# The Road to "ITIV Labs" – An Integrated Concept for Project-Oriented Systems Engineering Education

Thorsten Beuth, Tobias Gädeke, Carsten Tradowsky, Jens Becker, Alexander Klimm, and Oliver Sander

***Abstract*—This article proposes an integrated concept of an ongoing lab series giving electrical engineering and information technology students practical experiences in system engineering, project-based and team-oriented work. Labs start at the first semester with fundamentals based on simultaneously given lectures for three semesters. On the graduate level an adhesive integrated lab concept is offered for a multi-perspective view in the concept of project-oriented systems engineering.**

***Index Terms*—Business engineering, higher education, information processing, systems engineering.**

## I. Introduction

The implementation of the Bologna Process' aims presses the thought of independently designed modular education schemes at universities in Germany [1]. These course modules are usually without strong interconnection and are missing a red thread for students to orientate themselves throughout their course of study. These independent, stall structures waste the potential to motivate the students to benefit from hands-on learning [2].

Due to the Bologna Process the traditional "Diplom-Ingenieur" in electrical and information technology changed to a consecutive Bachelor/Master scheme at the Karlsruhe Institute of Technology (KIT) as well. Though it is possible to finish the course of study with the Bachelor degree, the majority of students still continue for the Master graduation. Therefore the final goal should be an integrated coursework concept from the first semester of the Bachelor studies to the last semester of the Master studies.

The Institute for Information Processing Technologies (ITIV) at the KIT teaches the master's module arrangement of systems engineering. Systems engineering concepts are necessary to design solutions for the need of customers in businesses or other ends [3]. Hence, systems engineering is a key element for future engineers, nevertheless it is often not directly applied in higher education [4].

On the one hand companies have certain expectations [5] on their future employees like working in teams and on projects. On the other hand graduates seem to have a lack in communicational, creativity and project management skills.

Furthermore, the German system of higher education is divided in several styles of universities [6]. For engineering education the technical universities and the universities of applied sciences are in a direct concurrent situation. While the technical universities are mainly focusing on theoretical scientific aspects, universities of applied sciences are focusing on hands-on education, i.e., applied sciences [7]. This is reflected in the educational style of each institution as well.

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## II. The Road to "ITIV Labs"

The issues, outlined above, are tackled by introducing a series of labs throughout the undergraduate and graduate level. Students should learn to use theoretical knowledge in practical engineering work: The students analyze a (given) problem, create a solution concept and finally solve it. In the beginning of their academia life they get strict instructions of solving tasks. But with increasing experience the ways for solving those tasks are getting less restrictive and thereby animate the student's creativity. An overview of the overall here presented integrated lab series is given in Fig. 1.

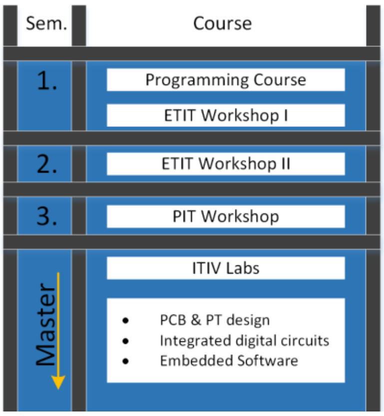


Fig. 1. The integrated concept for hands-on labs by semesters.

An optional course is offered in the first semester to teach programming to students. This course is mentioned in Section III-A. Starting with the first two semesters, students have to take part in a mandatory lab. This lab runs concurrently to the corresponding lectures and teaches hands-on experience of the respective theoretical backgrounds in topics like analogue circuit analysis and design or information processing. The basis for all lab modules is a specifically designed electronic all-in-one platform solution. This lab is presented in Section III-B. In the third semester, students have to take part in a project-oriented lab on information processing technologies for programming a control algorithm for a two-wheel self-balanced vehicle while the all-in-one platform is reused. This course is described in Section III-C.

Students can attend the "ITIV Labs" in their graduate courses. The "ITIV Labs" are using the same two-wheel vehicle as mentioned before. They consist of three integrated project-based block courses with a continuous mutual dependence and shall simulate system engineering as close to industrial reality as possible. The "ITIV Labs" are presented in Section IV.

## III. Fundamental Labs

### A. Programming Course

The programming course is offered by the MINT-Kolleg Baden-Württemberg at the KIT [8]. The MINT-Kolleg's purpose is to support students of technical and natural sciences in their academia life. If a student has not learnt an object-oriented programming language so far, it is recommended by the electrical engineering department to take part in a programming course in C/C++ at the MINT-Kolleg. Otherwise, if the student feels comfortable about his programming skills, it will not be necessary to take part in such a course. Missing knowledge and skills are usually learned on the fly then. Nevertheless basic knowledge in programming is expected in the beginning of the second semester for the "ETIT Workshop" and the course "information processing technologies" consisting of a lecture, a tutorial and a lab.

### B. ETIT Workshop

The "ETIT Workshop" (electrical and information technologies) is an integrated course along the first two semesters for the electrical engineering, mechatronics and some engineering pedagogic students [9]. It covers the four topics of "measurement and regenerative energy creation", "analogue filter and circuit analyses", "sensors" and "digital signal processing". The course uses a self-developed electronics platform called "EI-Board" to suit the overall needs of the different topics which is depicted in Fig. 2. This lab is based on initial team work. The teams consist of a maximum of four members but at least two. The interdependencies of the tasks are tried to be minimalized but existent. The main focus is to force students in first team communication experiences but not to rely on bad outcomes.

Fig. 2. The EI-board in version 5.2.

The "EI-Board" platform consists of an Atmel AT32UC3B0256 microcontroller, several different analogue circuits and power supports for the pre-intensification and creation of signals, eight light emitting diodes for triggering, a microSD-Slot, a 12 MHz quartz for frequency pulsing, a JTAG-connector an USB-Port for communication purposes, as well as power supply. It is under constant development to fit the changes of the workshop to its fullest extent. Nevertheless it is to some extent over engineered since not all features are used by the four courses. On the one hand the reason is to enable students the possibility of using some advanced technologies at home, on the other hand the institutes of the electrical engineering and information technology department can use the same technologies for their hands-on labs as well. Thus a big potential for higher education synergies exists.

The workshop reuses the theory of the lectures to show the students that there is a meaning behind the mathematics and formalisms. In the first part of the course "measurement and regenerative energy creation" students will measure the characteristics of solar cells and understand the charging and discharging of capacitors for energy conservation. In the second part "analogue filter and circuit analyses" analogue circuit design is taught e.g. by designing a low-pass filter for a given microphone filter specification. In the third part "sensors" temperature sensors are used to design a two-level cooling system and light barrier sensors to estimate the speed of an item. The microcontroller is finally used in the fourth part "digital signal processing". The students learn to program a microcontroller in C as well as to use registers for the first time. The final work for this course part is to design a beat detector by estimating the local signal energy. The fourth part is the base for the next lab described in IIIC.

The benefit of such early hands-on course is to on the one hand enhance the connection between theory and praxis but on the other hand a psychological as well. The experience shows that students lose the fear of working with technical instruments and are gaining fun and creativity to an extent that they even ask for or invent more difficult tasks themselves.

The original intention of this lab has been to lower dropout rates in the attending engineering courses [9]. Literature suggests that early hands-on labs are the key element to enhance retention rate [10], [11]. It will be interesting to analyze the data of dropouts in some years whether the intended aim was reached. Nevertheless, the "ETIT Workshop" is used as a base element in the here presented concept for higher education of engineering.

### C. PIT Lab

The "PIT" lab is part of the lecture module information technologies [12]. The module consists of a lecture, exercises, tutorials and the project laboratory. The students receive an open lab task, on which they work during the fall term. Herewith they built on the necessary fundamentals, which were taught in the previous term, to solve the problem. To fulfill the task, algorithms are developed in C/C++, which are further tested and then implemented. These tasks comprise of an integrated problem with project character to program the control of a two-wheel self-balanced single-axis vehicle, the "TivSeg". This work is done with the help of tutors, who provide support in the fields of project management and technical programming questions. The lab comprises of five phases that stretch over seven weeks.

Students usually take part in groups of three people. Since the interdependence of the single work packages is very high and thus students are relying on each other, there is a team work evaluation scheme after the first three weeks to ensure a final success of the group's work.

The starting point is an introduction in the first week, during which the students study the specification and define their project tasks accordingly. In the next phase of one week, the students plan their project by creating the module description with all sub tasks that are necessary to solve the task. Next, during the realization phase that takes three weeks, the students implement all required functions in C/C++ according to their project plan. The students learn the writing of complex C/C++ code and the use of an integrated development environment during the implementation of functional, usable and yet readable code, in compliance with the coding guidelines. This code should be fully functional on a microcontroller platform, whereat skills on hardware, its programming and test are conveyed. For this task, the EI-Board, mentioned in the previous section IIIB, is reused.

Fig. 3. "TivSeg"-platform driven by one of the authors.

In the 6th week, the system test is focused, which is done by building on the module tests that have been used to develop the code. Furthermore the evaluation of the test sequences and appropriate documentation is mandatory to fulfill the project requirements. Then the project can be transferred to the "TivSeg"-platform for the first time. The here presented "TivSeg"-platform is built on top of the "EI-Board" such that the students are able to easily transfer their project to the "TivSeg"-platform.

In the last 7th week of the lab, the students demonstrate their achievements to the other teams, their tutors and the scientific staff. For this purpose, they use the "TivSeg", which they programmed and tested during the course of the project as shown in Fig. 3.

"PIT" is an extraordinary chance to keep the students motivated during the course of the lectures. Even afterwards, they continue to refine their work, contributing own creativity resulting in self-driving "TivSegs". This "TivSeg"-platform is then applied later in the teaching schedule as well. The following section will outline how different parts of the vehicle can be applied as a system engineering concept for teaching on graduate level.

## IV. Advanced Labs

The final course of the integrated lab concept takes place in the master studies. At this point, the students have gained a high theoretical background and are able to solve engineering problems individually. Thus, the lab is based on a project structure with a specific goal but without specifying an approach to solve the problem.

Building on the established concepts and platforms of the earlier labs in the undergraduate levels, the development of the complete electronic control system for the two-wheel vehicle is considered as the goal of the lab. Therefore, the project is split into three concurrent labs, with each of them targeting a major engineering sub-problem. Furthermore, using a project management oriented approach, all individual groups have to synchronize their work schedule, fulfil deadlines and milestones and actively participate in a very tight team-work structure in order to successfully reach the common goal of riding their own implementations of the vehicle's system.

### A. *Integrated Course*

The integrated lab runs fulltime over four weeks and is organized into four phases which are depicted in Fig. 4. It starts for all students with a common introduction, giving basic information on the project goals, project management and systems engineering methods.

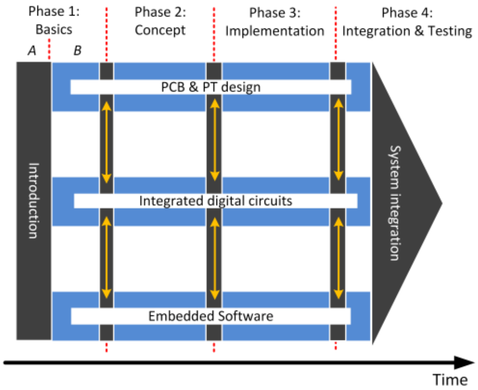


Fig. 4. The four phases of the integrated "ITIV Labs".

A detailed introduction to the necessary computer and hardware tools are given separately in the individual groups. Upon that, the students set up their time schedule, define global project milestones and assign tasks within each group in the conception phase. Also, the technical concepts will be developed during this phase, ending in synchronization with the other groups and assuring the definition of all common hardware and software interfaces. During the implementation phase, the groups individually implement their tasks with strong in-group-synchronization. Finally, all groups come back together for the system integration phase, which will reveal, how well the project has been planned and how the planned interfaces work together finally. Proper supervision during the whole lab reveals possible bottlenecks or misleading strategies to ensure a successful result within the limited time-span.

The interdependence of the group work is here at its highest peak so far. To ensure an overall good team work experience, the students are supervised full time by the tutors. Still, the tutors try not to directly influence the students' solutions but to mediate between different opinions.

By the strong interconnection and the forced overall team meetings, it is intended to enhance the communication skills of the participants. The students are usually specialized in one and not in all of the topics. Thus communication has to be broken down to some extend depending on the communication partner [13].

### B. Interdependent Labs

The three interdependent labs are built on the same two-wheel vehicle "TivSeg" platform. Here, the focus is put on the development of the complete electronic control system and power train of the "TivSeg" platform. Therefore, three individual labs concurrently working on the different subsystems were chosen. These are the circuit board and power train design, the integrated digital circuits' development and the embedded software. In particular, each of these interdependent labs has specific goals.

**Printed circuit boards and power train design:** In this lab, the complete analogue circuit design for the motor control is designed and implemented on a printed circuit board. The design has interfaces to the digital control logic and has to offer flexibility to the embedded software to control the behavior of the system in different scenarios.

**Integrated digital circuits:** This lab designs specific integrated circuits on programmable or reconfigurable hardware platforms. These are typically complex control algorithms, which react in real-time upon certain input parameters.

**Embedded Software:** Within this lab the software to control the platform, including advanced control algorithms are developed. Depending on various user or sensed environmental input parameters the software controls is closely coupled with the digital circuits and the motor control circuits.

From this highly integrated technological system concept it is obvious that design and interfaces have to be carefully specified throughout the whole lab period. The interface specifications between the labs are vital to the work and have to be rechecked by tutors to ensure the functionality of the final system.

The tutors have prepared a set of fully functional system parts of all three courses which fit within the scopes of the courses based on the given specifications. If one of the teams fails to succeed in their development, there is always a finalized backup option for the other teams of the other labs for redundancy purposes.

Nevertheless the student teams are free to build within the given specifications and within a certain given budget, thus encouraging the students in collaboration and creativity.

## V. Conclusion

In this article we have shown an educational series in hands-on engineering education. Starting in the first semester with training in programming and specific analogue circuit design, continuative labs are giving more complex and freed tasks to stimulate the students' creativity and enthusiasm. At the end of this educational chain, the students can participate in an integrated systems engineering course representing project-oriented business engineering from three different perspectives.

The simplicity of the first courses are mainly focusing on the hands-on work. The focus on team and project work rises towards the end when students are depending not even on their own team members but on the students of other lab modules as well. The interconnection experience is enhanced by an integrated course.

It is intentional that students are taken to more complex systems on the base of already known systems. The change from the known EI-Board platform to the same Atmel microcontroller of the two-wheeled vehicle platform and then from the two-wheeled vehicle microcontroller to the analogue and digital circuits, as well as the software design should make the obstacles as small as possible. Also students recognize the platforms as something to identify the hands-on labs with.

In future we are going to implement the last two missing labs "Integrated Digital Circuits" and "Embedded Software" to the planed concept. Experiences are going to be published when some runs of the advanced labs have been done.

The authors are looking forward to help and adept hands-on labs of other institutions to benefit from the so far gathered experience in building up an interdependent lab course series. They hope that this experience and concept report is going to encourage other institutions to follow similar concepts.

The authors want to promote hands-on teaching on university level by showing that higher education in technical universities must not focus purely on the commitment to theory but applying the known to enhance and settle the understanding of lecture materials. On the one hand practical work is now being taught along the overall course of study and not just in the corresponding theses; on the other hand not just universities of applied science can be considered for a future student's applied studies. The authors think that technical universities are going to lose the dogma of theory when interconnected measurements are implemented like in the here presented way.

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