Flexible teaching content can improve learning Mechatronics

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***Abstract*— This paper investigates the potential improvement in qualitative student learning, by introducing a flexible course structure in the multifaceted course of Mechatronics. Several methods are introduced to facilitate flexibility in teaching content, based on prior student knowledge, discussions, and interactions during the course. An anonymous quiz is developed to test students' prior knowledge. Course structure is constructively aligned to allow flexibility, while preserving intended learning outcomes. Class discussions and interactions are encouraged by introducing a forum concerning home assignments and by implementing pedagogical content knowledge that does not only relate to mandatory subject matter, but includes also informative material in the form of demos, historical notes, practical examples, videos and short questions. Results from course evaluation show that the students appreciate the flexible course structure.**

***Index Terms*— Mechatronics, flexible teaching, curriculum development, engineering education.**

I. Introduction

MECHATRONICS is a multidisciplinary course that teaches the understanding of the basic technologies for design and integration of a mechatronic system. The course teaches the fundamental engineering science in Mechatronics, it provides means on how to apply the learned knowledge in practice, how to design and conduct experiments, to analyze and interpret data. This typically requires knowledge in electronics, electric machines, mechanics, computer science, programming, automatic control, mathematics, etc., which has to be covered in a limited time framework. Therefore, providing a qualitative student learning introduces pedagogical challenges and relies to a certain extent on the prior knowledge that students bring to the course. Another important aspect in Mechatronics is to enable the development of social and communication skills, teamwork and creativity, which typically includes tasks delegated to multi-disciplinary teams. Proposed type of learning that has been found to successfully address these aspects is the problem-based learning [1].

It is common for lecturers to design their Mechatronics course, in part or entirely, as a problem or project based course [2]-[6]. These lecturers have also pointed out that the quality of student learning depends not only on the practical projects carried throughout the course, but also on the theory communicated on lectures. However, designing lectures for a multifaceted course is not trivial. The possible course content is vast and including dense theory may overload the students with excessive information. Similarly, a poor theoretical coverage may significantly reduce the quality of learning.

The goal of this project is to propose a flexible theoretical content in lectures in Mechatronics, based on prior student knowledge, discussions, and interactions during the course. Several methods are introduced to facilitate the goal. The course material is divided into mandatory course content relevant for the practical project and the final exam, and informative content, which is not part of the final exam, but provides alternative explanations and extends the knowledge beyond the mandatory course material. Course structure is constructively aligned to allow flexibility, while not infringing the intended learning outcomes. An anonymous quiz is developed to test students' prior knowledge within the first week of study, thus providing the first insights to tailoring cognitive activating tasks to prior knowledge, in order to challenge students' beliefs and further test their prior knowledge throughout the course. Class discussions, interactions and peer instructions are encouraged by introducing a forum concerning home assignments.

The implemented problem/project-based learning for the particular Mechatronic course, which is subject of this paper, is introduced in Section II. The pedagogical issue is presented in Section III. The role of students' prior knowledge is discussed in Section IV. The method used to introduce a flexible course content is provided in Section V. Results are given in Section VI followed by reflections and conclusions in Section VII.

II. Bachelor course in Mechatronics at Chalmers University

At Chalmers University of Technology, Mechatronics is taught in several programs, both in bachelor and master level of studies. In this paper, a Mechatronic course is considered that is taught to second year bachelor students in the technical design program. The course's wide content is covered in 16 lectures (90 minutes each), 12 problem-solving sessions (90 minutes each), and 7 mandatory laboratory sessions (105 minutes each). Yet, the scheduled sessions are not sufficient to cover all the basics in the different disciplines. To meet some

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TABLE I
ORGANIZATION OF TEACHING CONTENT IN THREE PARALLEL BRANCHES

Lectures	Problem solving	Project tasks
Introduction (1 session)		Session 1: borrow platform
Microcontroller and programming (1 session)		Session 2: programming
Electro-technical theory (5 sessions)	Electro-technical theory (4 sessions)	
Digital theory (2 sessions)	Digital theory (2 sessions)	Session 3: user interface
Actuators (2 sessions)	Actuators (2 sessions)	Session 4: actuators
Sensors (2 sessions)	Home assignments (1 session)	Session 5: sensors 1
Control theory (1 session)	Sensors (1 session)	Session 6: sensors 2
Design of a mechatronic system (1 session)	Design of a mechatronic system (1 session)	Session 7: logic/control
Repetition (1 session)	Repetition (1 session)	

of these challenges, part of the course is organized as a project (building a robot and performing tasks with it), which is carried throughout the entire course, in parallel with the lectures and problem solving sessions. Moreover, the course includes mandatory home assignments that are to be completed by students working in groups of two.

The course is organized in three parallel branches; 1) a fundamental knowledge taught through lectures, 2) problem solving sessions with focus on mathematical problems and 3) a design project, where students work in groups of two. The organization of teaching content is detailed in Table I. Sessions are aligned in temporal order, from top to bottom, thus illustrating activities performed in parallel, within a single week of study.

Lectures are designed in a problem-based style [7], where particular lectures address the main building blocks in the problem of building a generic mechatronic module. The generic mechatronic module is illustrated in Fig. 1, together with its main components, which include a microcontroller, motor drives, actuators, transmission, sensors, filters and links between these components. The figure is also used as a course outline, wherein different components and links are being highlighted for the lectures that address the content of the particular link or component.

While lectures are designed to target the acquisition of knowledge that is mainly directed by problem-based learning [7], the course includes a project work to directly connect to the application of knowledge. The project work is designed to include several small tasks closely connected to individual lectures. While completing the tasks, the students also build a robot, which culminates to a final task where the objective is to implement a logic and control the built robot, subject to given objectives and constraints. The project work is assisted by the teacher and the teaching assistant, while content is delivered and directed by the teacher.

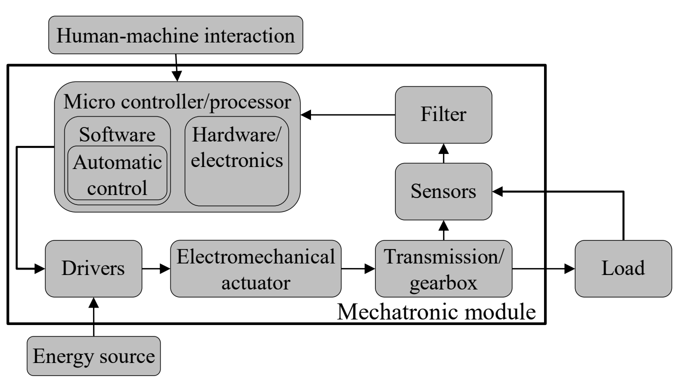

Fig. 1. Problem-based learning in Mechatronics. Lectures are designed to describe the main building blocks of a problem in building a generic mechatronic module, including a microcontroller, motor drives, actuators, transmission, sensors, filters and links between these blocks. The figure is also used as a course outline, wherein different blocks and links are being highlighted for the lectures that address the content of the particular block or link in the mechatronic module.

Students may gain half of the course credits by completing all the tasks in the project. To get the remaining credits, students need also do home assignments and pass a final exam on gained theoretical knowledge.

III. PEDAGOGICAL ISSUE

Course evaluation from previous years shows mixed responses from students on the level of difficulty of taught material. While some students find it suitable, others object that more repetition is needed on what is required as prior knowledge. Some students value the lectures, home and project assignments as clear means to better understanding the material, while others complain on workload and suggest to remove some of the assignments and teaching material.

The goal of this paper is to provide a deep theoretical coverage, while preserving a balanced workload. The quality of student learning will be investigated by introducing flexibility in the first branch of the course content, where fundamental knowledge is covered through lectures and problem solving sessions. The intended type of learning is student oriented, where the flexible content is selected from students' prior knowledge, interactions, and discussions during lectures. For achieving the goal, both the prior students' knowledge and the teacher's pedagogical content knowledge (PCK) are instrumental ingredients [8], [9].

IV. ROLE OF STUDENTS' PRIOR KNOWLEDGE IN PEDAGOGICAL CONTENT KNOWLEDGE

Prior students' knowledge and its implication on learning has been subject of study by many researchers and lecturers, see, e.g., [10], [11] and references therein. Research has repeatedly indicated that *the development of an integrated and generative knowledge best rests upon the learner's prior knowledge* [10]. The relevance of students' prior knowledge is even more important in Mechatronics, since teachers have argued that their lectures do not teach entirely new things, but try to remind students of what they already know from other courses [3].

Yet, it has also been indicated that prior knowledge may actually hinder the learning process, since students may resist altering their views even when presented with plausible evidence that provides *a more adequate account of a phenomena* [10]. Garner & Gillingham [12] have also stated that the benefit of prior knowledge is unclear. They have concluded that individuals with moderate prior knowledge are more likely to be interested, while individuals with low and high prior knowledge are more likely to be uninterested in the learning activities.

Nevertheless, nearly all lecturers would agree that they have to work with students' existing beliefs and prior knowledge, since grasping the student beliefs and prior knowledge is a core component in PCK [11]. One such example is the cognitively activating tasks that are tailored on prior knowledge to challenge students' beliefs. Class discussion may also trigger cognitive activation if it encourages students to evaluate and reflect upon their decisions, instead of simply declaring right or wrong answers [11]. Indeed, grasping the students' prior knowledge and encouraging discussions and interactions, are the pillars of the methods for flexible teaching content, discussed in the following section.

V. Method

Teaching and learning activities in Mechatronics are organized according to the constructive alignment principle, where assessment tasks directly address intended learning outcomes [13]. In this section, methods are provided that enable flexibility in the teaching content, without infringing the intended learning outcomes.

The course material, which consist of a course book and an extra printed material, is divided into material that is **mandatory** to read and is likely to be included in the final exam and material that is **informative** and recommended to read, but is not included in the final exam. This allows deep theoretical coverage, while balancing the students' workload. The initial selection of mandatory material is decided by the necessary book chapters that address the intended learning outcomes. The remaining part, which comprises about 20-25% of the book content, is listed as informative. The initial selection of informative book material is decided by a quiz on prior knowledge, which is given to students in the first week of study. More details on the quiz is provided below, in Section V.A.

The informative course material is flexible and may change during the study period. Parts of it could be excluded, or moved to the mandatory content, or augmented by other material beyond the book content. Decisions on selection of flexible informative material are made according to class discussions and interactions during lectures. Discussions and interactions among students and between students and the teacher are encouraged by implementing a pedagogical content knowledge, which is detailed below, in Section V.B.

A. Quiz on prior knowledge

Students' prior knowledge in Mechatronics is tested with a multiple-choice test; this is widely considered as one of the valid measures to test prior knowledge [10], [14], [15]. A quiz is constructed with 15 questions, each including 3-4 possible choices and one correct answer. The questions are divided into four categories,

1. computer science and programming,
2. electrical theory,
3. digital theory,
4. mechanics,

where higher prior knowledge is expected (and desired) in computer science and mechanics, since lectures for these two disciplines are not initially included in the mandatory course material, but a certain knowledge is required in order to complete the project and home assignments. For the remaining two categories, electrical and digital theory, several lectures have been initially designated within the mandatory material.

The quiz is introduced on the first lecture and the students are informed that although being mandatory, the quiz will not influence their final grade. The students are given three days to submit their answers on an individual basis. After starting, the time to finish the quiz is limited to two hours. The interval of two hours is considered sufficiently large to answer the 15 short questions based purely on their accumulated knowledge, while not allowing much time for searching answers elsewhere.

The main goal of the quiz is, thus, to acquaint the teacher with the basic understanding of students' prior knowledge. However, the quiz also provides the first insights to tailoring cognitive activating tasks to prior knowledge, in order to challenge students' beliefs and further test their prior knowledge throughout the course. In addition, the quiz provides initial clues to students on what this course is about and what is expected by them.

B. Pedagogical content knowledge

According to Ball et al [16], the pedagogical content knowledge (PCK) *underlies the development and selection of tasks, the choice of representations and explanations, the facilitation of productive classroom discourse, the interpretation of student responses, the checking of student understanding, and the swift and correct analysis of student errors and difficulties*. PCK is the knowledge that enables the teacher to encourage learning for understating and to demonstrate an ability to transform and extend knowledge [8], [9]. In Mechatronics, PCK is addressed by carefully designing curricular and cognitive tasks, providing individual support during the forum and project assignment, offering multiple representations and explanations that facilitate deep understanding of content, motivating more interaction and discussions among students and between students and the teacher. A detailed information on the implementation of PCK is provided below.

1) Transforming and extending the course material

With the goal of encouraging learning for understanding, an additional information is communicated on lectures, which provides alternative explanations and extends the knowledge beyond the mandatory course material. Despite the fact that such information is often a spontaneous, conditional or enthusiastic reaction, an attempt is made here to introduce some structure and organize the material in a written electronic form.

Three set of slides have been created to accompany each lecture: 1) slides that are projected on a screen; 2) slides that include the information to be written on the black board; and 3) slides that include teacher's notes in an electronic form. The first two sets of slides are delivered to the students at lectures, while the last, which includes the informative material beyond the book's content, remains with the teacher. This extra information currently includes: historical references of the great researchers behind the laws and theories; interesting or peculiar facts from the inventors' lives; historical notes on the development of electric motors, sensors, computers, electronic components; Nobel prizes awarded to various inventions; state of the art research in specific subjects; practical applications of theories used in the course; analogies that provide an alternative explanation of phenomena; correlation of ideas across different disciplines; association to common and well known objects/subjects from everyday live, etc.

The idea behind the teacher's notes is to produce a live document and a collection of audio and video files, which are constantly enriched with novel information, typically originating from questions raised by curious students. Even after being used only in a single study period, this document includes more information than what can be communicated on lectures. Hence, depending on students' interests, available time or other circumstances, the teacher can select the appropriate information that provides an additional explanation or simply lifts the study spirit.

After informative material is collected, a decision has to be made on the quantity and frequency of extra information communicated on lectures. Without performing a rigorous analysis, in this project informative material has been delivered in time intervals of less than 5 minutes, after each 10 to 15 minutes of communicated mandatory material. It was envisioned that such schedule would keep students interested and motivated to learn the mandatory material, while at the same time learning topics that are outside the mandatory material.

2) Demonstrations and experiments

Experiments captivate students' interest and are therefore desirable in the course curriculum. Besides the project task, where students experiment themselves by building a robot throughout the course, additional short experiments have been included on lectures. These include live programming of a microcontroller, simulation and control of a motor-load system, development of a simple electric motor, etc. In addition, examples of electronic components, instruments and machines are brought on lectures and circulated among students, whenever possible. Demonstrations of components and principle of operation are also carried out through videos, which is further described below.

3) Audio and video stimulation

The current information age provides us with plenty of excellent audio and video material that is easily available and is free to stream or download. As part of the lectures, several videos have been played, many of which have been made by professionals. These videos typically include demonstration of particular electronic and electric components and their principle of operation. In addition, videos are included from other lecturers and of phenomena that are dangerous to demonstrate in the classroom.

During the 15 minutes break between lectures, audios have also been played. These include the first song where Fourier transformations have been applied for mp3 compression and motivational songs with an engineering topic.

4) Cognitively activating tasks

Several cognitively activating tasks have been included in lectures to check student understanding and possibly encourage discussions and interactions. These include swift questions from the taught material and recognition tests for electronic components. In addition, the lectures include a designated slide for cognitive activation, called "Question of the day".

"Question of the day" is a single slide with one question and multiple-choice answers, given at the beginning of each lecture, just after a brief repetition of the previous lecture. The students need to select one or several answers within a couple of minutes. The question is typically connected to the previous lecture, but often slightly outside the taught material. The goal is to teach students how to think, instead of what to think. In the style of peer instruction, students are encouraged to evaluate and reflect upon their decisions together with their peers, instead of simply declaring right or wrong answers. Students then commit again to an individual answer, while the teacher reviews the responses and decides whether more explanation is needed [11].

5) Forum for assignments

A forum is organized to help students refresh the required prior knowledge and bring more fun and enthusiasm for learning the novel material. Although assignments are designed to be submitted by a group of two students, for the purpose of the forum larger groups are created by randomly selecting 5-6 members. The forum discussion is directed by posing a list of five questions, which are closely related to tasks in the assignments. The students are given 45 minutes to discuss and propose solutions, while having the opportunity to act as teachers and argue in favor of their own arguments [4]. Both the teacher and the teaching assistant supervise the forum, by providing help when needed, or by pointing to a suitable direction of reasoning. After the allocated 45 minutes for discussion, additional 45 minutes are reserved for collecting the groups' solutions, potentially pointing out differences among solutions, discussing the typical sources of error, and eventually providing additional hints to the correct solutions.

TABLE II
SUCCESS RATE FOR QUIZ QUESTIONS, CLASSIFIED IN FOUR CATEGORIES

	Quiz category	Success rate
1	Computer science and programming	57%
2	Electrical theory	53%
3	Digital theory	39%
4	Mechanics	67%

VI. RESULTS

This section provides several results obtained from the quiz on prior knowledge, statistics from “Question of the day” and course evaluation.

A. Quiz on prior knowledge

In total 33 students have submitted the quiz, with average success rate of 57%. From the maximum possible score of 15 points, the maximum and minimum achieved have been 12 and 3 points, respectively. The success rate per category is provided in Table II, where it can be seen that in most of the disciplines the students have success rate of more than 50%, except in Digital theory, with success rate of 39%. The highest success rates are in Mechanics, 67%, and Computer science and programming, 57%, which has also been expected, as these two disciplines were not initially included in the mandatory material, but prior knowledge is required to complete the course.

In average, the students needed 17 minutes to answer the 15 questions. The longest time needed to finish the quiz has been 64 minutes, indicating that 1 to 1.5 hours is probably enough to answer all the questions. Two of the students finished the quiz in less than 5 minutes and not surprisingly, they achieved the lowest score. This suggests that some of the students may not have taken the quiz seriously, which might have affected the results in Table II. A remedy could be to make the quiz voluntary, although this might negatively affect the number of students participating in the quiz.

High variance has been observed in the success rate on questions in Electrical theory (5 questions in total) with highest and lowest success rate of 88% and 18%, respectively. From the results, it has been decided to alter the course content by providing additional information on lectures and moving some sections from informative to mandatory.

Although the quiz has been designed to be most useful to the teacher, a question has been included on the course evaluation on how students perceived it. On the question

- *The quiz on prior knowledge, which was given in the first week of study, gave a useful indication of the wide multi-disciplinary topic that will be covered in this course*,

the students gave a grade of 3.52, out of 5. One of the students’ comments is that the quiz was a good way to refresh their memory. However, some students indicated that it would have been better to include free-text answers, as it was easy to guess the correct answer from the provided choices.

TABLE III
STUDENTS’ EVALUATION OF THE LAST THREE QUESTIONS THAT TARGETED THE MAIN COURSE CHANGES FROM THE PREVIOUS STUDY YEAR

Question	Grading
The forum for home assignments was useful for sharing knowledge within the groups.	3.81
The informative content (e.g. historical notes, analogies, state-of-the-art research, informative book chapters, extra material, etc.), has been well balanced with the mandatory course content and improved the quality of learning.	3.76
Demonstrations and experiments that showed components and operating principles supported well the theory.	4.05

B. Question of the day

Fourteen of the lectures, excluding the first and last lecture, included a “Question of the day”. The average success rate of the initial answers, before instructing with peers, has been 60%, which after peer instruction has increased to 65%. Interestingly, for two of the questions the success rate has decreased after peer instructions, as peers with wrong answers managed to exert their influence on their colleagues. For seven of the questions the same success rate has been observed before and after peer instructions. Six of these questions had success rate of 100% and one with 0%.

To quantify the usefulness of the “Question of the day”, a question has been included in the course evaluation,

- *The “Question of the day” and the repetition at the beginning of lectures was useful for improving understanding and learning quality,*

which the students graded with 4.29 out of 5. The students’ comments were nearly all positive, except one comment that indicated that the actual class knowledge and the one interpreted from the answers might not match. This possibly refers to students who select answers that other students have chosen, without given much thought on their own.

C. Course evaluation

The course evaluation included standard course questions grouped within 11 categories and additional five custom questions that targeted the main course changes from the previous study year. A detailed grading of the standard course questions will not be shown here, but only the total impression for the course is provided. The evaluation showed an improvement of about 16% from the previous year.

The five custom questions have been divided into two groups. The first group focused on prior knowledge and the second focused on other changes introduced in lectures. Three questions in the first group evaluate the main mechanisms introduced to test and refresh the student’s prior knowledge and adjust the course content accordingly. Two of these questions have been discussed in the previous two sections, while the remaining question and the additional two questions from the second group are provided in Table III.

The usefulness of the forum has been graded with 3.81 out of 5. Students have also commented that the forum was a good starting point for successfully completing the home assignments. They have also noted that guidance throughout the forum is necessary for better understanding the assignments.

The informative content introduced in the course has been graded with 3.76 out of 5. Students have commented that this: *clearly lifted their interest; it was fun to listen to; it made the subject livelier and fun and not just something to be learned from a book*. However, students have also commented that it was sometimes difficult to distinguish the transitions from mandatory to informative part and vice versa.

The usefulness of demonstrations and experiments has been graded with 4.05 out 5. Students have also asked for *more LIVE experiments, if possible*. However, one student has complained that it is difficult to listen to lectures and inspect the components at the same time, as some components have been passed around during the lectures.

VII. Reflections and conclusions

This project aimed to improve the quality of student learning in Mechatronics, by introducing a flexible course structure, based on prior student knowledge, discussions, and interactions during the course. To this end, several methods have been introduced, including an anonymous quiz on students' prior knowledge, forum for home assignments and constructively aligned and pedagogically organized syllabus that allows flexibility, while not infringing the intended learning outcomes. It has been proposed to create a new set of teacher's notes, with informative material on historical notes, interesting facts, analogies, applications, correlations and associations across different disciplines.

The course evaluation showed that the students appreciated the flexible course structure, requesting for even more informative material and live experiments in following years. Lectures were accompanied by increased interaction between students and teacher and discussions were initiated on topics that were often outside the mandatory course material, but still closely connected to the intended learning outcomes. Based on the quiz on prior knowledge and interactions during the lectures, the flexible course content has been changed accordingly. The changes strongly enriched the informative material by adding new analogies and in-depth explanations of physical phenomena.

Students showed concerns that it might be difficult to distinguish informative from mandatory material. The concerns did not relate to book sections, which have clearly been annotated for being mandatory or informative, but instead referred to the transition during the lectures, from mandatory to informative material and vice versa. Future investigations will closely focus on finding a better way for signaling these transitions.

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