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A practical study

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INTRODUCTION

An experimental undergraduate course in fluid mechanics, coupling theory with practical implementation, has been offered on a regular basis since the 1990's at the Technical University of Denmark. Because of the way it was taught, it was unique already when being established. To the authors' knowledge, there exists no similar course in the world today where the students are introduced to the setups and are thereafter allowed to work on them alone using the delicate and often quite expensive equipment that is usually used also in the research work of the department. Though the course has been running for over 3 decades, there have been no major casualties, neither to the students, nor to the equipment.

The course has achieved a widespread reputation and high popularity among the students for being able to couple theory and practice in a manner that engineering students tend to highly appreciate. In the January 2013 course, a new approach was chosen to make this coupling between theory and practice even

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stronger using the theory of inductive and experimental learning based on the well known Kolb’s learning cycle [1]. In particular, emphasis was put on the signal processing part, which is an overarching concept in the course and experienced as a notoriously difficult subject by the students.

Previously the course has been structured around introductory lectures for approximately the first week accompanied by gradually increasing amounts of laboratory exercises. The following two weeks were then devoted to experimental exercises and the course was finally wrapped up with an oral exam. This year, the students were allowed to start the experiments early in the first week and the lectures were coupled with practical exercises that were directly related to the upcoming experimental laboratory work. Three types of practical exercises were introduced:

- Design of a fictitious experiment from a signal processing point of view
- Treatment of pre-existing data using a computer program to highlight the importance of a correctly designed experiment
- Design of an actual experiment to be conducted within the course from a signal processing perspective

The purpose of the exercises was to make the connection between what was taught in class and the work performed in the laboratory stronger. The students were asked to fill out questionnaires before, during and after the course and the results show that the exercises were highly appreciated by the students, who just kept asking for more similar tasks. This behaviour among the students confirmed that active learning methods where the students are involved in meaningful problem solving can contribute to enhance the motivation for learning and thereby the learning outcome [2]. To develop intrinsic motivation among the students and to give them opportunity to find their incentives for learning a subject is one of the critical processes in teaching [3] [4]. The experimental learning method as used in this course seems to be helpful in this respect. Another implication of this is the result of the assessment in the course that also displayed that the students had reached a higher general level of understanding than previous years within signal processing.

In this paper the implementation of inductive learning and use of Kolb’s learning cycle as a major teaching method and philosophy are investigated and evaluated. The work shows that more direct coupling between theory and practice enhanced the students’ learning considerably even before starting the practical laboratory exercises and that their learning was able to reach higher levels than previously observed in the course. Hence, the results of this study can be considered general and not only applicable to practical experimental courses. The main point is that students experience the applicability of the theory to a realistic problem or case which helps them in their understanding and forming of new knowledge.

1 COURSE BACKGROUND

1.1 Course description in brief

The course is a 5 ECTS points Experimental Fluid Mechanics (FM) course given during three weeks. Traditionally the first one and a half weeks have consisted of lecture sessions in the mornings and practical experimental exercises in the afternoons. During the remainder of the course the students have worked on the experimental exercises full-time. However, the lectures were still relatively decoupled from the exercises and were suspected to hold a lot of potential for improved constructive alignment and hence increased student learning. In the recently updated course structure, the students were assigned in groups of 4 persons to perform three experiments on different types; A, B and C. The groups are in turn divided into sub-groups of 2 persons that each submit their own part of the reports for assessment.

- The **type A experiment** is conducted during a single day, assessed by submission of a short note describing the experimental setup and some brief results (specified).
- The **type B experiment** is the main one, on which the students spend several (up to 4) days. This experiment is followed by a proper technical report.
- The **type C experiment** is an open flow visualization experiment planned by the groups themselves. The students are given a range of options, but are also welcome to come up with suggestions of their own. The report consists of recording still or moving images of the visualization that are reported as an oral presentation with video or, for still images, on a poster.

The summative assessment consists of an oral presentation, where each group is assigned to present one experiment for 15 minutes including questions. The course grading is pass/fail. Having the lectures more incorporated with practical exercises, the learning objectives and teaching activities were coupled more closely together. Further, the examination is already directly reflecting the teaching activities. Hence the course was much better constructively aligned than previous years [5].

1.2 Main challenges for learning

The most difficulty for the students in the course is by far the signal processing aspect, since it is highly abstract and hard to relate to unless one has seen the effects of incorrect applications of signal processing. However, the subject is vital and overarches the entire subject, since a proper understanding of signal processing is crucial to being able to interpret measured signals correctly. Therefore, the objective was to expose the students to the theoretical subject coupled to practical implementation to a larger extent so that they not only gain the theoretical knowledge, but also the vital experience to identify the signs of these kinds of problems in the data. This is important, since these effects can (and are) often interpreted as being actual results of the flow measurements while they actually are only effects of the incorrect or insufficient signal processing. The chosen approach to improve the students' learning was to couple the abstract theory to practical exercises where the students design both fictive and real experiments and experiment themselves with the effects on the measurement data.

2 METHOD

2.1 Implementation of experimental & inductive learning

The general teaching and assessment methodology is even from the beginning very much based on Kolb's learning cycle (chapter two of [1]). The course is about 30 years old, so the course was initiated almost simultaneously with the presentation of the theory. Teaching is performed by presenting the theory in lectures at the beginning and then letting the students implement it in practice. During guidance of the experiments, the students then had the opportunity to continuously ask questions about the experiment based on their practical experience. This experimental/inductive learning approach is further strengthened this year with a number of exercises performed in class after the lectures but *before* the students reach the lab. These exercises were directly linking the lectures and practical laboratory exercises to maximize constructive alignment [5]. The hypothesis was that by making the students work actively on the problems in a practical manner after having been introduced to the theory, this should facilitate and strengthen inductive learning according to Kolb learning cycle [1]. Four practical approaches to more closely couple theory and practice in the line of experimental learning in the course and the current work are described below. The associated steps in Kolb learning cycle [1] are indicated at the beginning of each bullet:

- **Abstract conceptualization/Active experimentation/Concrete experience:** During the **signal processing lecture**, while having the theory fresh in mind, the students are asked to sit down in groups of 4-5 students and **'design' a fictitious experiment based on the theory just presented**. An idea is to make this process step by step, i.e., let the students discuss after each important aspect has been presented. In the light of the new information give to them, what needs to be changed in the experimental planning? After the discussions, the results of their discussion will be discussed in plenum.

- **Active experimentation/Concrete experience/Reflective observation:** In direct conjunction with the lecture, the students will be given a set of real data (similar to the ones they will acquire themselves) and a **programming task where they apply the theory** and can see the consequences of both correct and incorrect processing by their own experimentation.

- **Active experimentation/Concrete experience/Reflective observation:** Before they start their actual experiments, they are asked to sit down with their group and go through **the same process as described in the first bullet, but this time with the actual experiment that they are going to perform**. The idea is that they should have thought their experiment through before starting the measurements. The students were asked to summarize their work orally or on 1-2 pages. Then a brief discussion was held between the teacher and the group to help them on the right track if necessary. Teachers also discussed with all the groups while they were performing the experiments to further improve their understanding. This is an iterative process where Kolb's learning cycle really comes into play.

- **Reflective observation:** During the oral examination, a discussion about the signal processing was a mandatory part of the discussion.

2.2 Assessment

Formative assessment is conducted continuously during the course in conjunction with pre-experimental exercises and discussions as well as during the exercises. Summative assessment is performed at the end of the course, where the students give oral presentations of their work and the teachers can, in a constructive manner, interrogate and look for weaker elements in the understanding. At this stage, the students are again learning, since any misconceptions are made very clear here and the whole class can discuss these to make sure that everyone understands.

RESULTS AND DISCUSSION

2.3 Pre-test

A pre-test was handed to the students during the very first gathering of the course. Out of 39 students, 35 answered the questionnaire. First, the students were given six technical questions related to signal processing and next the students were asked about their background in signal processing. The first six questions reflected well the answer to the seventh question: Only 7% stated that they had any background in signal processing. 78% stated that they had none and 15% some experience.

Further, they were asked about their opinion on the coupling between theory and practice at courses taken at DTU in general and whether they wished for this coupling to be stronger. Their answers are summarized below.

Q: In previous courses at DTU, has the coupling between theory and practice for the benefit of your learning been:

a. Sufficient: 27%
b. Somewhat sufficient: 56%
c. Somewhat insufficient: 12%
d. Insufficient: 5%

Q: Do you wish for this coupling to be stronger?

a. Yes: 76%
b. No: 7%
c. Don't know: 17%

Clearly, there exists a demand for more practical exercises coupled to theory.

2.4 Midterm evaluation and learning outcome

The midterm evaluation consisted of questions relating both to technical and pedagogical aspects of the course, just like the pre-test. The midterm evaluation questionnaire was answered by 33 out of 39 students. The technical questions were chosen based on the main aspects of the signal processing. The results from these displayed a significant increase in the level of understanding of the technical aspects, as expected from the formative assessment.

The questions about the teaching and learning aspects were formulated as a follow-up on the pre-test. The questions were asked about the coupling between theory and practice of signal processing in the course: Whether they found it sufficient, if they wish for it to be even stronger and how they ranked the exercises coupling the theory to practice. An open question was added asking for own suggestions about coupling between theory and practice.

Some of the questions and respective answers are summarized below:

Q: What is your opinion on the coupling between theory and practice of signal processing in the course so far?

Sufficient: 17%
Somewhat sufficient: 62%
Somewhat insufficient: 17%
Insufficient: 4%

Q: Do you wish for this coupling to be stronger?

Yes: 62%
No: 17%
Don't know: 21%

Q: How would you rank the exercises given in the course in terms of how they helped you in your understanding of signal processing? Please mark in ascending order, i.e., 1 – prefer least and 4 – prefer most.

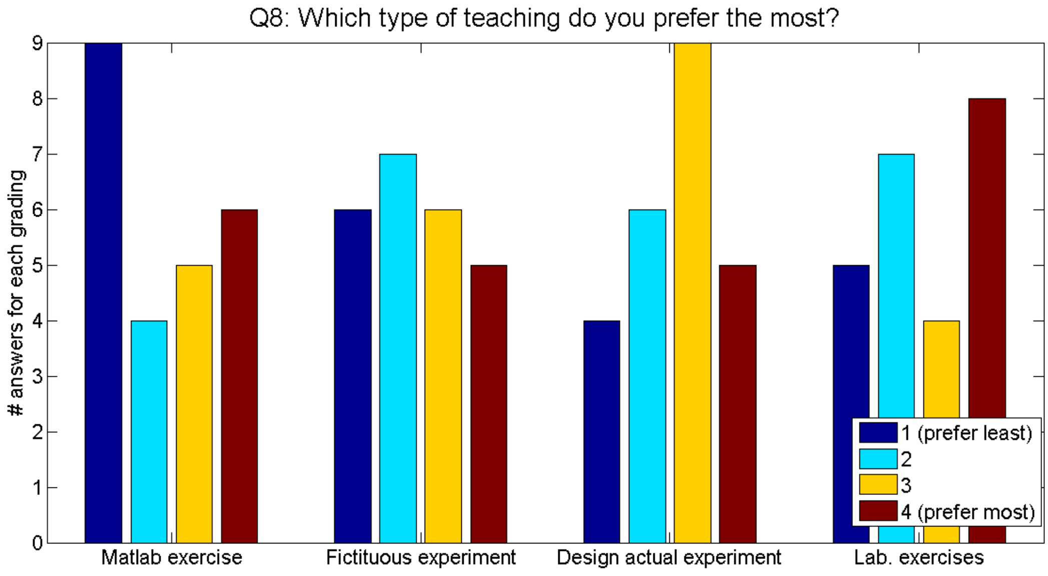

Fig. 1. Differentiated grading of each alternative.

Q: Do you have any suggestions of your own how one can better couple theory and practice for better learning/understanding of signal processing in this course?
Some suggestions are summarized below:

"Start with small and simple examples and accumulate."
"Giving more mental images that describe the meaning of the theory like the drawings of the window for explaining windowing."
"Start with simple connection of physics and theory – just like the video on helicopter and aliasing."

From these results one can draw a couple of conclusions:

- The technical questions were on purpose designed to be tricky. Still, the students generally answered correctly and the questions where they went wrong they usually chose the alternative 'trap' option. Judging from the technical questions and comparing to the results of the pre-test, the students display a steep increase in learning of signal processing.
- Even though the coupling between theory and practice has been very strong throughout the course, the students still want even more. Some suggestions to increasing the coupling is more concrete and physical examples during lectures that facilitate the understanding of the physics and introducing even more exercises that the students can perform to increase their active learning.
- The laboratory exercises were, not very surprisingly, the most popular. However, the signal processing design of the experiments before entering the lab were also highly appreciated and similar tasks can be elaborated on for coming years. Still, the distribution of rankings between the four options was fairly even.

2.5 Course Experience Questionnaire (CEQ)

The standardized Course Experience Questionnaire [6] was handed to the students at the end of the course. The most relevant and marked result was the relatively high ranking on the Motivation Scale (MS), which received a score of 4.1.

2.6 Formative and summative assessment

The lectures proceeded as expected based on experience from previous years. However, the students were a lot more active in the exercise sessions and we received much more questions from the students than usual, which is interpreted as a sign that they really start thinking about the theory presented. The same happened during the computer exercise and markedly during the experiments. It is clear that the students actually understand the complicated theoretical concepts by applying the theory to a concrete case and in the few cases when they don't, the discussion based on their application helps them to finally understand. Further, they explicitly expressed that they learned a lot from these direct discussions with the teachers.

During the lectures, the students were moderately active, but once given a task coupled to an application they worked very hard and even asked for more tasks and examples. In fact, if they finished their task for the day, they usually started working on next day's task without having even been introduced to it. Further, new questions just kept coming, showing signs that the students were reaching higher and higher levels on the Bloom's taxonomy [7]. It is clear that for this batch of engineering students, the implementation of the theory was highly appreciated. Some sample comments from the midterm evaluation emphasize this fact: "More examples during the lecture" and "Start with small and simple examples and accumulate". In individual discussions with the students, the same appreciation was frequently displayed. The approach didn't cause any major changes in the course planning, since the course was designed to allow the teaching to develop in the manner of the student's way of working and discovering in conducting the experiments. The objectives of the experiment assignments were on purpose formulated in an open manner to let the students think actively and creatively about them and to facilitate inductive learning. Regardless of the path they chose, their activities were aligned with the learning objectives. Formative assessment was thus carried out continuously during the course through small assignments and discussions with the teachers.

The summative assessment consisted of a written report and an oral presentation at the end of the course and a poster/video session of their flow visualizations. All group members were obligated to participate in the report writing and the oral presentation as well as the flow visualization presentations. The oral presentations were 10 minutes allocated for each group with 5 minutes for questions where students in the audience were expected to ask questions to the presenting group. As a mandatory part of the report and oral presentation, signal processing aspects were discussed in terms of design and execution of the experiments.

3 SUMMARY AND CONCLUSIONS

The objective of the current work was to find out whether the theory of experimental learning and Kolb's learning cycle can be implemented in our course in a more pure and explicit form to facilitate the learning of signal processing in a setting of introductory lectures followed by implementation of the theory in practical and experimental exercises. We were of course doing this also before, but the additional exercises created have definitely helped reduce the ambiguity and misconceptions among the students. Judging from the formative and summative assessment, we indeed perceive that the effects of implementing this method have widely exceeded our expectations on the student's learning: The student's understanding reaches considerably higher levels compared to previous years. Further, looking at the evaluations and questionnaires, the students seem to feel the same way. The students were craving for even more exercises and implementations and become increasingly independent at a faster rate, which the authors interpret as a very good sign. This approach may require a bigger effort initially, but has the potential to pay off even better in the long run. Or expressed in metaphors: By properly teaching the students how to walk, they can more easily learn themselves how to run.

The more direct coupling between theory and practice raised the level of the students' understanding and the students were much better prepared when entering the laboratory. Hence, the results of this study is not limited in applicability to experimental courses, but can with advantage be implemented also in theoretical courses. For our future teaching we have a number of suggestions for improvements.

- Even more practical exercises coupling the theory presented in the lectures to the actual activity of acquiring and interpreting measurements.
- The students ask for more simple, physical and intuitive examples of the various aspects of signal processing (as suggested in the evaluations).
- The students need a primer on the mathematics to have a better background when tackling the physics aspects of the material. Due to the diversity of the students entering the course, sometimes basic concepts like the Fourier transform are unknown to some students.

To summarize, this practical course has apparently a lot of hidden potential in coupling theory and practice, which can and will be further pursued in coming years. Though the paper discusses the application to an experimental course, inductive learning has proven to be a powerful tool in general and the authors would like to encourage others also teaching more theoretical courses to try it out.

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