Introduction of research labs in the engineering curriculum

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INTRODUCTION

This paper describes the introduction of ongoing research activities in the engineering curriculum using an multidisciplinary approach incorporating several courses from the master year. The research topics were delivered by the research groups Lab4U (Environmental and process technology) and Cel Kunststoffen (Polymer processing and technology) which support the master of Science in Chemical Engineering.

In the framework of the Bologna declaration of 1999 [1] the engineering educational programme at the Flemish university colleges was confronted with the requirement to follow a more academic approach in the framework of integration in the university and of a qualified master programme. Moreover an internal and external curriculum audit pointed out that the visibility of the ongoing research activities in the curriculum should be improved.

The idea was launched to introduce a research lab, which helps the students to obtain the necessary competences in research and development. Through the involvement of the own research groups supporting the research lab, all students are also introduced to the ongoing research.

1 HISTORY AND INTRODUCTION

A first phase of research labs was introduced in 2007 at a relatively small scale (1 ECTS - approximately 25 hours over three weeks) starting with a dedicated research question and background information at the beginning of the lab phase from an ongoing research project within the LAB4U group. However, given the short period, students were not able to combine and / or structure existing knowledge in order to create a basic research plan on their own, which was one of the main objectives.

Therefore in 2009, the master curriculum was changed by the introduction of a preparation period during the first semester including an early presentation of the research area and ongoing challenges, followed by dedicated seminars and labs and a visit to a specialized research centre (University of Göttingen,Germany). Based on this background information and a literature review, students had to propose their own research question related to the presented context and define a (labscale) process which could be improved by the use of technologies provided by the research group. They had to specify which methods, experimental set-up and materials they needed before the lab phase started. However, students turned out to focus on experimental details as set-up but missed a structured approach in planning their experiments and using literature information to define the range of experimental conditions.

As a result the integrated approach was in 2010 extended by introducing a course on “Design of experiments (DOE)” in the engineering curriculum during the first semester offering statistical tools and a methodological approach for the design of experiments. Students were also obliged to perform a literature review on the topic starting from a given set of 10 publications which had to be extended depending on the group size. As student numbers doubled over this period, the research group Cel Kunststoffen (*polymer processing and technology)* also became involved. It turned out that with small adaptations within specific context related courses in the master year, the developed concept could be easily extended to another research area based on the same common core curriculum during the first semester. Finally, over the last period 2010-2013 twelve research labs were organized according to the approach described above.

The aim of this work is to present the general approach and implementation in the curriculum in different courses. For each course, the specific approach and aimed ojectives are presented in general. Afterwards, this approach is illustrated by two different case study’s e.g. a research lab on acoustic crystallisation supported by Lab4U and a research lab about water injection moulding supported by Cel Kunststoffen. Finally, based on five years of experience, some findings and recommendations on implementing research labs in the engineering curriculum are made

2 GENERAL APPROACH AND LEARNING OUTCOMES

2.1 Definition of research and competences

The definition of research and competences from Frascati [2] was followed:

Research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications.

Also the criteria/competences for an academic master degree [3] were stated in Table 1. The different competences are evaluated in different courses and will be quoted where suitable.

Table 1. Criteria for Academic Master’s Curicula [3]

1	Is able to reformulate ill-structured research problems for problems of complex nature. Also takes into account the system boundaries in this. Is able to defend the new interpretation against involved partners.

2	Is observant, and has the creativity and the capacity to discover in apparently trivial matters certain connections and new viewpoints. Is able to put these viewpoints into practice for new applications.
3	Is able to independently produce and execute a research plan.
4	Chooses the appropriate level of abstraction, given the process stage of the research problem.
5	Is able, and has the attitude to, where necessary, draw upon other disciplines in his or her own research.
6	Is able to deal with the changeability of the research process through external circumstances or advancing insight. Is able to steer the process on the basis of this.
7	Is able to assess research within the discipline on its scientific value.
8	Is able to contribute to the development of scientific knowledge in one or more areas of the disciplines concerned.

The goal of the research lab is to bring these competences together in an integrated approach in the framework of the research lab. The research lab thus aims, starting form a dedicated research question and additional background information, to learn students how to (i) formulate a research question, (ii) design experiments, (iii) evaluate results, (iv) formulate and set-up additional experiments and finally (v) scientifically report the results. Students should therefore be able to combine knowledge from different disciplines and apply it in a new context.

2.2 TIMELINE

Generally, research can be divided into five phases being problem definition, research design including the design of the experimental set-up, data gathering, analysis and interpretation and finally report writing. Often an iterative loop is activated by readapting experimental design based on the obtained results in order to obtain finally a working solution for the problem. All five of these phases were incorporated in the research lab or in the framework of involved courses as indicated in Table 2. Table 2 presents a general timeline for the different activities and courses that were involved during the preparation phase in the first semester and during the implementation phase in the second semester. All courses in the first semester belong to the common core curriculum, meaning that all students came into contact with the different research topics. As shown in Table 2, during the first week the different research topics are presented by invited speakers from industry or research assistants with the aim of presenting the larger context or project wherein the students will participate and situating problems and challenges. Afterwards, students can choose between approximately 4 different projects, all of them guided by a research assistant offering a starter package of literature and advising and supporting them with their own literature survey. Students also receive more background information during specific context related courses in master courses around polymer materials, water- and waste treatment or chemical engineering. Hence in this first semester, students already go through the phase of problem definition and research design. This is done in a literature review and a course on design of experiments. Data gathering, analysis and interpretation, adapting the experimental set-up and report writing are done in the actual research lab in the second semester before starting their master thesis. However, the number of iterative loops typically for engineering research is limited due to time constraints. Students however have to give recommendations for further work including changes in the experimental set-up.

In this way, students gained a systematic approach for starting and evaluating research activities and define iterative procedure. This turned out to be very useful for their master thesis. Students report in informal contacts that they could really use the competences gained during the research lab for translating a general assignment into a specific research plan, starting from the formulation of specific research questions and a first experimental design, followed by developing the experimental plan including DOE when relevant, iterating and finally evaluating and reporting their results.

Table 2. General timeline

	SEMESTER 1	**ACTIVITY**	**TEACHING METHOD**	**COURSE MATERIAL**
Problem definition	**WEEK 1**	Introduction of research topics	Seminar - 1 hour for each topic	Powerpoint, Article,…
	WEEK 2	Composition of research teams		
	WEEK 3-10	Specific and context related courses and labs	Ex cathedra and directed exercises	Course text, selected set of articles (app. 10)
	WEEK 3-10	Literature review	Independent group work	Science direct, Web of Science,
Research design	**WEEK 7-9**	DOE course	Ex cathedra and directed exercises	Course Text , software manual
	WEEK 10 -12	Writing an experimental plan / first design/DOE	Differentiated teaching	DOE Course text, literature review
	SEMESTER 2	**ACTIVITY**	**TEACHING METHOD**	**COURSE MATERIAL**
Data gathering, analysis and interpretation	**WEEK 1-4**	Laboratory work	Laboratory work in group	Experimental plan/DOE
Report writing	**WEEK 4**	Preparing the article, presentation	Independent group work	Software package

2.3 Literature review (1 ECTS)

Based on the problem description and a selected list of articles, students have to do a literature survey and find additional information on the topic with a minimum of five additional articles per group member. Students were encouraged to critically review the literature making connections between different viewpoint and formulate a new hypothesis (competence 2). The literature review should include the theoretical background, the relevant process parameters, their operational window and their influence or effects as far as known (competence 1). The literature survey then serves as a starting point for the development of the experimental plan and DOE and counts for 1 ECTS. The literature review is done in 2 stages with the research assistant as a first assessor of the text around week 7. Students receive feedback especially on missing information or references and on the structure of the text which they can use to improve the quality of the final literature review. This final version is then evaluated by the responsible senior lecturer.

2.4 Design of experiments course (1 ECTS)

In order to teach students how to set up an experimental plan starting from literature information, a design of experiment (DOE) course is embedded in the curriculum for 1 ECTS. This consists of an introduction section situating the importance of experimental design by limiting the number of experiments by a fast screening of possible process parameters. Students get familiar with different experimental procedures, factorial design using 2n experiments or with factors at 3 levels, robust designing and finally the use of a software package e.g. Design Expert 8 software in order to automate data processing.

Student learn by directed exercises how to set up, interpret and optimize an experimental plan using DOE. Examples are taken from literature [4] and earlier research labs. Finally students have to prepare an experimental plan including a DOE for their own research labs which counts for 0,25 ECTS (competence 1 and 3). In the beginning, rather large experimental DOE set ups were planned. This resulted in a laboratory work that only consisted of data gathering without room for analysis, interpretation and additional experiments. Therefore, from 2011-2012 supervisors reduced the initial DOE proposal to a limited number of experiments (2^2 or 2^3) which can be executed during the first lab week. Afterwards, based on this fast screening, students defined additional experiments in order to optimize and better understand the obtained results.

2.5 Research lab (2 ECTS)

During the laboratory sessions, students work in group and prepare an experimental plan and time schedule week by week, starting from the initial designed experimental plan. After interpreting the results of the screening tests using the DOE software, students define and execute additional experiments in order to optimize and better understand the obtained results (competence 6).

During the experimental phase, students have to communicate continuously with the research assistant about the progress of the project, new insights and additional tests and finally task distribution (competence 2, 3 and 5).

After approximately three weeks of laboratory work, students have to analyze and interpret all the results and write a scientific article about their research (competence 7 and 8). This article receives a group quotation which is individually corrected by a factor based on peer evaluation according to the Dochy method [5] and counts for 60%. Additionally co-evaluation was done by the lab supervisors based on attitude, lab work and intermediate communication.

3 CASE STUDY’S

3.1 Research lab on water assisted injection moulding

Cel Kunststoffen, a research group on polymer processing and technology, presents research topics to the students which are part of the current research on innovative injection moulding technology.

The presented case study was executed during the academic year 2011-2012. The topic this year was situated in the research on water injection technology which is done in the framework of a European project (EFRO) and ongoing PhD work. The research question posed to the students was the following:

What is the effect of crystallisation on the formation of defects in the processing of polyethylene (PE) with water injection technology?

To guide the students, this question was subdivided into 3 further subquestions:

- Is it possible to produce defect-free polyethylene products with water injection technology?
- Which process parameters should be used?
- What is the mechanism of defect formation?

In the course 'Polymer materials' a basic as well as a more advanced knowledge on polymer materials is given to all students. The classical lessons in this course deal with physical, mechanical and rheological properties of polymeric materials as well as production methods such as injection moulding. On top of this, two seminars on the selected topic were given by a research assistant. A first seminar dealt with water and gas injection technology and a second seminar was given on the specific properties of polyethylene, which is the material of interest for this year.

After these seminars, the students were given 10 articles to start up their literature study. The literature study of this group contains two pages and 33 cited references. The exert below shows that the students succeed in not only summarizing literature but also form a hypothesis about the mechanism of defect creation.

*'The **expectation** is that the crystallinity of the polymer is an important factor. This **because** the higher the crystallinity of a material, the bigger is the shrinkage during the cooling down period'*

However, the formulation in the report may still be improved. The formulation needs to be more scientific as well as provided with the necessary citations. Therefore, feedback was given to the students, which was used in their final article. The exert from their literature study for the finale article then became:

'The crystallinity of the polymer is an important factor: the higher the crystallinity of a material, the larger the shrinkage during cooling. More shrinkage of the polymer results in smaller residual wall thickness, but more part defects (fingering, double wall) will occur since these defects compensate shrinkage (Lin & Liu, 2009) (Gründler, 2010) (Sannen, De Keyzer, & Van Puyvelde, 2011).'

The students have adapted a more academic writing style and have included references in the right place. Based on the literature study, students proposed a DOE on the subject, in the framework of a separate course (Design of Experiments, 1 ECTS), which is given in Table 3. Here, feedback is extremely important since the feasibility of the experimental setup has to be taken into account, with which the students are not familiar with. Therefore, the allowed number of experiments was reduced by the guiding tutors. As can be seen in Table 3, the students first defined a 5^3 experiment which was eventually reduced to a 3^3 experiment.

In Table 3 the proposed settings for the process parameters are also visible. The latter were selected by the students based on literature values. However, these were adopted into more realistic values for the specific equipment in the laboratory.

Table 3. **Experimental design 2011-2012 on water assisted injection molding.**

Parameter	Original settings			Final settings		
Level	-1	0	1	-1	0	1
Flow rate (l/min)	40	45	50	10	20	30
Water injection Delay Time (s)	12	13	14	2,5	6,5	10,5
Melt temperature (°C)	280	330	380	200	225	250
Water hold time (s)	30	35	40	Not taken into account		
Smelt short shot size (%)	92	94	96	Not taken into account		

After this preliminary work during the first semester, the data gathering, analysis and interpretation was done during the actual research lab. Students had to deal with limitations of research such as changeability of the research process and unexpected outcomes. When trying to make a comparison between different materials, students were confronted with the fact that the material properties could influence the defect formation in several (often contradicting) ways, thus making a prediction difficult. These confrontations often lead to frustration during the research lab, but increase the learning experience as students are confronted with real research situations. Despite the experienced difficulties, they manage to form a reasonable and convincing conclusion in the final work. This is shown in an exert of the conclusion in the final article.

'Part defects are influenced by flow rate and melt temperature. The most important factor is the flow rate. A high flow rate and high melt temperature lead to a lower amount of part defects. ***Overall*** *zero shear viscosity, molecular weight distribution and crystallinity are important melt parameters. A low zero shear viscosity, high MWD and high crystallinity lead to a small RWT.* ***Contradicting****, a low viscosity of the polymer and a high crystallinity lead to more part defects but this can be compensated by the fact that a small RWT leads to less shrinkage and less part defects.'*

As can be seen from the exert, numerous result are summarized into reasonable insights and an explanation is given to results that were at first sight contradicting.

Finally, the experience by both tutors and students during the project lab in 2011-2012 led to a change in the program of 2012-2013. Namely, the course on polymer materials was extended with lab sessions, in order to give more insights into the behaviour of polymers during processing.

3.2 Research lab on acoustic crystallisation

Lab4U focuses on process and environmental technology, more specific on the use of acoustic waves and flow reactors to intensify industrial processes. Students participated in a FP7 research project on the use of Alternative Energy in chemical processes and ongoing PhD work.

This case study was performed during the academic year 2012-2013 starting from the following assignment: *Evaluate the effect of an acoustic field on the continuous crystallisation process of paracetamol.*

As ancherpoints three questions were also formulated:

- What are the most important process parameters of sonocrystallisation?
- What is the energy efficiency of the process?
- What about the product stability?

The necessary background information was given in two courses. The course on ecology and waste water treatment deals with the basic principles of acoustics, important process parameters and the principle of acoustic oxidation which is used for tertiary treatment of organic compounds in waste water. During the Capita Selecta Course on Separations Processes basic principles of crystallisation are yearly treated but in the framework of the research labs one seminar was devoted to the principle of sonocrystallisation and the hypothetical effect of different acoustic process conditions on crystallisation.

As mentioned above, students perform a literature review defining the most important process condition and their operational window. This lead to a 2^3 factorial design investigating the effect of flow and and acoustic poser on the crystallisation behaviour. During the implementation of the experimental plan, students experienced that during the start up a lot of operational problems have to be solved and experimental protocols had to be made in order to obtain reliable results. Problems as increased paracetamol concentrations due to inhomogeneous sampling, the implementation of an adequate temperature control in the experimental crystallisation set-up, a detailed characterisation of in house made acoustic reactors and final the necessary analytical protocols in order to measure paracetamol concentrations had to be finalized before even starting with the designed experimental plan.

Students indicated afterwards that they learned a lot about crystallisation and acoustics in general and were able to draw a clear conclusion about the effect of both acoustic power and flow rate on the crystallisation behaviour.

4 RECOMMENDATIONS AND CONCLUSIONS

Resonance group activities with students evaluating the engineering curriculum, considered the research labs as stimulating. In addition, it helps to develop the professional identity of the engineering student and promotes the live long learning competences.

However, the organisation of the labs demands an interdisciplinary approach since different topics/competences are usually united in a real problem. Preparation time for students should be sufficient and spread in time, in order to acquire the necessary background expertise before the lab phase starts. A structured approach by teaching and implementing the principles of design of experiment and dedicated seminars, directly results in an increased self-directing capacity of the student and useful results during the actual research phase.

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