Iterative development of an engineering laboratory course
– Insights after first iteration

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1 INTRODUCTION

With the new bachelor's programme at Aalto University a new laboratory course, Mechanical and structural engineering laboratory (5 ECTS), was added to the curriculum. Compared to a related course in the previous curriculum especially more hands-on laboratory experience wanted to be provided for the students. This should be realized with reasonable teaching efforts while maintaining the high quality of the teaching.

There were several sources to look after the learning objectives of this new course. Feisel and Rosa present the fundamental objectives of engineering laboratories defined by a colloquy of experienced educators [1]. These include for example being able to apply appropriate instrumentation, to devise an experimental approach, to demonstrate ability to collect and analyse data and to identify unsuccessful outcomes due to faulty equipment or process [1]. The knowledge from the preceding course and the role of this course in the curriculum was taken into account. Teachers of the courses following this course were asked, what should be the learning outcomes of the course. They emphasized the uncertainties in measurements, understanding how different measuring equipment work and systematic working approach. Both freshmen and experienced students were interviewed for their ideas for this kind of laboratory course. They wished that the students were let to run the experiments and that the basics from previous courses would be recalled. Finally, people from the industry were asked their opinions for the learning outcomes. They highlighted the importance of

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being able to build working measurement arrangements and to be able to analyse the results. Based on this research work the course learning objectives were defined as following:

After the course the student

- recognizes the basic concepts related to experimental methods and factors affecting measurements
- is able to compile research plan and experimental design and implement a simple measurement in practice
- is able to select suitable measuring instruments, sensors and software and to assess their impact on the results
- has the ability to document, report and present the results of an experimental study
- is able to identify sources of errors in measurements and flagrant errors in the measurement results.

An iterative design process [2] was chosen for the development of the course since it was still undecided what should be the exact content of the course and what teaching methods would serve it best. With an iterative approach (*Fig. 1*) new ideas could be tested quickly as revisions made too. In order to save teaching resources it was decided to increase the students' own contribution and take advantage of online teaching methods following the blended learning [3] approach. There are several possibilities to support learning with online teaching methods in a laboratory course. This could mean virtual laboratories, remote-access laboratories or other supportive content online [1-3]. During this course, supportive material in a study portal was provided. At the same time the hands-on experience that can be only achieved inside the laboratory was emphasized. Corter & al. also show that best learning outcomes could be achieved in group working in a hands-on laboratory, compared to remote and simulated laboratories [3]. While producing the online material is time consuming [4], with an iterative approach the time spent can benefit the next iterations of the course [2].

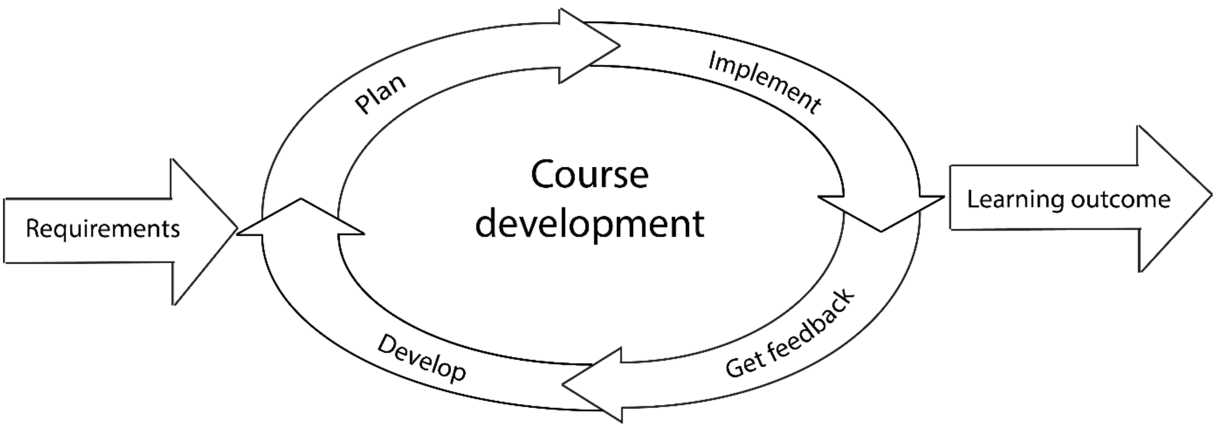

Fig. 1. The iterative design process for course development.

Fig. 1 shows how the iterative design process can be applied to course development. At the initial stage there are some requirements for the course. Based on requirements and resources a course is planned. The course is given for the first time and the students acquire knowledge and skills as an output of the course. Feedback is collected and utilized to make plans for the next implementation. Based on the plans and requirements the next implementation is planned and the cycle starts again.

2 COURSE PLANNING

The course was first implemented during the autumn 2015. A teaching assistant was hired as a summer worker for preparing the course. It was a challenging task to plan the laboratory exercises as the amount of students attending the course was unknown estimates ranging from 30 to 100. In a rather early stage it was decided to have six different laboratory equipment with three different topics. The topics were movement, temperature and miscellaneous measurements. The miscellaneous measurement kits were already available. They included for example a motor with an encoder and a cantilever beam with strain gauges and accelerometers attached. The teaching assistant developed equipment for movement and temperature laboratories. The temperature laboratories included heated chambers and three temperature sensors positioned in different locations. The movement laboratories included two mechanisms to provide linear movement, which could be measured with infrared and ultrasonic distance sensors.

Instead of predetermined tasks, the students could come up with their own ideas based on the possibilities provided by the equipment. Only documentation of the laboratory equipment and a video showing how to use them was provided.

The software to be used in this course was MATLAB for data analysis and LabVIEW for measurements. Basics of these software are taught in a freshman course. The students could also use other software like MS Excel for data analysis. NI USB-6001 devices were used for data acquisition.

3 IMPLEMENTATION OF THE COURSE

58 students attended the course in the first implementation. The duration of the course was 2 teaching periods (14 weeks). *Fig. 2* gives an overview of the activities of the course, described more in detail later in this chapter. The course was graded as pass/fail. If a student wanted to pass the course, all the partial assignments should be passed. There were one responsible teacher and one teaching assistant. The teaching assistant used 500 hours during the summer for preparing the course and 200 hours to help running the course.

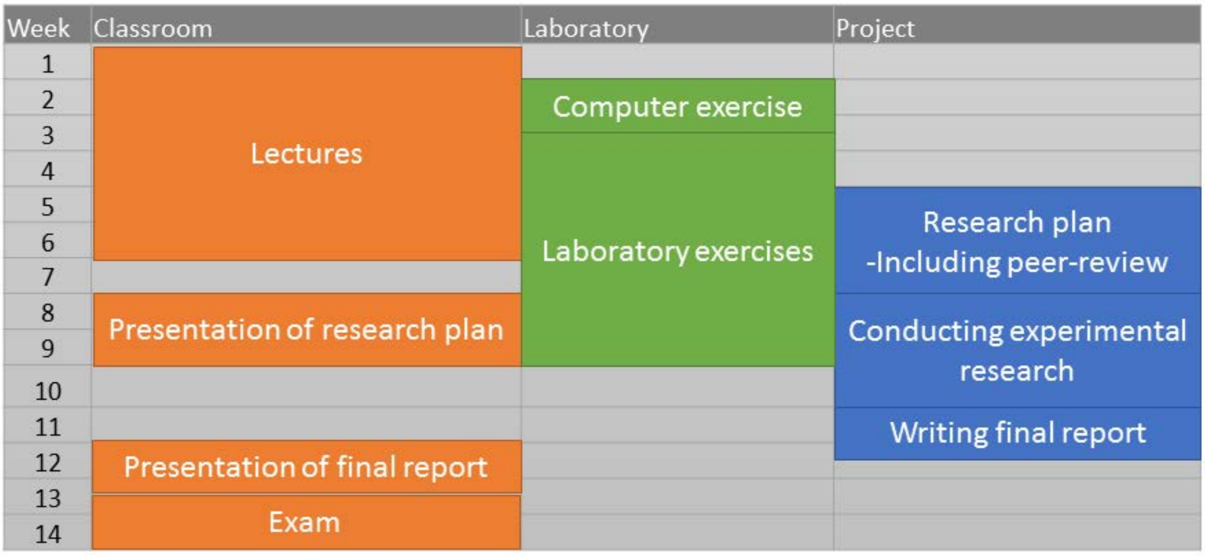

Fig. 2. Overview of the schedule of the course.

The essential concepts and terms of laboratory work and experimental research process were discussed in weekly lectures.

A computer exercise was organised in the first week of the course. The idea was to go through the software to be able to utilize them for the course. Students had to create a LabVIEW program with the help of detailed instructions and conduct analysis with MATLAB based on instructions. At the same time they were asked to fill a quiz in the course portal to see that they have actually done the exercise. Two advising sessions were organised by the teaching assistant but the students could do the exercises all by themselves if wanted. The quizzes were assessed by an automatic examiner and at least 11 from 12 answers had to be correct to get an accepted mark.

The laboratory work consisted of pre-laboratory exercises, actual laboratory exercises and post laboratory analysis and reports. These were done in groups of two to three people with six groups present in a laboratory session. Each group had to attend three exercises. The main role of the exercises was to gain hands-on experience and skills for conducting experimental tests. The pre-laboratory exercises recalled some relevant theory and asked questions related to the applied equipment and sensors in a quiz format. The groups were expected to get acquainted with the forthcoming laboratory by reading the material, watching a one-minute demonstration video and thinking what they were about to study during the laboratory exercise. During the exercises the students made the necessary wiring to run the experiments. They utilized example LabVIEW program prepared by the teaching assistant. During and after the exercise the students had to analyse the results and write a report consisting of a couple of pages on what they did and what were the results. Students could get asynchronous help for the pre- and post-laboratory tasks by contacting the teaching assistant. During the laboratory exercises, the teaching assistant was there to support students to run their experiments.

The same groups were used to carry out an independent project work. It consisted of writing a research plan, giving and receiving peer feedback for the research plan, presenting the study plan, conducting tests in a laboratory environment, writing a final report and presenting the results. Conducting the experimental tests of the project work was scheduled after the laboratory exercises so that the learned skills could be applied right away.

One task was that the groups had to write a short wiki page. The topic of the page should be related to measurements and preferably to the group's own project work topic. The idea was that the students could create and utilize a common knowledge base for measurements. The minimum word count for the page was 250 words.

A final exam was also organised to assess the individual learning of the students. The exam was held in a computer class so that the students could search the Internet for help, but cooperation via Internet was prohibited. One task also assessed the ability to perform data analysis tasks with chosen software. The other tasks consisted of combining some essential terms with their explanations, writing an initial plan of an experimental test and identifying errors and mistakes from different measurement cases. To pass the exam, 40 % of the total points were required.

4 FEEDBACK

Various methods were used to test the effects of the development work and teaching methods. Students were asked after lectures and laboratory exercises to give feedback. They could also write feedback in their laboratory reports. Students could send direct email to the teachers for example if there were some errors in the pre-laboratory quizzes. This feedback was used either straight away to adjust instructions of the exercises or documented for the next implementations.

The majority of students' written complaints fell upon how the laboratory exercises were instructed. Some students criticised the lack of accurate wiring diagrams and that they had to ask the teaching assistant for help. Also in the first exercises there were compatibility issues with computers and software versions, which frustrated the students. The students appreciated the practical experience they gained during the course. They also acknowledged the teacher's and the teaching assistant's proficiency and that they could get help when needed.

After the course there was a quantitative questionnaire. By answering it an extra point for the exam was given. This questionnaire received a response rate of 79 %. *Fig. 3* show the perceived learning by the students. Utilising software and identifying sources of errors seems to have developed a little less than the other measures. *Fig. 4* shows that the exam and the measurement wiki was seen as the least natural parts of the course. *Fig. 5* shows that there is room for improvement in both the computer exercise and the pre-laboratory tasks.

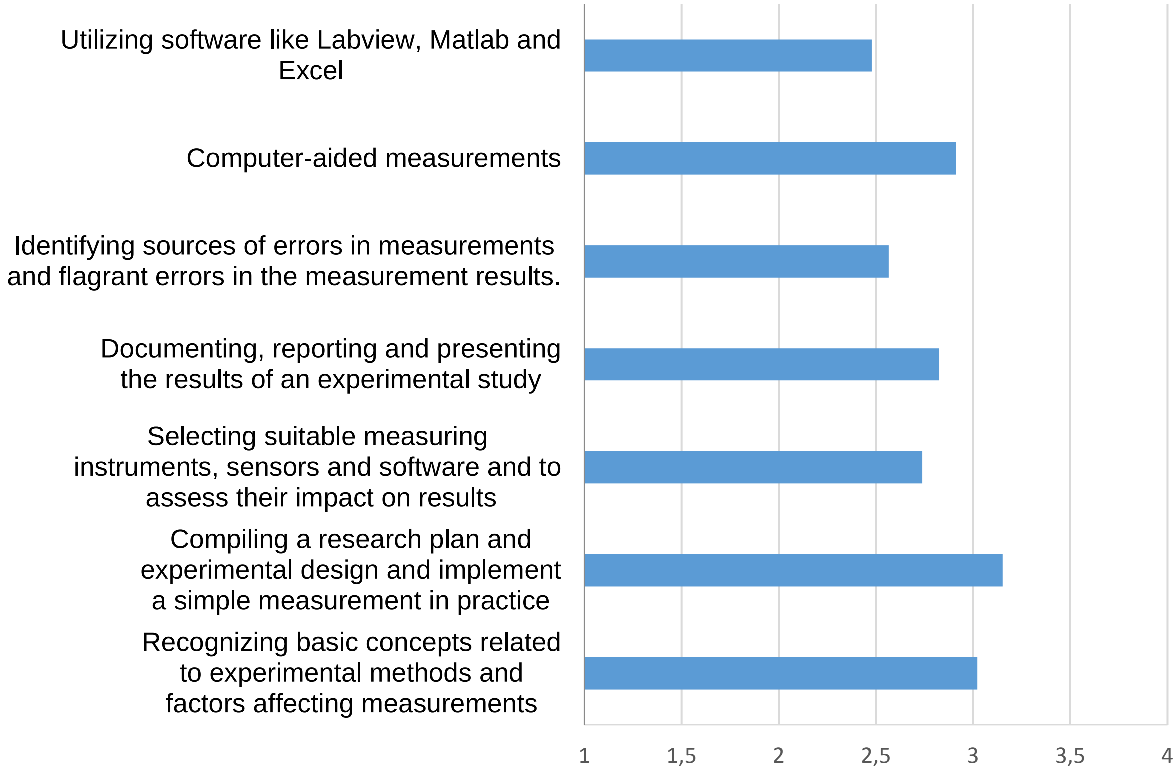

Fig. 3. How did your know-how developed in the following areas during the course? 1 = not at all, 2 = a little, 3 = remarkably, 4 = a lot. Means of the answers are shown.

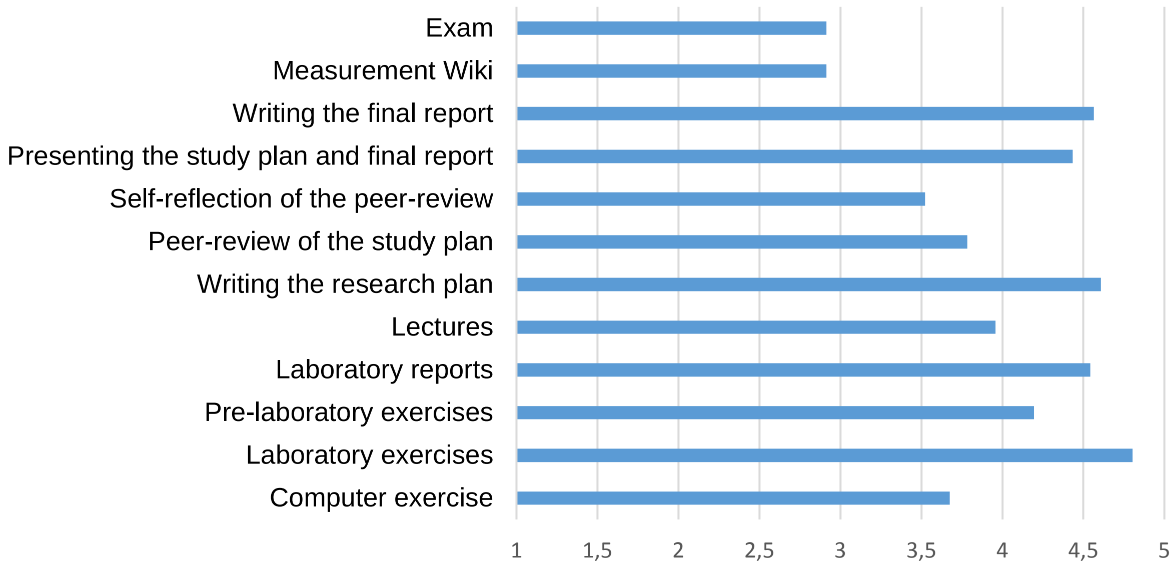

Fig. 4. I felt this part as a natural part of the course. 1 = totally disagree, 2 = somewhat disagree, 3 = neither disagree nor agree 4 = somewhat agree 5 = totally agree. Means of the answers are shown.

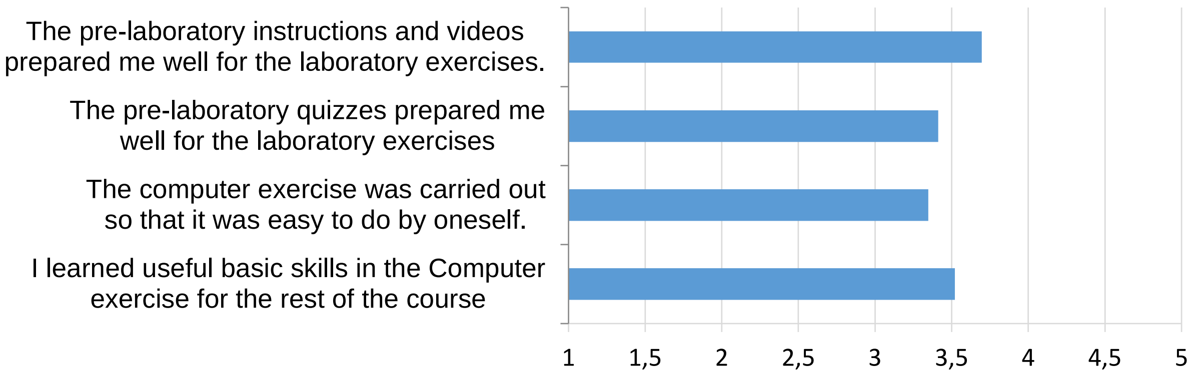

Fig. 5. Answer the following statements concerning learning. 1 = totally disagree, 2 = somewhat disagree, 3 = neither disagree nor agree 4 = somewhat agree 5 = totally agree. Means of the answers are shown.

5 EVALUATION AND DISCUSSION

In the first implementation, software skills were only taught during the one computer exercise. The effect of this can be seen in the results where the students think that they learned software skills less than other objectives. The students' previous knowledge was relied on too much. The content of the computer exercise could be combined to the laboratory exercises. Students should make their own LabVIEW programs and data analysis every time with the help of some instructions. It was also true that there wasn't enough effort to teach the students about measurement errors and computational error analysis. Teaching these should be added to the laboratory exercises.

In a laboratory course, the students get easily overloaded because they should master at the same time several user interfaces, mathematical analysis and design concepts, and the experiment itself [1]. This is a reason why the fluency of learning should be considered. Clear wiring diagrams had to be made to make the laboratory exercises more fluent. The pre-laboratory material could be developed by adding some more theory concerning the forthcoming laboratory.

The role of the wiki page and the exam should be considered based on the feedback. If no more relevant reason to make the students write a wiki page could be seen, the task should be left out of the course. Other possibilities for assessing the individual learning should be thought of. For example, it could be based on just pre- and post-laboratory exercises that every student would return individually.

Looking back the development work done a new model for course development process is suggested in *Fig. 6*. It contains three levels. The course has been planned to fit the curriculum. One course implementation has been planned and run and feedback has been collected from it. During the course, instant feedback was used to make small adjustments for the course. After a few implementations the role of the course in the curriculum should be looked at more closely.

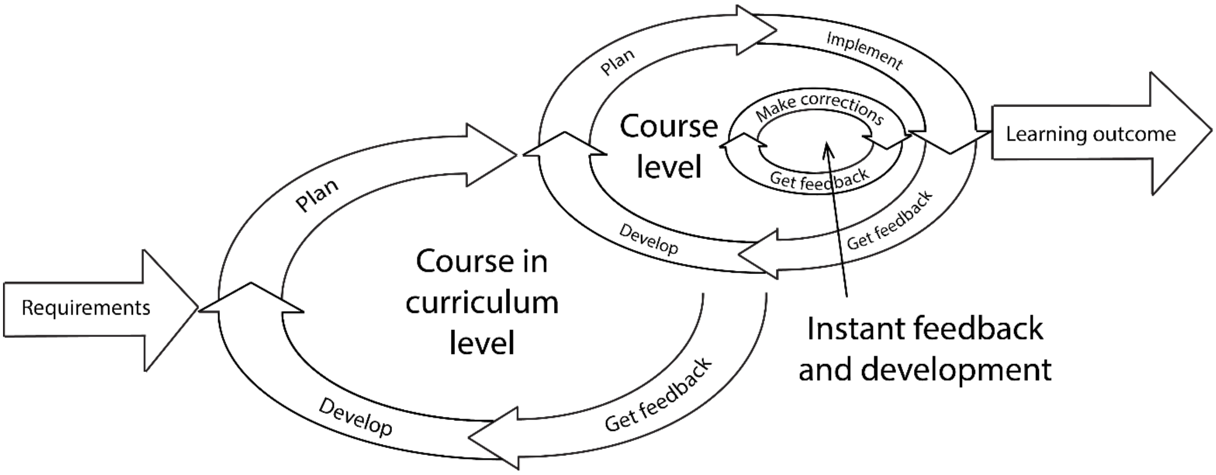

Fig. 6. A proposed model for iterative course development.

This paper shows the results of a systematic iterative course development after the first iteration. Some measures to assess as well as ways to continue the development work in a laboratory course context were presented. The effect of utilizing an iterative approach in course development can be seen only after a couple of iterations. Most likely it takes some time for the course format to settle. The basic organization of the course should be maintained, because changing it is time-consuming and the accumulated experience and material eases the organizing of the following implementations. A proper investment in the initial planning helps running the course for the next few implementations. It would be interesting to study whether an iterative approach provides a more efficient way for establishing a course than some traditional approach. At least the clear outline of the model should help a teacher to maintain the development process.

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