INTEGRATING RESEARCH AND DESIGN ORIENTED SKILLS IN A LEARNING TRAJECTORY FOR ENGINEERING STUDENTS

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Abstract

At educational programs at KU Leuven, a learning trajectory stimulating the development of Research and Design (R&D)-oriented skills is important. The paper studies such a learning trajectory belonging to the electronics-ICT engineering program at the campus in Bruges. Fourteen R&D skills are selected as mandatory learning outcomes. Spread over the curriculum, these skills are learned through a wide range of teaching methods. According to the 'Aalborg model', a range of project types distinguished by different student-centered approaches is introduced. Students experience a sequence of learning activities, being the backbone of a methodical and didactic responsible learning trajectory.

Keywords: Engineering education, learning trajectory, problem-based learning, R&D-oriented skills.

1 INTRODUCTION

Engineering curricula not only provide scientific and technical skills, also R&D-oriented and generic skills are important. Like all academic educational programs at KU Leuven, a learning trajectory stimulating the development of R&D-related skills is important. According to [1], to conduct research in engineering refers to the systematic method used to identify research area, to determine research problems, to formulate research questions and hypothesis. It is important to collect and to analyze data and to reach conclusions towards the formulated problem. It is an opportunity for students to connect theory and practice and to provide satisfaction in overcoming challenges. Consistent with the profile of the 'industrial engineer', students acquire experience in application-oriented research.

In the CDIO approach, structured around 12 principles of practice [2], the skills focus on conceiving, designing, implementing and operating systems in enterprises and social contexts. This approach holds that the product, the process or the system lifecycle (conceiving, designing, implementing and operating) should be the context, but not the content of engineering education [3]. Conceiving, designing, implementing and operating complex value-added engineering systems in a modern team-based environment, is the authentic role of engineers. Graduating engineers should appreciate the engineering process and be able to contribute to the development of engineering products.

In order to develop all scientific, technical, R&D-oriented and generic skills, a curriculum containing a three years academic bachelor (180 ECTS) and a single master year (60 ECTS) is organized. This curriculum contains several learning trajectories. In the present paper, we focus on a learning trajectory belonging to the electronics-ICT engineering program. This particular learning trajectory consists of several consecutive learning activities and is spread out over the whole curriculum. Besides the traditional theory lectures, a broad scope of laboratories are implemented, i.e. classical elementary laboratory sessions, a multidisciplinary project work, problem based laboratories with open smaller assignments, specialized project laboratories and a final master thesis.

In the learning trajectory, problem-based learning (PBL) is introduced as an educational tool gradually gaining importance. PBL is defined as [4] "a learner-centered approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem". The early definitions of problem-based learning adopted at McMaster University Medical School in Canada identify the following characteristics:

- Real world situations that have no single 'right' answer are the organizing focus for learning.
- Students work in teams to face the problem, to identify learning gaps and to develop solutions.
- Students gain new information through self-directed learning (teachers acts as facilitators).
- Problems lead to the development of problem-solving capacities.

Nationally and internationally, the Maastricht University has attracted much attention for the way it developed the student-centered PBL learning approach. Dutch as well as foreign schools of higher

education entirely or partially copied this concept of PBL [5]. A general procedure, guiding this approach to learning, is the so-called 'Seven-Jump' strategy, i.e. a strategy that students use to explain underlying mechanisms, processes or principles of phenomena described in a problem. PBL learning, the approach at the Aalborg University [6,7] i.e. the problem-oriented and project-based learning, is frequently practised. Similar with this 'Aalborg model' which integrates problem-based learning and project work, the learning trajectory contains a range of project types characterised by a gradual minimization of the instructional specifications. A distinction exists between:

- *Assignment project*: characterized by a considerable planning and control by the supervisor: The problem, the subject and the methods are chosen before. The educational objectives are subject-objectives. The supervisor knows exactly what is going to be explored and will direct the students' choices in the planned direction. The students have little freedom to influence the learning process.
- *Subject project*: characterized by subjects chosen before: The students have a free choice of the problem within the subject or the described method(s) to solve a given problem. The educational objectives are subject-objectives. Students are allowed to make choices giving them the opportunity to involve their own interest and to take responsibility for the learning process. The supervisor may be more uncertain but the scientific field is described well and almost no surprises occur.
- *Problem project*: based on problems at the starting point: This means the problem will determine the choice of disciplines and methods which correspond to the original idea of a problem-oriented learning process. The students have to start with a problem, analyze it, find fundamental solutions, choose the right solution and outline strategies for implementation. It is often an interdisciplinary project and allows to analyse and to obtain methodical skills. The problem has to be chosen within a frame, mainly described as a broader topic. Being a supervisor may be difficult because it is a self-directed process and the teacher may find him/herself at the edge of his/her capacity.

In order to obtain the structure of the learning trajectory, we formulated research questions:

- Which R&D-oriented learning outcomes have to be integrated in the educational program?
- Can the chosen learning outcomes be spread all over the curriculum in a well-balanced way?
- How can these learning outcomes be translated into authentic learning activities?
- Can a sequence of these learning activities be the backbone of the learning trajectory?

Section 2 of the paper presents the selection of the R&D-oriented skills of an 'industrial engineer' studying electronics-ICT. In Section 3, the spread of the R&D-oriented skills in the whole curriculum is described. Based on a questionnaire, members of the teaching staff indicate to what extent they realize the learning of the R&D-oriented skills. The results reveal that all the selected skills are taught to the students. Section 4 discusses the learning activities of the learning trajectory, including the teaching methods. Depending on the teaching method, the emphasis lies on different skills.

2 SELECTION OF RESEARCH AND DESIGN ORIENTED SKILLS

Table 1. Kardash based academic skills and 'adapted' electronics-ICT oriented skills.

	Kardash based academic skills	Kardash inspired mainly electronics oriented skills	Kardash inspired mainly ICT oriented skills
Skill 1	Know and understand the contemporary concepts in the scientific field.	Know and understand the contemporary concepts in the scientific and technical field.	Know and understand the contemporary concepts in the scientific and technical field.
Skill 2	Make use of the research literature in the scientific field: journal and conference papers.	Make use of the research literature in the scientific and technical field (datasheets, application notes, papers).	Make use of the research literature in the scientific and technical field (papers, technical documentation).

Skill 3	Formulate a research question based on the current research in the scientific field.	Formulate the goals of the electronic design: What do you want to design? What are the specifications (depending on the state-of-the-art)?	Formulate the research question based on the state-of-the-art: Analyze the functional requirements or specifications. Formulate the functional specifications.
Skill 4	Formulate a research hypothesis based on the research question (a possible answer to the research question).	Make a prototype-concept of the electronic solution based on theoretical knowledge. Make a dimensioning of the prototype (if necessary, use modules to be combined).	Make a prototype application giving an answer to the research question. Make the appropriate choice of the development environment (use a modular approach).
Skill 5	Design an experiment or theoretical test to control the correctness of the hypothesis.	Verify the functionality of the prototype-concept (e.g. using simulations). If necessary, redesign the prototype-concept of skill 4. Only when obtaining satisfying results, go to skill 6.	Validate the prototype based on software testing. Verify the functionality of the application using feedback of users. If necessary, return to skill 4. If acceptance tests are satisfied, go to skill 6.
Skill 6	Understand the importance of “controls” and parameters on the research results. A critical mind is required.	Have a critical mind towards the results when verifying the functionality of the prototype-concept (e.g. correctness of the simulation results).	Evaluate the acceptance tests of the new software product critically.
Skill 7	Observe and collect data.	Build the prototype-concept and test it. Perform measurements on the prototype-concept.	Convert the prototype to a real-life implementation which will be validated by acceptance tests. Split the application in components, formulate requirements concerning the interactions between these components.
Skill 8	(Statistically) analyze the collected data.	Analyze the results obtained by testing the realized prototype-concept (use measurements if possible).	Test software: Test separate modules, test collaborating modules. Collect feedback from future users on the acceptance tests.
Skill 9	Interpret data and draw conclusions concerning the correctness of the original hypothesis.	Interpret the test results and measurements. Draw conclusions concerning the realized prototype-concept.	Interpret the test data and draw conclusions concerning the separate modules.
Skill 10	Reformulate the original research hypothesis (if appropriate). Go back to skill 4 until the research hypothesis is satisfied (by skill 9 and skill 10).	Redesign the prototype-concept (if appropriate). Go back to skill 4 until the prototype-concept satisfies the requirements (by skill 9 and skill 10).	Redesign the concept, including the code (if appropriate). Go back to skill 4 until the prototype-concept satisfies the requirements (by skill 9 and skill 10).
Skill 11	Relate the research results to the “bigger picture” in the scientific field. Compare with existing research results.	After finishing concept and design: Keep an open mind towards improvements and alternatives originating from technical evolutions. Take environmental and economic aspects, safety issues,... into account.	Having finished the product: Keep an open mind towards improvements and alternatives originating from technical evaluations. Maintain the application, apply new strategies and design patterns.
Skill 12	Communicate orally and disseminate the results of research projects (in the own research group, on conferences and symposia).	Communicate orally and disseminate the results of the electronic design (own company, future customers, future subcontractors, ...).	Communicate orally and disseminate the results of the realized design (own company, future customers, future subcontractors, ...).
Skill 13	Write a research paper for publication (journal paper, conference paper).	Communicate on paper about the electronic design (published paper, in company communication, confidential communication).	Communicate on paper about the software design (a published paper, internal communication in the company, user guide, ...)
Skill 14	Think independently.	Think independently.	Think independently.

When considering R&D skills, Kardash [8] formulated 14 skills. We investigate to what extent these 14 skills are realized in the learning trajectory from the point of view of the teaching staff. Since these 14 skills are mainly adapted to pure science students, they do not cover all essential learning outcomes of an engineering program. The existing skills are 'adapted' to the more technical and application oriented profile of the 'industrial engineer'. Since the learning trajectory belongs to the curriculum of the bachelor and master students studying electronics-ICT, electronics and ICT oriented skills are formulated. Table 1 summarizes the academic and the electronics-ICT oriented skills.

3 RESEARCH AND DESIGN ORIENTED SKILLS IN THE CURRICULUM

All teachers involved in the learning trajectory have been asked to indicate to what extent their learning activities contribute to the acquisition of the selected skills, using a ten point scale. They were able to choose between the 'Kardash based academic skills', the 'Kardash inspired mainly electronics oriented skills' and the 'Kardash inspired mainly ICT oriented skills' (with the possibility to choose more than one single series of skills) as given in Table 1. The results of this questionnaire on the three series of skills are combined and averages (av.) and standard deviations (st.dev.) are calculated (Table 2). A distinction is made between traditional theory lectures (THEO. LEC.), classical laboratory sessions (CL. LAB. SES.), the multidisciplinary project work (MULT. D. PRJ.), the problem based laboratories with smaller projects (LAB. SM. PRJ.), the specialized project laboratories with larger electronics-ICT projects (LAB. LRG. PRJ.) and an electronic engineering or ICT engineering master thesis (MSTR. TH.). For each skill the three teaching methods having the largest average rating are indicated in bold. Based on Table 2, conclusions arise as discussed in Section 3.1 and Section 3.2.

Table 2. Teaching the selected skills using different teaching methods.

	THEO. LEC.		CL. LAB. SES.		MULT. D. PRJ.		LAB. SM. PRJ.		LAB. LRG. PRJ.		MSTR. TH.	
	av.	st.dev.	av.	st.dev.	av.	st.dev.	av.	st.dev.	av.	st.dev.	av.	st.dev.
Skill 1	8.50	1.02	4.56	4.09	6.90	2.43	8.00	0.63	8.80	0.98	8.71	0.88
Skill 2	1.70	2.05	3.44	3.20	7.90	1.22	6.60	2.87	8.20	0.98	9.29	0.70
Skill 3	2.90	2.51	1.11	1.10	8.00	1.90	7.20	1.17	8.80	0.98	8.86	0.83
Skill 4	3.10	2.91	0.56	1.57	7.80	1.83	7.20	3.19	9.80	0.40	8.71	1.16
Skill 5	3.10	3.11	5.33	3.65	7.60	1.62	7.00	2.61	8.60	1.36	8.43	1.05
Skill 6	4.90	3.05	5.78	4.34	7.60	1.85	8.00	0.89	8.00	0.89	8.00	1.31
Skill 7	2.30	2.76	7.56	4.09	8.40	1.20	8.80	1.17	7.80	2.71	6.71	1.28
Skill 8	2.80	3.52	6.67	4.71	7.30	2.53	7.40	1.50	6.40	1/02	6.14	2.10
Skill 9	3.20	3.94	9.11	1.10	8.10	1.37	9.00	0.63	7.20	1.94	7.71	1.48
Skill 10	3.10	3.14	0.22	0.63	6.80	2.52	6.40	2.80	7.60	1.20	8.14	0.64
Skill 11	3.70	3.49	0.56	0.83	6.50	2.11	5.00	2.61	4.60	3.01	7.00	1.69
Skill 12	2.00	2.93	1.00	2.21	8.60	1.02	3.60	3.14	10.00	0.00	9.00	0.53
Skill 13	1.20	1.54	5.89	4.28	4.90	3.01	6.40	3.20	9.40	0.80	8.14	3.09
Skill 14	5.20	1.17	2.22	2.25	7.20	1.78	8.80	0.98	9.40	0.80	8.57	0.49

The 'Kardash based academic skills' are dominant in the first three semesters of the learning trajectory where engineering students with different technical orientations share the same curriculum. Having a scientific foundation after these three semesters, the curriculum evolves to a more technical-scientific focus from the fourth semester where the 'Kardash inspired' skills gradually gain dominance. Already from the semester 3, the 'Kardash inspired mainly electronics or ICT oriented skills' arise and they are dominant from semester 4 in the academic bachelor where only students having specialty electronics-ICT follow the learning trajectory. The multidisciplinary project work [9] in semester 3 combines all three series of skills, linking the polyvalent base to the specialized semesters.

3.1 Conclusions for individual skills

Skill 1: 'knowledge and understanding' is very important when considering theory lectures (average: 8.50), laboratories with larger projects (average: 8.80) and the master thesis (average: 8.71). In order to achieve the main goal of theory lectures, these lectures mainly contain a 'closed table of contents' where all students gain the same knowledge and understanding. All projects in the laboratories have a more 'open table of contents'. Students gain different knowledge since the learning process is partially guided by the students (teacher acts as a coach). When considering the classical laboratory sessions with assignment projects, the contribution to skill 1 is moderate (average: 4.56). The standard deviation in the answers is high (st. dev.: 4.09). In some laboratory sessions, the students gain new knowledge but in other laboratory sessions knowledge studied before in theory lectures is practiced.

Skill 2: 'using the literature' is important when considering the master thesis (average: 9.29), the laboratories with larger projects (average: 8.20) and the multidisciplinary project work (average: 7.90). For solving a problem, information is needed which is not given by teachers. This is also the case when considering laboratories with smaller projects (average: 6.60). When regarding classical laboratory sessions (average: 3.44) and theory lectures (average: 1.70) the teachers themselves supply almost all the information. Concerning the use of literature, skill 2 can be strictly interpreted as only a consultation of scientific papers as is the case with the pure scientific skill of Kardash. It can also be interpreted in a more general way as it is done by the Kardash inspired electronics or ICT oriented skills. This diversity in interpretation implies a larger standard deviation of the answers.

Skill 3 and skill 4: In general, there is a large correlation between skill 3 'formulating a research question' and skill 4 'formulating a research hypothesis' when comparing different teaching methods. When considering the project oriented teaching methods, skill 3 and skill 4 are important. Regarding the laboratories with larger projects (average: 8.80 and 9.80) and the master thesis (average: 8.86 and 8.71), they are even more important. Skill 3 and skill 4 are not given a chance in theory lectures (average: 2.90 and 3.10) and in classical laboratories (average: 1.11 and 0.56). In classical laboratory sessions, the research question and hypothesis are generally formulated by the teacher himself.

Skill 5 and skill 6: In general, there is a large correlation between skill 5 'testing' and skill 6 'having a critical mind' when comparing different teaching methods. Skill 5 and skill 6 are mainly educated in project based teaching methods. Thanks to the growing importance of these teaching methods as the learning trajectory progresses, skills 5 and skill 6 also gain importance as the students go through the learning trajectory. Skill 5 and skill 6 have limited importance in the theory lectures (averages: 3.10 and 4.90) and in the classical laboratory sessions, (averages: 5.33 and 5.78).

Skill 7, skill 8 and skill 9: There is a large correlation between skill 7 'collecting data – measuring', skill 8 'analyzing data' and skill 9 'drawing conclusions' when comparing teaching methods. These skills are basic engineering skills (performing measurements, analyzing data, drawing conclusions) which are extensively practiced in the classical laboratory sessions in the first three semesters. The averages (7.56, 6.67 and 9.11) are higher than the averages of all other skills. These three skills are also important when considering the multidisciplinary project work and the project based laboratories. They are also relevant in the master thesis (averages: 6.71, 6.14 and 7.71).

Skill 10: There is a large correlation between skill 10 'reformulating research hypotheses – redesigning prototype-concept' and skills 3 and 4 for all teaching methods. Skill 10 is mainly important for the project based teaching methods.

Skill 11: In general, 'relating results to the bigger picture' gets less attention. Skill 11 is mainly taught by the master thesis (average: 7.00) and the multidisciplinary project work (6.50) which illustrates the broader approach of these teaching methods. The multidisciplinary of the engineering curriculum also originates from an overall set of several learning trajectories studying different topics (mathematics, mechanics, electronics, economics,...). Therefore, this type of multidisciplinary is not detected in one single learning trajectory. When considering the project oriented laboratory sessions, the importance of skill 11 is moderate (averages: 5.00 and 4.60) since these laboratory sessions are specialized in electronics and ICT related topics. In theory lectures, the average equals 3.70 and in classical laboratory sessions, only the very low average of 0.56 is obtained. Classical laboratory sessions are mainly taught to practice the more basic engineering skills 7 to 9 and not to "show the bigger picture".

Skill 12: 'communicating orally' is mainly practiced in the specialized project laboratories (average: 10.00), the master thesis (average: 9.00) and the multidisciplinary project work (average: 8.60). In all these cases, the students have to present and defend the results of their project work in front of a jury. As for the master thesis and the multidisciplinary project work, a public defense is organized implying

a jury which also contains external members from society and industry. Students not only give a PowerPoint presentation, they also must answer critical questions. For all other laboratory sessions, the students are mainly evaluated based on written reports implying skill 12 is not really practiced. In the first three semesters of the curriculum mainly written examinations are used to evaluate the knowledge and understanding of the students with the result that skill 12 is also not really practiced.

Skill 13: 'communicating on paper' is mainly practiced in the project oriented laboratories (averages: 9.40 and 6.40) and the master thesis (average: 8.14). Also the classical laboratory sessions (average: 5.89) and the multidisciplinary project work (average: 4.90) contribute to the development of the writing skills of the students. Skill 13 can be strictly interpreted as writing a scientific paper as is the case with the pure scientific skill of Kardash. However, it can also be interpreted in a more general way as it is done by the Kardash inspired electronics or ICT oriented skills (writing a technical report). This diversity in interpretation is reflected in a larger standard deviation of the answers (st. dev.: 4.28 and 3.01). Although the knowledge and understanding of the students are mainly evaluated using written exams, these exams mainly test skill 1 (average: 8.50) and are not intended to test skill 13. Notice the master thesis implies the writing of an extensive report of the research activities.

Skill 14: 'thinking independently' is very important when considering all project related teaching methods (averages: 9.40, 8.80, 8.57 and 7.20). Despite the open formulation of skill 14, rather small standard deviations are obtained (st. dev.: 0.98, 0.80 and 0.49) which indicates all teachers agree this skill is really practiced. When regarding the theory lectures, a moderate average of 5.20 is obtained although mainly the teacher guides the way of thinking. By following the arguments of the teachers, the students learn to think in a scientific and correct way. This attitude has an increasing importance when students go through the learning trajectory where the importance of skill 14 is increasing.

Concluding remarks: In general, using different teaching methods, we succeed to increase gradually the importance of the skills as the students go through the learning trajectory, ending in the complete integration of all skills in the master thesis. In the next paragraph, we will focus to these different teaching methods and their ability to teach the selected skills.

3.2 Conclusions for different teaching methods

In the learning trajectory, a distinction is made between traditional theory lectures, classical laboratory sessions, a multidisciplinary project work, problem based laboratories with smaller projects, specialized project laboratories with larger electronics-ICT oriented projects and a master thesis. Based on the results of Table 2, a number of conclusions arise.

Theory lectures: Theory lectures are mainly taught to give students basic scientific-technical knowledge and insight providing a solid base for the entire learning trajectory. When considering these theory lectures, skill 1 'knowledge and understanding' is very important (average: 8.50) but all other skills have low averages. Only skill 14 'thinking independently' has an average value of 5.20. The teachers learn students to think although the teacher guides the way of thinking.

Classical laboratory sessions: These basic laboratories mainly practice skill 7 'collecting data – measuring', skill 8 'analyzing data' and skill 9 'drawing conclusions'. These research skills will be needed later on in the learning trajectory. Since students write reports on their experimental results, mainly skill 13 'communicating on paper' (average: 5.89), and not skill 12 'communicating orally' (average: 1.00), is practiced. These classical laboratory sessions have really low averages when considering skill 3 'formulating a research question', skill 4 'formulating a research hypothesis' and skill 10 'reformulating research hypotheses – redesigning prototype-concept'. These research aspects are indeed performed by the teacher and not by the student.

Multidisciplinary project work: The multidisciplinary project work in semester 3 teaches nearly all selected skills. When considering for each individual skill the three teaching methods having the largest average rating, the multidisciplinary project work accounts for 10 different skills (this number is only higher for the specialized laboratory sessions and for the master thesis).

Problem based laboratory sessions with small projects: The lowest average is obtained for skill 12 'communicating orally' since the students mainly communicate in a written manner. All the other skills are quite important in this teaching method.

Project laboratories with larger electronics-ICT oriented projects: Except for skill 11, the specialized project oriented laboratory sessions teach all skills. Teaching large numbers of skills demands a

steady observation. Since these laboratories teach specialized electronics-ICT research and design techniques, less attention goes to skill 11 'relating results to the bigger picture'.

Final master thesis: The master thesis, which accounts for 20 ECTS, is an appropriate way to teach all 14 skills. The master thesis contains a lot of different learning activities. More precisely:

- Students have to consult and study scientific and technical literature and information.
- They have to (re)formulate their research question(s) and they have to find and test several solutions. In general, measurements and tests are needed and the obtained results need interpretations which influence the evolution of the master thesis.
- The master thesis contains an internship (6 weeks) in a university research laboratory or in the industry. This internship is important from a technical point of view but it also forces the students to communicate with, to collaborate with, to help ... other people.
- Using written reports, personal contacts and a daily logbook, the students communicate and collaborate with their coaching teacher.
- The students need to present their work by writing an extended final report. Finally, the students give a PowerPoint presentation and they must answer critical questions posed by a jury.

4 LEARNING ACTIVITIES OF THE LEARNING TRAJECTORY

The considered learning trajectory contains:

- traditional theory lectures (THEO. LEC.) including physics, chemistry, electricity and electronics in the first three semesters of the curriculum of the academic bachelor,
- classical laboratory sessions (CL. LAB. SES.) including physics, chemistry, electricity and electronics in the first three semesters of the curriculum of the academic bachelor,
- a multidisciplinary project work (MULT. D. PRJ.) in the semester 3 of the academic bachelor [9],
- problem based laboratories with smaller projects (LAB. SM. PRJ.) including analog electronics, digital electronics, programming techniques, digital signal processing in the fourth, fifth and sixth semesters of the academic bachelor and the first semester of the master program,
- specialized project laboratories with larger electronics-ICT oriented projects (LAB. LRG. PRJ.) in the sixth semester of the academic bachelor and the second semester of the master program,
- an electronic/ICT engineering master thesis (MSTR. TH.) in both semesters of the master program.

Table 3. Overview of the project types of the 'Aalborg model'.

Project type	Approach	Structuring by the teaching staff	Self management by the students
Assignment	Closed	Entirely	Results-oriented
Subject	Semi-open	Partially	Results- and approach-oriented
problem	Open	Limited	Results-, approach-, problem-oriented

Similar with the 'Aalborg model' which integrates problem-based learning and project work, the learning trajectory contains a range of three project types. Summarized and visualized in Table 3, these three project types have different approaches. The assignment project, the subject project and the problem project have respectively a closed, a semi-open and an open approach. This continuum of approaches is characterised by the decreasing structuring of the supervisor and the increasing self management of the students. The projects have an increasing complexity and size.

4.1 Classical laboratory sessions (CL. LAB. SES.)

In order to develop the necessary basic research skills (section 3.2), the students have to carry out short-term learning activities in the classical laboratory sessions of the first three semesters of the curriculum. In small groups (i.e. groups of 2 students), they perform uncomplicated experiments during one session obtaining measurement results and observational data.

The instructional specifications are substantial and consist of introductions, demonstrations and simulations. Furthermore, the step-by-step plan is fixed and written out by the teachers. There is an intense coaching of the teachers. They assess the students level of experimental preparation, monitor the experimental realizations and intervene if necessary. By giving the students the support just in time, the students gain a clear understanding of the technological matter. Finally, the teachers read the reports of the students carefully and add constructive feedback.

Typically for the assignment project (Table 3), the learning activities are entirely closed. The problem is defined and the procedures are fixed by the teachers. The teachers know the outcome of the problem solving and guide the students in the planned direction. Having everything under control, the supervisors can be definitely certain. The level of self-management skills of the students is low.

In conclusion, the classical laboratory sessions are a teaching method which enables the students to use skill 7 'collecting data – measuring', skill 8 'analyzing data' and skill 9 'drawing conclusions'.

4.2 Multidisciplinary project work (MULT. D. PRJ.)

The objectives of the multidisciplinary project work in the third semester of the academic bachelor are the development of all R&D-oriented skills on an elementary level and the enhancement of the problem solving capacity. Co-operating in a project group (a group of 5 or 6 students) under the supervision of a coach, the students perform an assignment during the whole semester. Using a systematic approach, they solve a realistic and relevant problem resulting in a concrete product.

The project coach outlines a clearly multidisciplinary problem, situated in a real-world setting, i.e. a professional environment in which the project problem takes place. During the first week of the semester, an introductory seminar takes place to explain the concept of the project work and to present the different projects. With exception of this introductory seminar, no 'ex cathedra' lectures are organized. The problem solving process of the students is built up by a step-by-step plan developed by the didactic team [9] and based on the seven-jump strategy. During the weekly face-to-face meeting with the project coach, the students report on the progress of their project work and receive feedback concerning the planning, the time management, the teamwork and the research methodology. The project coach helps to identify appropriate research literature, the coach comments drafts and discusses the different points of view. This learner-centered interaction offers the opportunity to cover the broad range of 14 R&D-oriented skills (section 3.2).

Typically for the subject project (Table 3), the learning activities in the multidisciplinary project work are semi-open. Although the problem is defined by the project coach, the coach does not know the outcome of the problem solving in advance. He does not determine the procedures to explore several pathways which may result in a good solution. All this unclear elements lead to a less comfortable setting for the project coach. However, the whole approach falls within his own spheres of competence. Students have an impact on the results and on the problem solving approach searched and found by themselves.

4.3 Problem based laboratories with smaller projects (LAB. SM. PRJ.)

In the fourth, fifth and sixth semesters of the academic bachelor and the first semester of the master program, problem based laboratories with smaller projects are organized for the electronics-ICT students. One particular problem laboratory will be considered as an exemplary case, i.e. the laboratory "digital design" in semester 5. The general objective of the laboratory "digital design" is the development of the problem solving capacity of the students. In a first session, the students are introduced into the appropriate use of the digital electronics development environment. Subsequently, they fulfill small assignments taking one or two sessions in a small group (i.e. a group of 2 students). At the end of the semester, the last project is slightly larger and stretched out over 3 to 4 sessions.

Each small project includes a clear and authentic problem inspired by theory lectures on digital electronics. In the last project, combining all topics previously seen, the students are expected to identify all the basic building blocks of the larger entity and to work out these blocks one by one. As concerning the instruction specifications, a larger self-reliance of the students is expected. No manual and no step-by-step plan are available. Leaving the preparation and the planning for the project to the students own initiative, they have to consult the theory. The theory lectures treated the problem solving strategy and is therefore perfectly matched with the laboratories.

The coaching of the teacher consists of asking explanatory questions to the students. In addition, the teacher supports the students by answering their questions. After ending a small project, the teacher

examines the proper functioning of the project outcome, verifies the followed working method and checks the originality of the experimental work. The students submit a report, containing the solution and conclusion of the small project. There is, however, no formal assessment of the experimental preparation of the project. After demonstration of the last project, the teacher gives detailed personalized feedback about all the previous projects. Typically for the subject project (Table 3), the learning activities in the problem based laboratories with smaller projects are semi-open. The teacher who defines the authentic problem and knows the appropriate problem solving strategy, is convinced that a well-functioning solution of the problem exists and can be found through different pathways.

In conclusion, the problem based laboratories with smaller projects is a teaching method that allows the students to develop all R&D skills (with the exception of skill 12 'communicating orally') by means of a diversified and partially structured instructional concept, creating substantial openings to a results- and approach oriented self management for the students.

4.4 Project laboratories with larger electronics-ICT projects (LAB. LRG. PRJ.)

The specialized project laboratories with larger electronics-ICT projects are part of the program of the sixth semester of the academic bachelor and of the second semester of the master. These laboratories aim the development of all R&D-oriented skills on an advanced level.

The students are working alone or they are working in a group (a group of 2, 4 or 5 students). They have to solve systematically a complex research/design problem requiring a targeted search of the literature. Each teacher constructs several projects to realize a subject-matter diversity. In a first session, the organization of the laboratory as well as all new projects are presented. The students are allowed to express a preference for a particular project.

The instructional specifications are limited to the minimum, i.e. there is no manual. The supporting feedback has specific characteristics; it is demand-driven consequently 'tailor-made'. Each teacher coaches the students who work out his projects and checks the students work in progress during the weekly laboratory sessions. In case problems occur, the student has to take initiative to contact his coach and/or other staff members. The students give twice an intermediate presentation to the whole didactic team. In the last week of the semester, the students present and defend their project results in front of a jury consisting of the whole didactic team and other staff members.

Typically for the problem project (Table 3), the learning activities in specialized project laboratories with larger electronics-ICT oriented projects are open and not structured by the teaching staff. The teacher who defined the complex research/design problem, does not know at all the outcome of the project. Due to the unpredictability of the project, he may feel less comfortable but his research excellence will ensure that he is not confronted with any major surprises.

In conclusion, the specialized project laboratories with larger electronics-ICT oriented projects are a teaching method considering all R&D skills (with the exception of skill 11 'relating results to the bigger picture'). In the context of a specialized and complex project, the students apply these acquired skills autonomously, although under the careful oversight of the educational staff.

4.5 Final electronic engineering or ICT engineering master thesis (MSTR. TH.)

The engineering master thesis teaches all R&D-oriented master skills in combination with a number of generic skills. The results of Table 2 indicate the master thesis, which accounts for 20 ECTS, is indeed appropriate to teach all 14 selected skills. The master thesis is a teaching method integrating all R&D skills which the students utilize quasi-independently in a real-world and high-tech research setting.

The master thesis is realized in an external collaboration with the industry (emphasizing the profile of the so-called 'industrial engineer') or in a university research laboratory (embedding scientific and technical research in the educational system). The students have to formulate their research question(s) and they have to find and test several solutions based on the available scientific and technical literature. In general, measurements and tests are needed and the obtained results need interpretations. The master thesis contains an internship in the industry or in a university research laboratory. The students need to present their work by writing a final report. Finally, they give a PowerPoint presentation and they must answer critical questions posed by a jury.

The instructions are limited to the minimum. The students are supervised by a member of the teaching staff, often in cooperation with an external coach active in the industry. The supervisors mainly

evaluate the first 11 skills in Table 1. The students have evaluations midway (December) and at the end (June). The evaluation of the internship (March) mainly focuses on generic skills since students need to collaborate with, to help, to communicate with other people during their internship. The evaluation of skill 12 is mainly performed by the jury while judging the PowerPoint presentation and defense of the master thesis. Skill 13 is mainly evaluated by the supervisor based on the final report.

Typically for the problem project (Table 3), the master thesis is not structured by the teaching staff. The open approach is comparable to the educational method of the specialized project laboratories with larger projects. Since the research problem is defined by the external coach, the teacher does not know at all the outcomes of the master thesis. The students rely on their self management skills, developed during their previous years of study.

5 CONCLUSIONS

A learning trajectory stimulating the development of R&D-oriented skills is important in the engineering education. The present paper focused on such a learning trajectory belonging to an electronics-ICT engineering program at KU Leuven. Fourteen R&D skills are selected. Spread over the curriculum in a coherent way, these skills are learned through a wide range of teaching methods: classical laboratory sessions, a multidisciplinary project work, problem based laboratories with smaller projects, specialized project laboratories with larger electronics-ICT projects and a final electronic or ICT engineering master thesis. This approach is supplemented by lectures providing the theoretical foundation. According to the 'Aalborg model', a range of three project types distinguished by different student-centered approaches is used. The continuum of these approaches is characterized by the decreasing structuring of the supervisors and the increasing self management of the students.

REFERENCES

- [1] R. Said, A. Kaba, "Exploring Research Skills among Undergraduate Students of Private Universities in UAE", IEEE Global Engineering Education Conference (EDUCON) – "Learning Environments and Ecosystems in Engineering Education", pp. 260-264, 2011.
- [2] E. Crawley, J. Malmqvist, S. Östlund, D. Brodeur, "Rethinking Engineering Education: The CDIO Approach, New-York: Springer – Verlag, 2007.
- [3] E. Crawley, Cha Jianzhong, J. Malmqvist, D. Brodeur, "The Context of Engineering Education", Proceedings of the 4th International CDIO Conference, Hogeschool Gent, Gent, 2008.
- [4] J. Savery, "Overview of Problem-Based Learning: Definitions and Distinctions", Interdisciplinary Journal of Problem-Based Learning, vol. 1, no. 1, pp. 9-20, 2006.
- [5] J. Moust, H. Van Berkel, H. Schmidt, "Signs of erosion: Reflections on three decades of problem-based learning at Maastricht University", Higher Education, vol. 50, pp. 665-683, 2005.
- [6] A. Kolmos, "Reflections on Project Work and Problem-Based Learning", European Journal of Engineering Education, vol. 21, no. 2, pp. 141-148, 1996.
- [7] K. Edström, A. Kolmos, "PBL and CDIO: complementary models for engineering education development", European Journal of Engineering Education, vol. 39, no. 5, pp. 539-555, 2014.
- [8] C.M. Kardash, "Evaluation of an Undergraduate Research Experience: Perceptions of Undergraduate Interns and Their Faculty Mentors", Journal of Educational Psychology, vol. 92, no. 1, pp. 191-201, 2000.
- [9] A. Janssens, R. Rousseau, P. Coudeville, L. Scherpereel, P. Vandegehuchte, L. Vanden Abeele, J. Vanderhaeghen, W. Haegeman, "An Example of Multidisciplinary Project-based Education in the First Phase of the Bachelor in Industrial Sciences: The Scientific Project", Higher Education Research & Evaluation, vol. 5, pp. 70-74, 2008.