LEARNING BY DOING

Systems engineers often grow into their role gradually within the context of one company, with their role evolving due to the increasing complexity of the systems they develop. Once in a while, the question arises as to whether the correct systems engineering methodology has been chosen for a particular project. Where does the innovation in engineering methodology come from? Saxion University of Applied Sciences and the TValley robotics and mechatronics innovation cluster have developed a method in which education, training, knowledge sharing and learning are connected in a practical feedback loop that ensures continuous innovation in systems engineering.

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Introduction

Systems engineering (SE) is often 'learned on the job' within the context of a certain company. As such, it is hard for systems engineers to get practical experience regarding other methodologies. Different companies have different ways of applying SE. High-tech OEMs have several defined SE roles and often put high demands on their suppliers. Production SMEs sometimes follow a more pragmatic approach and even combine the role of systems engineer with that of project leader. There is no single best SE methodology, only a good (or bad) fit between the chosen methodology and the (business model of the) company.

The variety of companies, business models, systems complexity levels and application fields therefore leads to the need for different SE methodologies. This imposes high demands on any SE training or educational programme. In addition, the field is developing quite rapidly and new methodologies such as model-based SE are becoming popular. Within their projects, the Mechatronics research group at Saxion is experimenting with different SE methods in order to obtain and expand experience in this field.

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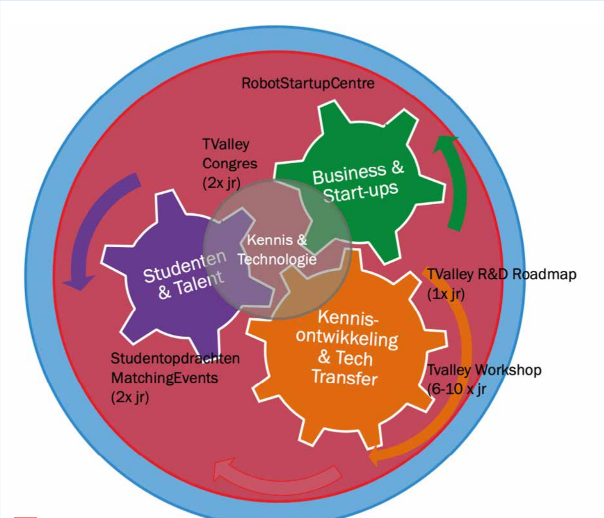
Examples of A3 Systems Overviews papers.

Experimenting with SE

At the beginning, the research group adopted the well-known V-model [1]. However, practice learned that the V-model did not fit the applied research process very well. Therefore, we started experimenting with new methods. The holy grail has not yet been found, but the research has led to interesting findings that have impacted our work.

It was found that the use of A3 Architecture Overviews [2] helped enormously in communicating effectively with our project partners. These documents were used in several projects, most successfully while gathering the requirements. Even after having finished lengthy discussions about what the project partners would like to have in a project, the moment we put the A3 Architecture Overviews paper on the table a lot of new comments on the system of interest were made (Figure 1). By making some (preliminary) design considerations explicit throughout this A3 procedure, we learned a lot about the limitations in design space, for example due to legislation in the application area concerned.

For writing down the requirements, two methods that were tested deserve attention, because our approach to requirements definition appeared to leave a lot of room for interpretation, as was also seen in the work of our students. Research into formal requirements syntax has resulted in these two methods: Easy Approach to Requirements Syntax (EARS) and Planguage. EARS [3] was developed at Rolls-



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TValley's working model consisting of three pillars: Talent (Students & Talent), Technology (Knowledge development & Technology transfer) and Business (Business & Start-ups).

Royce and is now widely used in industry, with proven merits such as being less wordy and having better testability and less complexity within each requirement.

The EARS syntax is very simple but requires good thinking on system functionality while writing the requirements down. The syntax was 'augmented' in Saxion's own documentation with a 'rationale' per requirement. Students were also involved in building systems based upon EARS documents and writing their requirements in EARS. EARS appeared to really enhance the system understanding.

The other requirements technique experimented with was Planguage [4]. A course by Gilb/ValueFirst was followed to obtain a good understanding of this method, which can be used to describe quantified higher-level requirements such as 'reliability' or 'security'. At Saxion, Planguage was used for the case of a fire-extinguishing robot in the Firebot project. Describing such high-level requirements was new, but provided very good insights into what was really important for each stakeholder. The methodology, on the other hand, appeared too advanced for bachelor students. The project management method Evo [5], usually combined with Planguage, is very interesting, but has not been tested yet.

TValley Competence Group

The importance of SE has been recognised by the TValley robotics and mechatronics innovation cluster [6]. Its working model consists of three pillars: Talent, Technology and Business (Figure 2). The need for sharing SE experiences is acknowledged by industrial CEOs. A competence group was created this autumn, comprising systems engineers with around 10 years' experience. In a safe technical intervision setting they can share best practices and analyse challenges. In this manner, all the engineers involved get feedback on their questions regarding the methods used in a professional and efficient manner. Saxion, as a partner within TValley, also shares its experiences and uses the experiences and knowledge from the competence group for developing the Robotic Systems Engineer master.

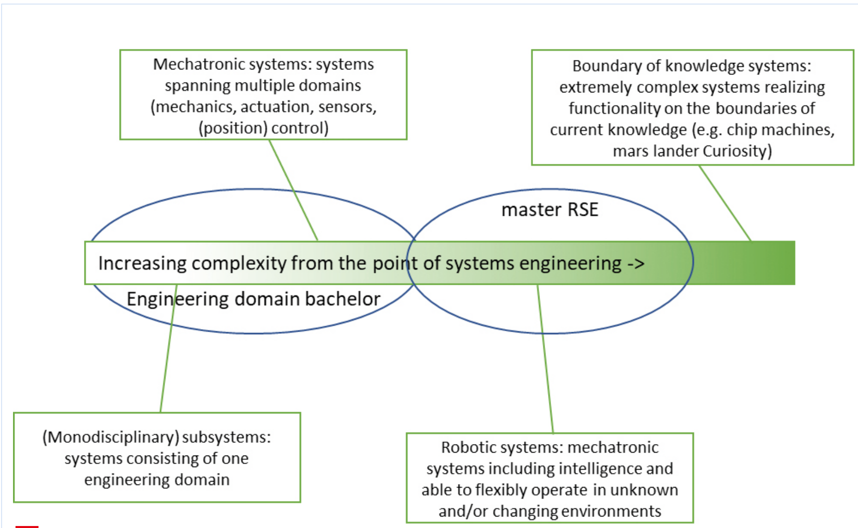
Robotic Systems Engineer master

The Robotic Systems Engineer master's degree programme is currently being developed, with the request for accreditation being recently submitted to NVAO, the Accreditation Organisation of the Netherlands and Flanders. Upon graduation, students are entitled to use the M.Sc. degree. Saxion aims to start the programme in September 2021.

As a professional master's degree, the programme will focus on training students in SE by developing – together with industrial partners – systems that can be brought to market. This is opposed to the focus of an academic master's degree, which trains students in scientific knowledge and technology itself. The scope of the programme (Figure 3) is robotic systems viewed as mechatronic systems incorporating intelligence and the ability to flexibly operate in unknown and/or challenging environments.

Students holding a bachelor's degree in engineering (e.g. mechanical engineering, electrical engineering, computer science or mechatronics) are entitled to enroll. They will be provided with a solid foundation of knowledge in robotics, but the focus is on equipping them with real-life, hands-on experience in SE tools and methodologies. The curriculum is shown in Figure 4.

In the 1.5-year master's degree programme, the first year consists of a combination of courses and projects (light



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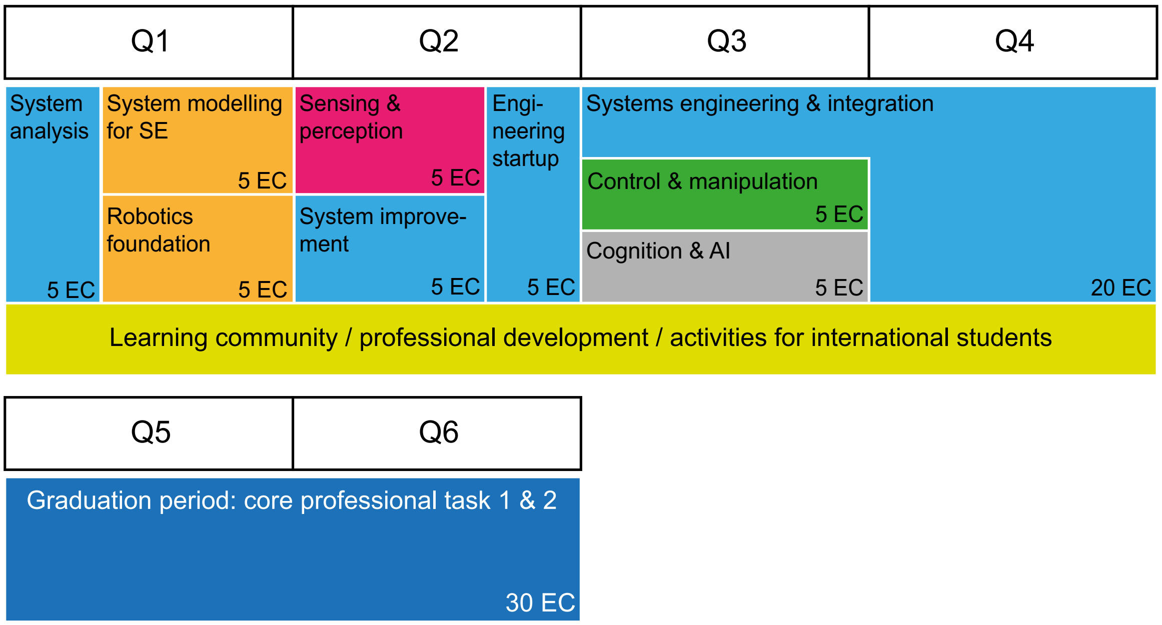
The scope of Saxion's Robotic Systems Engineer master.



4 *Saxion's Robotic Systems Engineer master curriculum.*

blue). The last six months is dedicated to the graduation assignment (dark blue). Similar to the current practice of learning 'on the job', learning within the projects is an essential part of the curriculum. The projects providing SE training make up 55 per cent of the first year's syllabus. Students will work on cases coming from projects in the Saxion Mechatronics research group's collaboration with its industrial partners.

The first project comprises analysis, verification and validation of the requirements for an already existing system. During the first year, the projects increase in complexity towards performing a complete design cycle. Via masterclasses, students will become familiar with various SE tools and methodologies. As students work on relevant cases and assignments, they can work with and learn under the supervision of experienced systems engineers from industry as well as the research group.

The outcomes will be presented within the TValley Competence Group, closing the important learning feedback loop. It couples the SE competence group directly with the master's degree programme and allows engineers to start low-cost experiments by setting up student assignments using other SE methods. The students' reflections on the applied SE methodology in projects will provide valuable input for the SE competence group. Students can learn from the advice of experienced systems engineers in the field, and at the same time they can provide a fresh look on the way SE is implemented in different companies.

Conclusion

Systems engineering can be studied in an academic way, but just like with cycling, in the end it requires 'learning by doing'. The art of SE is best taught in a master-apprentice setting. We hope we can completely roll out this training programme once the final approval of NVAO has been received in spring 2021. Meanwhile, we will keep on experimenting, sharing best practices and learning from them.

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