



## Research Article

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# An advanced teaching scheme for integrating problem-based learning in control education

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**Abstract:** Engineering education needs to provide both theoretical knowledge and problem-solving skills. Many topics can be presented in lectures and computer exercises are good tools in teaching the skills. Learning by doing is combined with lectures to provide additional material and perspectives. The teaching scheme includes lectures, computer exercises, case studies, seminars and reports organized as a problem-based learning process. In the gradually refining learning material, each teaching method has its own role. The scheme, which has been used in teaching two 4th year courses, is beneficial for overall learning progress, especially in bilingual courses. The students become familiar with new perspectives and are ready to use the course material in application projects.

**Keywords:** control education, problem-based learning, simulation, computational intelligence

## 1 Introduction

Goals of the education of engineering are changing with time. Control engineers need to know the mathematics behind the control concepts and have a wide experience implementing these solutions in real problems [1]. Problem-solving skills and deep understanding of engineering principles best serve the future demands of an engineer during their career [2]. Thus the education of engineers must adapt to meet the new goals. To reach the new goals of education, there are many challenges while planning the curriculum as well as exploring new teaching methods that provide students with the required skills [3]. The challenges in planning the curriculum are not addressed in this paper but some related issues can be found, for example,

from [3–5]. The focus of this paper is on the teaching methods that have been found effective.

Traditional instructional teaching methods, *i.e.* lectures, are not the best possible method in reaching the goals mentioned above [6, 7]. Felder *et al.* [6] suggest that the lecturing should start by providing students with a description of the topic and proceed through examples already familiar to the students instead of giving students immediately with new information. They also suggest that concrete (observations, applications etc.) and abstract (concepts, theories etc.) information should be well-balanced. Also the importance of illustrations and interactive teaching is highlighted in [7]. Virtual and remote labs, which can be found in the internet, have an increasing popularity in control education [8].

Problem-based learning (PBL) aims to activate students to learn [9] and acquire knowledge and improve understanding [10], critical thinking, collaboration and self-directed learning skills [11]. PBL provides incentives and feedback during the learning process, development of skills, peer teaching (explaining to others), drawing conclusions from data, and reflecting on the learning process [12]. Comparisons with traditional instructions have revealed that PBL students had higher levels of intrinsic goal orientation, task value, use of elaboration learning strategies, critical thinking, metacognitive self-regulation, effort regulation, and peer learning compared with control-group students [13]. For teachers, PBL requires considerably more preparation time and resources than the traditional teaching [10]. Comments from students are highly valuable in designing PBL curriculum [14].

Methods for testing and grading have influence on learning [6]. If courses are graded through exams, the exams should be challenging but fair [7]. Continuous assessment is proposed as an alternative to exams. Both types of assessment are often used concurrently in higher education institutions. A question that often arises when formative and summative assessment practices are used in continuous assessment is the extent to which student learning can be facilitated through feedback [15].

Domain expertise is essential in university teaching and the course topics are closely linked to research and in-

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ternational cooperation. Industry is expecting to get cooperative employees with professional skills and willingness to a long term learning in their work. Not everything can be taught with lecturing, but students can achieve a better study outcome if they have a high motivation to do so. Increased motivation may also lead to interests on research, which is beneficial both for current projects and the continuity of the academic area [16, 17].

Problem-based learning is used in this teaching scheme as a primary engine of the course to get the self-study working. Instructional lectures given as classroom education provide fuel for the PBL. Balanced grading is challenging when the scheme includes several types of teaching methods.

This paper is organized as follows. First, a description of the overall teaching scheme with its goals and methods is provided. The ideas presented in [16, 17] are brought to gradually refining teaching practice and extended. Then, the contents of the courses are presented followed by the discussion. Finally, some concluding remarks are given.

## 2 Overall teaching scheme

The teaching scheme aims to active students in their learning process. The guided teaching is helping them in finding the ideas and tools to complete their self-study tasks. The course is a project where the students are researchers and the teachers are project leaders.

### 2.1 Teaching goals

Engineers require deep understanding about engineering principles and problem-solving skills. In order to achieve this, three key areas need to be studied: theory, implementation and application (Figure 1). Deep theoretical understanding gives the basis for the other two fields. Nevertheless what is deep enough in this case? Students need to know the context of the topics and the connections to other engineering topics. In other words, students must recognize what they are studying, why they are studying and what is the significance of the courses. Combined theory and practice also provide a sound basis for methodology development.

Students also need to understand the significant theoretical concepts and be able to combine different concepts to find a solution for the given problem. Beside the theoretical concepts, another significant field of knowledge is how the theoretical concepts are implemented. Nowa-

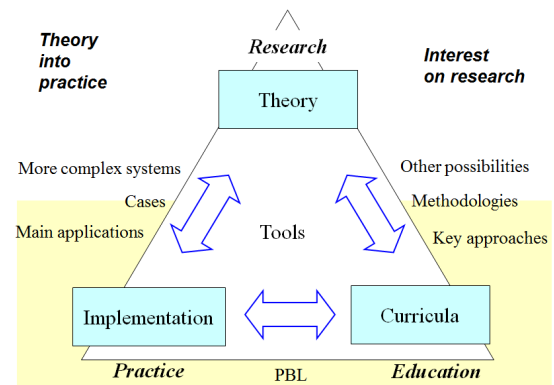


Figure 1: Different aspects of control engineering [17].

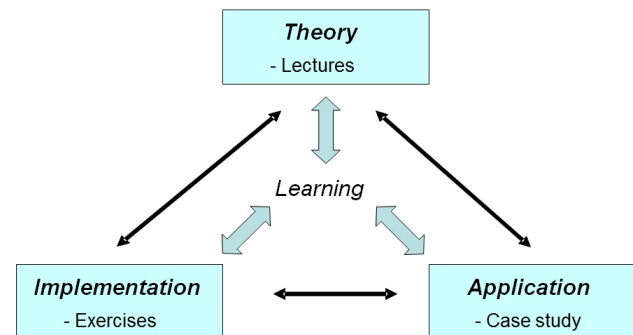


Figure 2: Overall organization of the courses [17].

days, implementation is usually done by computers which make the management of some coding language essential. The last important field on knowledge is how to apply the learnt concepts in real-life problems. Typically, real-life problems are complex and require a combination of different methods in order to find a suitable solution.

The teaching goals are following:

- profound background information,
- deep understanding of theoretical concepts,
- tools for implementing the solutions, and
- tools for applying course topics to real-life problems.

The background, theoretical concepts and links to research are covered in the lectures. Problem-based learning is used in exercises and case studies (Figure 2) to reinforce the tools and to build links to practical implementation (Figure 1). Seminars and case studies are increasingly important in the integrated scheme (Figure 2). Their goal is to strengthen both theoretical and practical knowledge [17]. Seminars are aimed to provide conclusions and ideas for the use of the course topics in the research and practice. Students need to explain their findings to others and open critical thinking during the discussions. Reflecting is included in the final report.

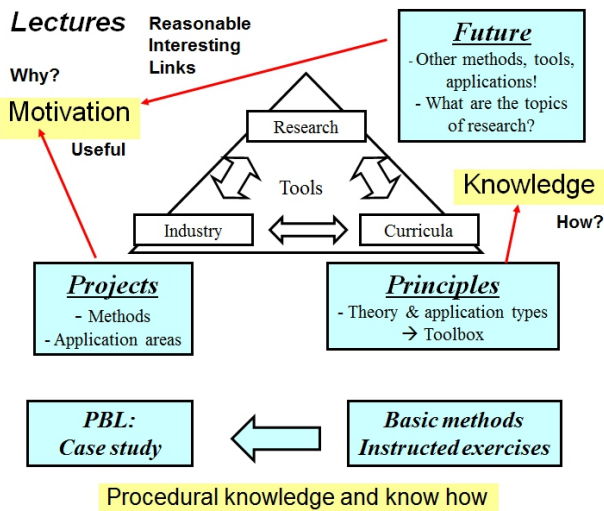


Figure 3: Goals of the lectures, exercises and case studies.

Learning an efficient way of working is as important as the course material since the course can only cover a limited set of methodologies and applications. More complex systems and other methodologies are needed in various applications. Demonstrations of application oriented software packages provide ideas on how the course topics are applied in real applications.

## 2.2 Course organization

The courses focus on theory, implementation and application covered in lectures, exercises and case studies, respectively (Figure 2). The course schedule includes 32 hours guided teaching, consisting of lectures, demonstrations, exercises and seminars. Totally 64 hours are allocated for self-study, which consists of three parts: (1) a case study covering several topics applied in a chosen problem, (2) a seminar work concentrating on a single topic, and (3) the final report.

The lectures are mainly for teaching the theoretical concepts and the practical sessions provide illustrations and implementation of the concepts (Figure 3). The training and testing environment presented in [16] has been used in exercises. Recently, lecture questions have been introduced to help the students to gradually build up the course topic. The questions are given before the lectures in the on-line learning environment Optima [18] and the reports are uploaded in Optima before the following lecture.

The case study is about applying the studied concepts but the interface between different teaching methods is vague: the lectures provide various examples of imple-

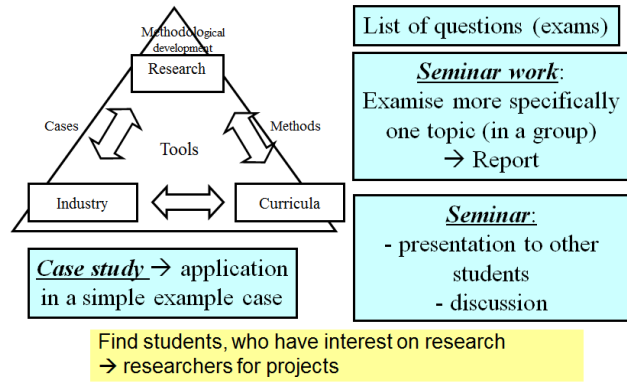


Figure 4: Deepening of the curricula.

mentation and applications, the practical sessions include some theory and show some applications, and the completion of the case study requires understanding of the theory and implementation. Thus the building blocks for overall learning are obtained from all the teaching methods.

In the seminar presentation, students examine more specifically one topic of the course, write a report and give a presentation to other students (Figure 4). The aim of the seminar work and presentation is to obtain deeper understanding about one topic and then contribute that understanding to other students. The seminar presentations are completed in small groups. The group size depends on the number of students participating in the courses. Each presentation is followed by the questions of the opponents and discussions where all students can participate. The goal of the seminar is to summarize the lecture material and experiences obtained during the exercises and case studies. Students need to search for additional material to answer some questions on the advanced applications of their topics. The seminar tasks are given earlier during the course to allow about two weeks to prepare the presentation before the seminar.

After the student presentations, the lecturer presents a concluding lecture on the advanced applications of the seminar topics. The aim of this is to give feedback and some ideas of applying the topics in research and industrial practice, see Figure 1. To avoid extensive theory packages in lectures, some advanced ideas are presented in these seminar lectures. Work during the course provides a better basis for understanding of more complicated topics. After each seminar, the students individually prepare a report about the discussions and other seminar presentations.

The course is concluded by the final report which contains four parts:

- A short description of the combined approach,

**Table 1:** Reports and their assessments.

Report	Primary evaluation	Additional evaluation	Report type	Weight factor
Lecture reports	Theory	Applications	Individual	0.5
Exercises	Implementation	Theory	Group	0.5
Case study	Application	Implementation, theory	Individual	1.0
Seminar	Theory	Application	Group	1.0
Final report	Overall learning	Synthesis	Individual	2.0

- Updated seminar work
- The main points learned from other presentations,
- Experiences from the course.

The lecture questions help the students to gradually build up the combined approach during the course. Learning step by step proceeds towards a personal toolbox for further use and development in practical work.

### 2.3 Teaching environment

The instructional lectures are given as regular classroom education and the lecture notes in Finnish and in English are available in Optima [18]. The practical sessions are given in a computer classroom. Matlab® software is used in the computer exercises [19]. The practical sessions and the case study, also instructed in Finnish and in English, are carried out in small groups (2-3) depending on the number of participants. Also, the seminar work and presentation are completed in small groups since the length of the seminar limits the number of topics. The only individual reports are the lecture reports and the final report.

Simulators and process models are utilized during the practical sessions and the case study. That is due to the fact that both allow the analysis of systems in small parts [20]. Both also suit well for the synthesis where individual concepts are combined to build full applications. The use of simulators and models has earlier delivered good results when it comes to the understanding of the course topics [16].

### 2.4 Teaching and grading methods

During the course, a number of reports are required from students. They must hand in reports about the lecture, practical sessions and case studies. A report is also written about the seminar work together with a final report. When evaluating students' learning progress, each report is graded while having the goals set for the courses in mind. Table 1 summarizes the reports and indicates what

is mainly evaluated from each report. It also shows the additional goals that are evaluated from the reports. The testing and grading system described above demands a great amount of work from students. Thus there is no final exam but only the assessment of reports and presentations is used in grading.

The courses are intensive and grading is based on continuous assessment. The final grade is the weighted average of the grades of the reports (Table 1). The weight of the final report is high since it includes the upgrades of previous reports. The load is smooth since the main parts of the final reports are built during the course and there 5-6 weeks to complete them. Finally, there is no last minute hard work for the exam.

The feedback is given during the course to help and motivate students. Therefore, the lecture reports are discussed during the seminars by raising questions on the difficult matters detected in the reports and the seminar presentation and the opponent tasks are also oral examinations with feedback provided by the lecturer. The final reports indicate the knowledge level obtained during the course. The students learn how to present efficiently and how to be critical. After the seminar, the quality of the reports improves considerably from the draft submitted before the seminar. The grading method takes into account all the stages of the course and motivates to upgrade understanding of the course topic by giving more weight for the aggregated reports: case studies and the final report (Table 1).

## 3 Simulation course

The objective of the course is to provide advanced understanding about the methodologies and applications of simulation. The most important part is reinforced by exercises; other main topics are introduced through lectures and case studies and finally, future ideas are discussed in seminars. After the course, the student is capable of explaining the concepts and operation principles of process

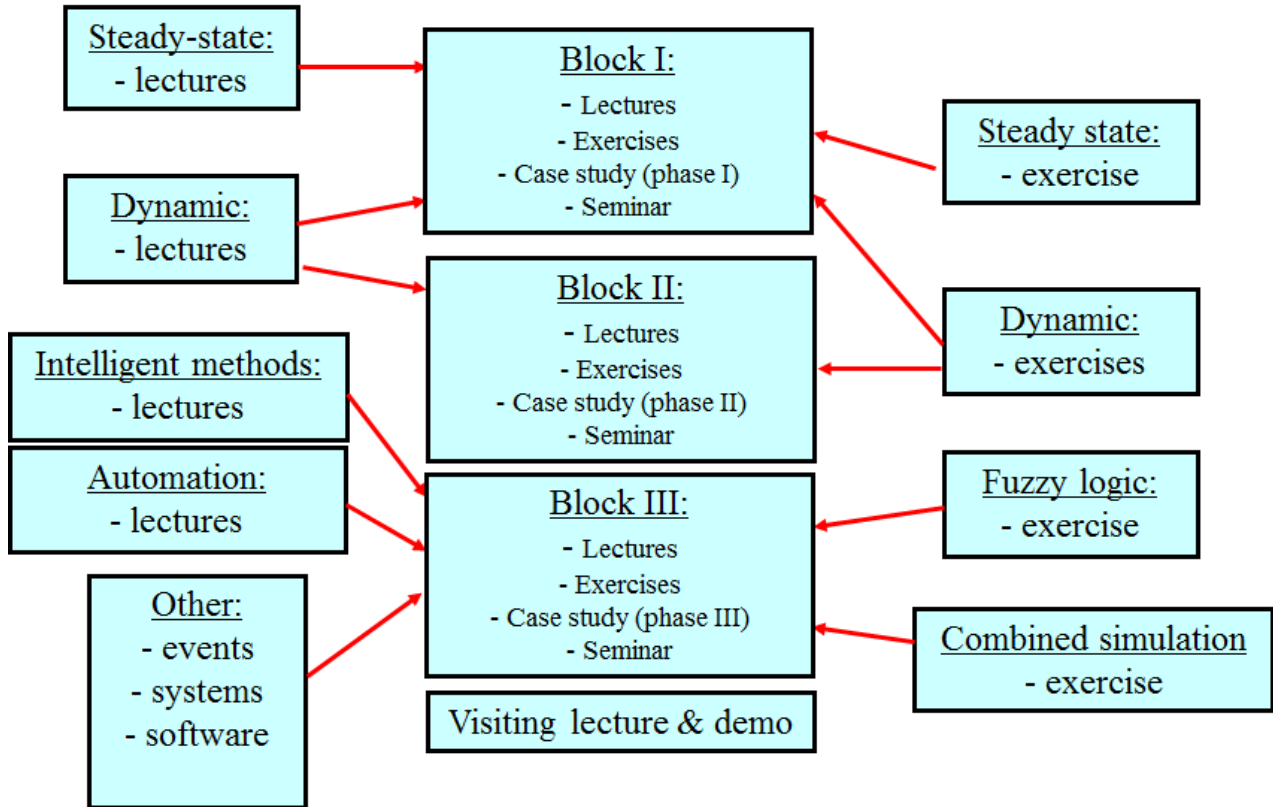


Figure 5: Block structure of the simulation course.

simulators. The student has skills to construct simulation models in Matlab-Simulink environment and to explain the operation of these models. The student recognizes the key problems of the simulation and is able to choose suitable modelling solutions in process modelling and control. Moreover, the student is able to use key concepts of event based, interactive and distributed simulation. After the course, the student is able to search other relevant simulation languages and programming tools.

The main topics of the simulation course are modelling, modular and equation based simulation, dynamic simulation, intelligent methods in simulation, simulation in automation, event handling in continuous simulation, simulation of production processes, distributed simulation, integration with other systems, simulation languages and programming tools.

The popularity of the simulation course is increasing: recently 30 - 40 students attend the course annually. The course is organised by using both Finnish and English since in all years, many exchange students participate in it.

### 3.1 Lectures and seminars

The lectures start by an introductory lecture which aims for given students the context of the simulation. The introductory part discusses the history and development of simulators as well as different types and usage of simulators. The introductory part concludes by presenting the differences between steady-state and dynamic simulators which serve as an introduction to the main topics: steady-state and dynamic simulation, intelligent methods, automation, event simulation and other system integration (Figure 5).

The part of the steady-state modular and equation-based approaches has been reduced during the years. The course focuses on modular simulation, including typical solving methods (sequential and simultaneous) and iterative techniques, and equation oriented simulation. Also combined modular and equation-based simulation is discussed. The dynamic simulation is the main part including several numerical solution methods of ordinary differential equations, integration methods, the typical problems of dynamic simulation and differences between linear and nonlinear models. The first seminar covers the steady-state simulation and the numerical solutions of the dynamic



simulation (Figure 5). The second seminar focuses on the other topics of dynamic simulation.

The course also introduces simulation with intelligent methods, which are discussed with more details in the course "Computational intelligence in automation". Dynamic simulation and fuzzy set systems are used in automation design. The lectures also include material on the discrete event simulation, distributed simulation and integration of simulation to other systems. Also some links to simulation software are given. Recently, functional mock-up interfaces have been added. The third seminar covers all these topics (Figure 5).

Applications ideas are activated in the automation lecture and fuzzy logic exercise. A visiting lecture on the industrial applications of a simulation package has been taken in the program to demonstrate the industrial practice.

### 3.2 Practical sessions and case studies

The practical sessions follow the course topics given above. Throughout the exercises, a few simple process models are studied. The models are a nonlinear model of a tank where the outflow is proportional to the square root of the liquid level, a linear heat exchanger model and a nonlinear reactor model with constant volume. All these can be fused together to build a nonlinear model of a reactor (exothermic reaction) with a cooling jacket.

In the case study, a processing system including a heat exchanger and a reactor with a cooling jacket is studied. Students are assigned to do tasks from all the topics studied during the practical sessions. First, a sizing task is done with temperatures set on different flows in the system. The methods are not predefined but are chosen by students. The next task is to build a dynamic simulator. The dynamic simulator is used to studying how the system should be controlled and students are assigned to build a simulator of the controlled system. The dynamic simulator with predefined disturbances is also used to generate some data. The data is then used to build data-based input-output models of the system.

### 3.3 Course schedule

The course schedule includes three blocks and a visiting lecture which includes an advanced demonstration (Figure 5). Each block starts with lectures followed by related exercises and a seminar which concludes the topic block. Students upload answers to lecture questions and exer-

cise reports in Optima, prepare a presentation and a draft report. The seminar includes 5-7 presentations and time is reserved for opponents and general discussions. After the seminar, students update the reports which will be included in the final report. This schedule is followed in all three blocks.

The case study proceeds in parallel with new topics given in the exercises. The case study and the final report are completed individually within a month after the course.

## 4 Computational intelligence in automation

The objective of the course is to provide advanced understanding about the methodologies and applications of intelligent systems, especially in process automation. Lectures, exercises, case studies and seminars follow the same principles as in the Simulation course. The course is divided into three blocks:

- Fuzzy set systems,
- Neural networks and neurofuzzy systems, and
- Other methodologies.

After the course, the student is capable of explaining the concepts of intelligent systems and operation principles of fuzzy set systems, neural networks, neurofuzzy systems and genetic algorithms. The student has skills to construct and tune fuzzy models in Matlab-Simulink environment and to explain the operation of these models. The student is able to explain the principal concepts of neural computing in an integrating way and construct neural network models in Matlab-Simulink environment. The student recognizes the key problems of the data-driven modelling and is able to choose suitable solutions which ensure generalization. The student is able to explain the operation principles of genetic algorithms and to use them in optimization. Moreover, the student is able to describe alternative solutions for dynamic models, hyperplane methods and hybrid solutions. The student can explain the key concepts of cellular automata and evolutionary computation. After the course, the student is able to search for other relevant programming tools.

### 4.1 Lectures and seminars

The lectures start with the principles of the fuzzy set systems and fuzzy calculus and continue with fuzzy reason-

ing, fuzzy control, adaptive fuzzy control and fuzzy clustering in data-based modelling. The part of neural networks and neurofuzzy systems includes structures, learning algorithms, modelling and control. The third part includes evolutionary computation, linguistic equations, cellular automata, dynamic and data-based intelligent systems, intelligent fault diagnosis and applications to process automation. Examples are shown with Matlab® (Fuzzy Logic Toolbox and Neural Network Toolbox). The seminars are organized in the same way as in the course "Simulation". Three seminars focus on the three blocks listed above. The final reports should contain comments on all the topics.

## 4.2 Practical sessions and case studies

The practical sessions about the fuzzy systems start with the basics of fuzzy logic: fuzzy set theory, membership functions, fuzzy propositions and fuzzy arithmetic. When the students are familiar with the theoretical concepts of fuzzy logic, the exercises proceed to expand the fuzzy propositions to rules and further to systems with multiple rules. With more complex systems, the different parts of fuzzy logic systems (fuzzification, fuzzy inference and defuzzification) are studied more carefully. Also different kinds of fuzzy systems with their pros and cons are presented and illustrated through assignments. The final topic about the fuzzy systems is fuzzy control which is during the practical sessions only illustrated through a demonstration.

The neural network simply illustrates different kinds of neural networks. Especially the differences of different network structures are highlighted. Also, the general concepts of network training are illustrated. Somewhat bigger assignment is carried out about the backpropagation networks. In that assignment, the concepts of overtraining and generalization are studied in more detail.

In the practical session of the genetic algorithm, students are provided with an appropriate Matlab® code for a maximization problem handled with binary-coded genetic algorithms are used. During the session, students are assigned to study the influence of the parameters regulating the evolution of the population. The results are analysed.

In the case study, the case is a simple, nonlinear model of a tank. The study is synchronized with the lectures and exercises and done step by step during the course. The first assignment is to build a fuzzy model for the tank. The model is rather simple but it clearly illustrates how the nonlinearities can be taken into account in fuzzy systems. Also the selection of different operators is significant in

this assignment. The second task is to build and tune a fuzzy controller for controlling the liquid level. The results are compared with the results of a PID-controller. The final assignment is to use genetic algorithms in tuning the fuzzy controller.

## 5 Discussions

The teaching scheme has been developed within two courses started in 1995-96. The courses are "Simulation" and "Computational intelligence (CI) in automation", which was until 2010 called "Fuzzy-neuromethods in process automation". The topics were extended already earlier. A great challenge in both courses is that students have almost no prior knowledge about the contents. Also, no courses about the same topics are available after these so both courses should contain descriptive part, analysis and synthesis. The simulation course was until 2007 arranged for the 2nd year students. The current location as an advanced course for the 4th year students deepens the topic: the case study and the seminars are now increasingly important. The teaching scheme can be used in full for 30 - 40 students in the advanced phase not for 120 students in the 2nd year. The CI course has been all the time on the 4th year.

The schedule, where the lectures, exercises and case studies form a continuing, gradually refining content, has found to be beneficial for overall learning progress. The experiences support the fact that the future ideas should be given at the end of the seminars when the students have worked with basic ideas. The present practice with three seminars, all with 5-7 presentations, is much better than one long seminar with all the topics. The goal of the gradual refinement of the course topic is achieved by the discussions which become more and more active when the experience of the advanced topics grows. The courses are now organized in a similar way.

Both courses have been organized parallel during an eight-week period starting on October. Earlier the simulation course started on the last period of the autumn term and the CI course was done in the spring term. This was a natural sequence of the courses for the students who take both of them. Intensive teaching periods are followed by home and group work. As the tasks are slightly overlapping, group work is encouraged. Running the courses in parallel has been very challenging for the teachers and for those students who take both courses simultaneously. During the academic year 2017-2018, the courses return to

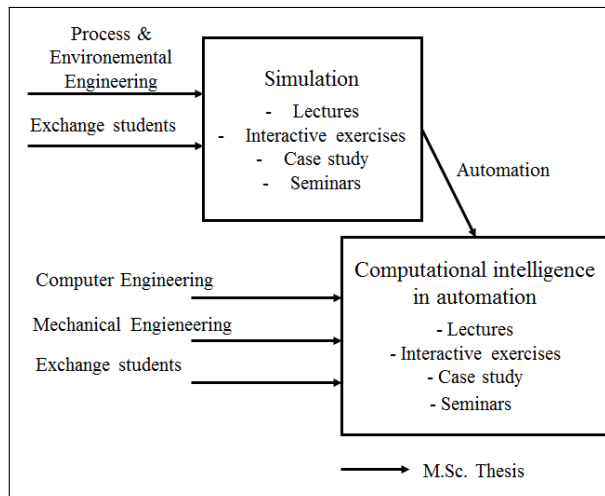


Figure 6: Sequentially organized courses.

the previously used sequential practice: simulation in the autumn and CI in the spring (Figure 6).

Almost all students complete the courses when they take the course the first time. Personal schedules may move some parts to be done later but the modular implementation allows this as well. As a result of this, the common repeating sequence of exams is not activated in these courses.

The scheme has clearly improved learning of basic skills which are needed in application projects. According to the student feedback, the teaching scheme improves understanding of the course topic considerably and the students would like to have more interactive exercises. However, lectures have an important role in integrating the course material and guiding the course towards the overall goals. The lecture questions introduced in the autumn of 2016 have activated students to raise questions and work more intensively during the course. The seminar presentations have been improved and reports are completed faster.

The students come from different education programmes, e.g. process, environment, mechanical and industrial engineering, information processing and computer science, and there is a considerable number of international students in both courses. The bilingual education and versatile goals are facilitated by the problem-based learning. Materials, instructions and reports are in two languages. Cases and seminar works directed towards different education programmes are natural extensions.

The student feedback has been positive every year for both courses: basic topics are well delivered, lectures and exercises provide a good basis and the case study clarifies the content. New perspectives were recognised in the semi-

nars. General assessment is that the work and credit points are in balance and the grading is fair. Only concerns have been about the workload risen for those students who have taken both courses simultaneously. Also for teachers, two courses of this kind are hard to run in parallel. This problem will disappear during the academic year 2017-2018.

## 6 Conclusions

The advanced teaching scheme combines lectures, exercises, case studies, seminars and reports. This teaching practice improves learning results and the students are ready to apply the skills and knowledge acquired from the course material in their thesis work and application projects. According to the feedback, the students have experienced improved learning and recognised new perspectives during the courses which use the gradually refining scheme. The bilingual education and versatile goals of different education programmes are realized with the problem-based learning.

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