difficult and time consuming than modelling a simple system.

Duration: Due to time restrictions the SysML teaching was conducted in five lecture hall sessions of 90 mins each instead of a two-day workshop. The intensive practicing of modelling with SysML is part of the development project. During office hours the students can discuss questions regarding SysML.

Modelling process: A reference modelling process has been developed to support the students with an overview of all modelling activities. Figure 3 shows the process as a SysML activity diagram. This process is based on the modelling process taught at HAW Hamburg from Abulawi [9].

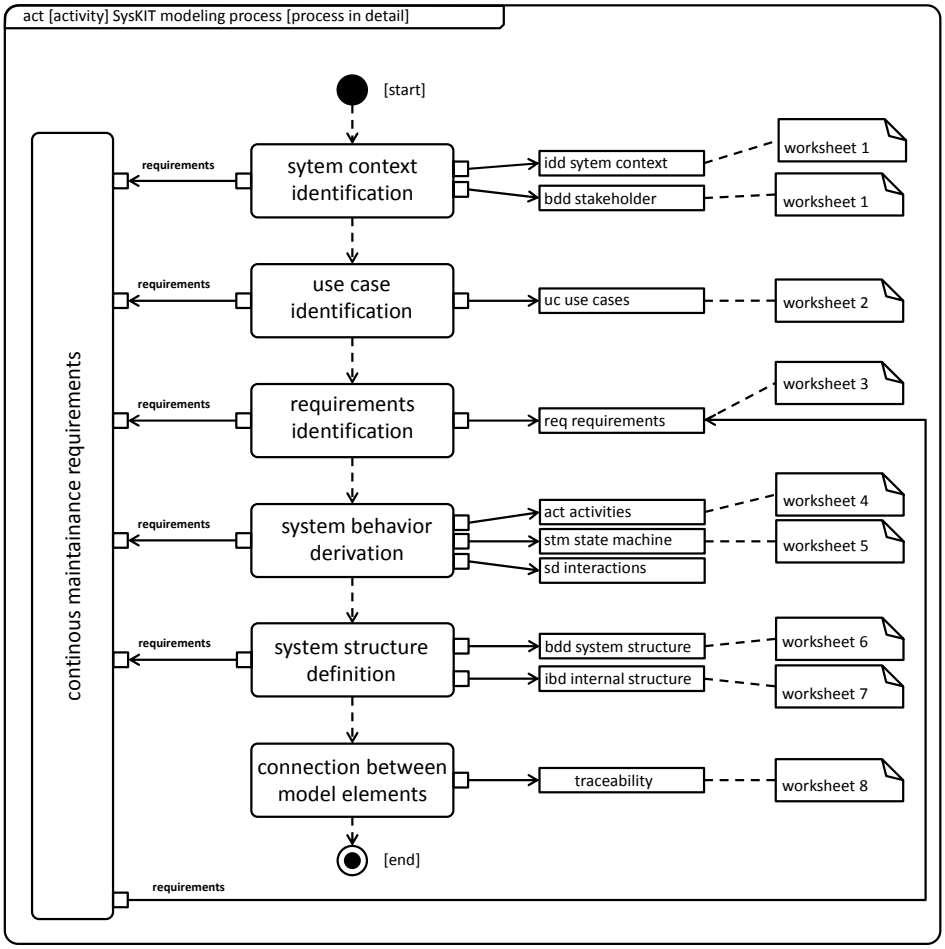

Figure 3. SysKIT modelling process

4 SYSTEMS MODELING OBSERVATIONS BY MECHATRONIC TEAMS

As mentioned above the students get knowledge (I) and comprehension (II) of SysML in lectures, they apply (III) their knowledge in exercises and analyze (IV) and synthesize (V) a system using SysML in a development project under realistic industrial conditions. In this development project, the students develop concepts, build prototypes and conduct validation and optimization activities. To support all these activities they build up a common understanding by modelling with SysML.

One of the key elements of the development project is cooperation – for the final succeeding – two groups have to work together very closely as one team [6]. Thus, each group is responsible for its own subsystem, but to achieve the shared goal, the team has to continuously discuss, negotiate and decide about the requirements and constraints for the overall system, resulting from their jointly pursued

strategy. During the lecture hall sessions it was recognized that it took a couple minutes for the students to switch from lecture to exercise and get familiar with the new task. At the end of the exercise sessions student questions were still left. The following findings were made during the development project: It was observed that modelling with SysML achieved very good common system knowledge throughout the teams. All teams used the memox©-cards to start modelling with all team members. The discussions while modelling helped to find answers for questions like: '*What aspects of the system context are relevant for our development*?', '*How important is a certain requirement*', '*How do we structure our system?*', '*How is the order of actions in our strategy in detail*?' Especially modelling the strategy with activity diagrams was a big benefit. After modelling on whiteboards the diagrams have been redrawn with MS Visio. These diagrams (more nicely than photos of handwritten whiteboads/memox©-cards) are used for documentation purposes and have been changed if any new findings required so (compare Figure 4). This ongoing model updating as not observed on all diagrams. Since no modelling software was used, a high effort would have been necessary to do so if an element was changed which is used in several diagrams for example. Finally the diagrams have been used to communicate and discuss the project results during the workshops with supervisors.

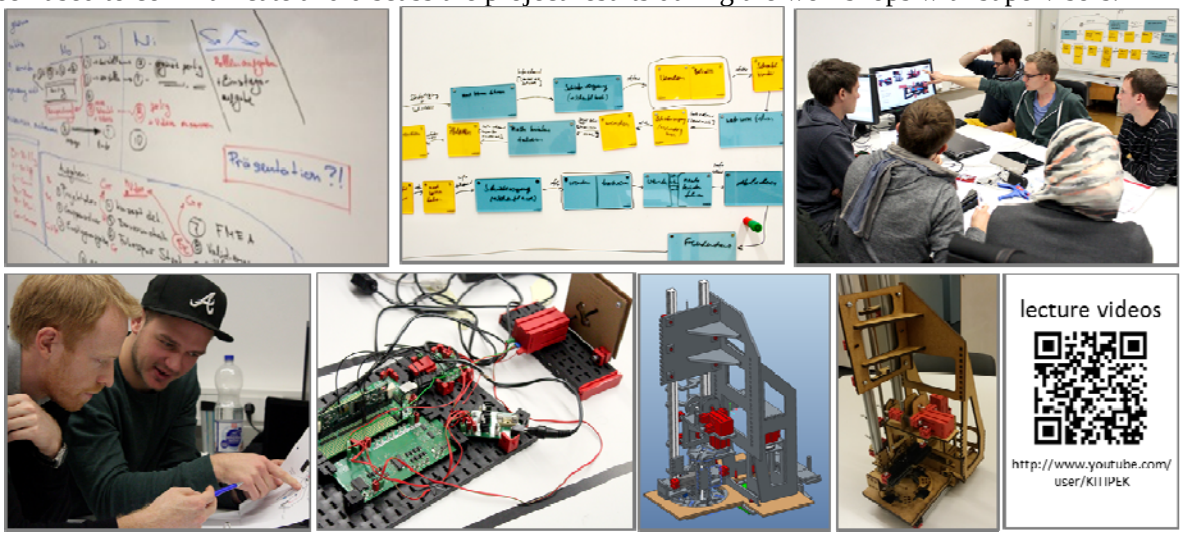

Figure 4. Observation of mechatronic teams during the development project

During the discussions with the teams it was observed that interfaces between the cooperating systems and system structure have not been modelled very in detail. A lot of information was saved in spreadsheets, text documents (as part of meeting minutes) and mostly in visualizations such as sketches, detailed drawings and CAD models. Without the knowledge of a single team member it would not have been possible to navigate to these information sources from the system model. Further on some information were not documented, but were available upon request from mind. Further on it was noticed that some more elements should be introduced in lecture. Especially elements to model more complex loops and exceptions in activity diagrams were requested by the students to model adequately for a good preparation of control strategies. Some students have been able to look up possible elements to do so by their own. Others modelled only with the elements from lecture. Thus the models were imprecise, but the teams knew that the model didn't exactly reflect what they have been developing. Some students hesitated to state that modelling had a benefit for them It was observed that this was influenced a lot by (1) missing connections between the elements, (2) by missing a real traceability (beside the drawn arrows) and (3) by missing an auto update of one element in all diagrams if changed in one diagram. This impression resulted from not using modelling software. Students stated the willingness to learn and use modelling software:

> *'A SysML software tool would have helped us to realize the benefits of traced models and could save time because of the reuse of elements.'*

At the end of the course there was an evaluation and the students were asked, if they like the structure of the SysML teaching, order of introducing the elements and the mixture of lectures and exercise. Nearly all students enjoyed the course and would keep the concept as presented in this paper. Some minor potential for optimizations have been stated. Most important was that the students wished to get the SysML lecture and exercises earlier in the semester to start modelling in their development project

at the beginning. A judgment on the benefit of using SysML in mechatronic teams is not possible, since the effects of not using modelling software have been severe (see above). A subjective overall judgment on using SysML is positive because it helped a lot to gain common system knowledge and to communicate project results.

5 SUMMARY

This paper introduces the revise of the educational teaching approach for SysML presented in 2014. The approach was tested in a pilot study, modified and taught for the first time in the multidisciplinary mechatronic course with 40 students. The new version is called SysKIT 2.0 and the modifications compared to the first published concept were pointed out. The new SysML teaching approach consists out of the two steps and is structured according the Bloom taxonomy levels. In the course SysML teaching is conducted during lecture hall sessions and further practicing of SysML modelling was made during a development project under realistic industrial conditions. The students built SysML models of their mechatronic systems, which helps to build up a better communication and increased system knowledge of all project team members. Nearly all students recognized the benefit by using SysML.

6 OUTLOOK

During the SysML lectures and by analyzing the development project some potential for further optimization for the next class were found: (1) SysML will be introduced one week earlier in the course curriculum, so that SysML modelling already supports the early needs of the development project. (2) Additional elements for modelling loops and exceptions will be introduced. (3) Due to the fact that the number of student will rise to approximately 100, more assistants for answering questions will be needed. (4) To be more time effective during lecture hall sessions there will be an exercise stage after every second lecture stage but doubled in time. So there will be less changes between lectures an individual work of the students and more time to answer all questions. (5) To experience the main advantage of model based systems engineering compared to document based engineering (traceability, interconnected models, etc.), a software modelling tool will be introduced. The effect of tool based modelling compared to pen and paper modelling will be observed and published.

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