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A 21ST CENTURY APPROACH TO ENGINEERING MECHANICS EDUCATION

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ABSTRACT
In product design engineering education, classes in engineering mechanics are often difficult, unrewarding and unsatisfying for both students and lecturers.
Within the Product Design Engineering program at Rotterdam University of Applied Science, a new approach has been developed and tested, leading to significantly higher pass rates and more active student participation, leading to deeper and more lasting understanding of the subject.
Based upon field research and present day learning theory, an interactive course line was designed in which students build, test and calculate real-life design problems. By gradually increasing the complexity of the cases given, students gain deeper insight in theoretical basics, skills in calculations by hand as well as computer-assisted, analysing constructions and applying forces. Students learn in an informal class-setting in which they are stimulated to experiment, to measure, to calculate, to check outcomes and to ask questions. A mixture of online resources, frontal teaching, peer teaching, individual coaching and team coaching is being used to create a rich learning environment. In this environment it is safe, even encouraged to make mistakes, learn of them, evaluate and improve. Both slow and fast students benefit from this approach.
In this paper, we will assess the bottlenecks in the "classical approach" towards teaching engineering mechanics, describe and discuss the "new approach" and draw conclusions on several factors. Thus, making classes more or less effective in creating deeper, durable understanding of construction engineering in a motivating, challenging yet safe learning environment.

1 MAIN CHARACTERISTICS OF THE IDE COURSE

Since 2013 the Industrial Design Engineering course at Rotterdam University of Applied Sciences hereafter referred to as "IDE course", offers a four-year fulltime bachelor program based in Rotterdam, the Netherlands. Bachelors in IDE are expected to solve complex design problems in a multidisciplinary environment in an independent and substantiated manner, leading to innovative, producible, marketable and useable product solutions.
The IDE curriculum is designed around the main professional design engineering competencies: Analyse, Design, Verify, Manage and Learn.
As of the academic year 2016-17, the IDE course is attended by approximately 300 students. Each year 100 freshmen enrol after a selection procedure carried out by the course team itself.

2 THE ENGINEERING MECHANICS COURSE LINE WITHIN THE IDE CURRICULUM

The engineering mechanics course line is one of 5 course lines within the IDE curriculum and consists of 5 classes throughout the 1st, 2nd and 3rd year, each accounting for 5 EC or 140 nominal study hours:
1st Semester: Engineering basics: how products work
2nd Semester: Statics: How external forces are conducted within a product
3rd Semester: Mechanics: How products deform or fail under applied forces
4th Semester: Optimisation: How to optimise a product using FEM analysis
6th Semester: Dynamics: How to construct moving structures
The main goal of the engineering mechanics course line is to provide students with the appropriate knowledge and skills to enable them to design products as material/cost efficient, light, safe, useable and durable as possible.

3 PROBLEMS OCCURRING WITHIN ENGINEERING MECHANICS COURSE LINE

Unsupported by empirical evidence, but widely recognised by almost every student or alumnus of any industrial design course, for IDE students most classes covering mechanics, engineering, statics and dynamics as well as their supporting mathematics classes are considered difficult, abstract and often demotivating. Many engineering mechanics classes experience low pass rates, as shown in Table 1.

Table 1. Pass rates for IPOCON30 (3rd semester, 2nd year)

IPOCON30	‘13-‘14	‘14-‘15
N	77	106
% passed after 2 attempts	53,2	36,8

Based on learning and teaching experience of the authors and their colleagues, we are suggesting two main underlying causes of the problems on hand:

3.1 Lecturer-student gap

A typical industrial design process is strongly based upon intuitive and holistic decision making, considering a wide scope of hard-to-measure variables such as usability, market value, sustainability, aesthetics and “look and feel”. Most engineering mechanics classes are being developed and taught by mechanical engineers who are considered specialists in executing exact calculations based on thorough understanding of stresses and forces. As a result, a “clash of cultures” often occurs, leading to, low class attendance and widespread procrastination.

3.2 Safety and challenge gap

Within all student groups, students vary substantially in learning speed and basic knowledge. Specifically, skills and knowledge in mathematics and physics vary due to substantial differences in pre-university education. Furthermore, the ability to acquire abstract knowledge varies highly between students. Hence, some students find the classes proceeding way to slow, where at the same time others have huge difficulties to keep track. Both groups are likely to attend classes less often or not at all.

3.3 Engineering Mechanics needed in IDE practice

Besides the pedagogical and didactical flaws mentioned above, the IDE course team was dissatisfied with the applicability of the actual learning outcomes of the engineering mechanics classes.
Graduating students often experience difficulties in solving basic engineering problems where engineering mechanics knowledge is needed. Hence, to specify which are the demands of design engineering professionals for knowledge and skills in engineering mechanics, an e-mail survey was carried out amongst 25 professional industrial designers.
Questions asked were:

1. Which professional skills should engineering mechanics theory be targeted on?
2. How do you use engineering mechanics theory in daily practice?
3. Which elements as taught in the engineering mechanics course line have contributed to your engineering mechanics skills?

The main findings of this survey were:

1. None of the respondents is ever making serious calculations as learned in the classic approach. Most verifications are done by building a prototype (physical or CAD) and testing it.
2. A designer should be able to quickly develop alternatives for constructions and quickly assess them without calculations, thus evolving towards a really ‘smart’ constructed product.
3. To be able to perform trustworthy FEM-analysis, thorough knowledge of units, forces and supports is necessary, alongside a well-developed “gut feeling”.
4. For an industrial designer, the main goal is to have a well-developed intuition to make quick, yet understated choices. Where to add material, where to safely remove it, etc.
5. Some respondents stress the need for an industrial designer to be able to communicate with mechanical engineers, knowing the right professional language and units used.

We conclude that the knowledge and skills provided in the engineering mechanics course line must focus on developing a sound intuition for solving engineering problems. In it a sufficient understanding of underlying theory is essential and the ability to test in the physical and virtual world (FEM) is more important than the ability to perform exact calculations.

4 SET GOALS FOR A NEW APPROACH

During the years, many attempts have been made to improve pass rates and study behaviour within the engineering mechanics classes. Nevertheless, no substantial improvements were achieved.
As of the academic year 2015-2016, course management and concerned lecturers have decided to look out for a major change, starting off with an experiment in the 3rd semester "Mechanics" class.
As a starting point, four main goals were distilled of the findings above:

1. How to create a connection between real world problems and abstract mechanical theory
2. How to create a safe environment for learning of slow students
3. How to create a challenging environment for learning of fast students
4. How to create deeper and lasting understanding and intuition

5 FRAMEWORK: HOW WE LEARN

As an appropriate theoretical framework, we have relied on *How we learn* [7]. Illeris states that most learning theories focus on a particular aspect of the learning process and brings on a more comprehensive theory of learning. A model is presented, based on several guiding learning theories to do justice to the dynamic interdependence of different elements. This holistic approach matches the way designers work, which is described as *Design thinking* [1]. Two fundamental assumptions are made:

1. All learning includes two different types of processes: an external interaction process between the learner and his environment and internal psychological process of connecting new impulses to results of prior learning. Integration of both processes must actively be involved for learning to take place and to address the whole person [7].
2. All learning includes three dimensions: a cognitive dimension of knowledge and skills, an emotional dimension of feelings and motivation, a social dimension of communication and cooperation. Overall this approach specifies four levels of learning: cumulative learning, assimilative learning, accommodative learning and transformative learning [7].

6 ALIGNING LEARNING THEORY AND PRACTICAL EDUCATION

To design a mechanical engineering course that achieves a full learning situation, that is safe, addresses both real world problems and abstract theory, and creates deep understanding, we have combined the three dimensions and two levels of learning [7].

Table 2. Educational measures linked to learning theories

Goal	Illeris [7]	Learning Theory
Connection between real world problems and abstract mechanical theory	Content	Experiential Learning Cycle [8] Change by Design [1]
Safe environment for slow students	Incentive	Self Determination Theory [3] The End of Average [10] Attachment Based Teaching [2]
Challenging environment for fast students	Interaction	Cooperative Learning [5] Blended Learning [9] Feedback [6] Assessment as Learning [4]
Deeper and lasting understanding and intuition	Level Learning	Triple Loop Learning [11]

7 COURSE DESIGN

Kolb's *Experiential Learning Cycle* [8] and Brown's *Design Thinking Cycle* [1] have resembling steps. This leads to a new model: Mechanical Engineering Learning Model (Persaud, 2017) Figure1.
To achieve both cumulative and assimilative learning, a minimum of two loops is required. Within this framework of the new double loop learning cycle we have implemented both Incentive and Interaction [7].

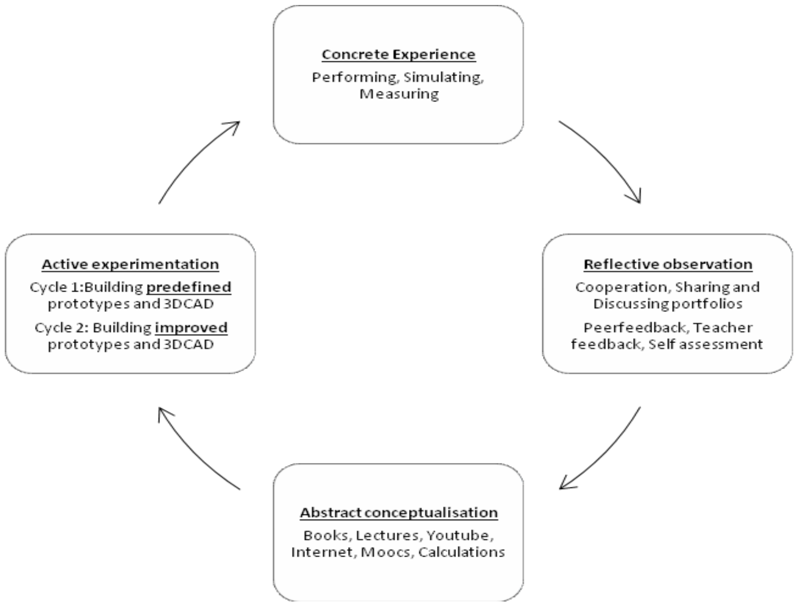

Figure 1. 21st Century Mechanical Engineering Learning Model (Persaud, 2017)

7.1 Experiential learning

The class we designed consists of a series of five projects and a final project. The work in every project consists of performing experiments, writing a portfolio including photographs and movies of the experiment, having discussions about the observations, looking for theoretical explanations and performing calculations (by hand and online) for checking the results. Based on: Experiential Learning Cycle [8], Change by Design [1].

7.2 Multiple cycles for deep learning

Every project consists of two learning cycles [8]. First, students execute a predefined experiment and when finished they design and perform a new experiment for improvement of the problem solution. The first loop will mainly be focused on cumulative learning and the second loop of redesigning (educated guess) the experiment will support assimilative learning. Based on: Triple Loop Learning [11].

7.3 Safe, yet challenging learning environment for both slow and fast students

For slow students, there is a “basic” level project, for fast students there is an “advanced” level project with extra elements like more complex experiments, more measurements, discussions on more complex theoretical issues, more complex calculations. Based on: The End of Average [10].

7.4 Autonomy in learning approach

Students will start their experiments in class, but they cannot be finished in class. Although it is a predefined experiment, they will have the opportunity to start the cycle where they feel most safe: either experimenting or studying theory. Sometimes they will be waiting to see how others start, to copy activities. Finally, all participants will have to do the full learning cycle. Based on: Self Determination Theory [3].

7.5 Cooperative learning

The project week will have a kick off class at the beginning of the week, self-guided group work (in pairs) in the middle of the week and finishing the project at the end of the week, with an individual portfolio. In the first class, the teacher will do a short presentation of the experiment and basic theory. This presentation is a combination of pages from literature, PowerPoints, YouTube movies, Moocs, a small experiment or instruction. At the end of the week, every student shares his/her portfolio and several will be discussed centrally. The teacher will again use a combination of sources to provide in depth information about experimenting, experiencing, observation and theory. Based on: Cooperative Learning [5], Blended Learning [9].

7.6 Constant feedback

Students share an online portfolio with their results. The teacher can give an interactive lecture about theory or practical experimenting feedback, or the whole group can brainstorm about connecting findings to theory or real world products. These portfolios are discussed in class and provided with peer feedback, teacher feedback and finished with a formative self-assessment, based on a rubric. Every project adds complexity in experiments, experiences, reflections and theories. After five of these projects the duos will do a final project. This project is about analysing and improving a real product. With a cumulative assessment based on a rubric, the teacher gives a grade with feedback. Based on: Feedback [6], Assessment as Learning [4].

7.7 Lecturer as learning coach

Class size is maximized to 25 students. The lecturer's main task is consulting the student pairs by constructive dialogue, sensing the developments of each individual student. When similar misunderstandings occur, those can be shared with all attendants, providing discussion and problem solving strategies. The formative nature of each project, sharing success and failure, and asking feedback about his own performance, creates a safe, secure space, where the lecturer functions as an attachment figure. Based on: Attachment Based Teaching [2].

8 RESULTS AND FINDINGS

8.1 Pass rates

As low pass rates were our main concern, the effects of the new approach were measured in terms of pass rates after two attempts (the maximum in our system; if a student fails a second time, the class must be attended all over again the following year).

Table 3. Pass rates of 1st and 2nd grade engineering mechanics courses

IPOCON2x	'13-'14	'14-'15	'15-'16	**IPOCON3x**	'13-'14	'14-'15	'15-'16	'16-'17
Approach	Classic	Classic	New	Approach	Classic	Classic	New	New
N	95	110	101	N	77	106	84	82
% passed after 2 attempts	40	70	73,3	% passed after 2 attempts	53,2	36,8	85,7	86,6

Note: the relatively high pass rate in IPOCON2x in the last classic system ('14-'15) is due to an intensive program, offered to students taking this class after their 2nd or 3rd failure.
It is obvious that pass rates have risen significantly for both 1st and 2nd grade students.

8.2 Student appreciation

As to assess student appreciation for the new approach, an evaluation was held under 2nd year students. All of them (N = 64) had experience in both new approach and classic approach. Evaluations were held by open questionnaires, in which students were asked to compare the classic to the new approach by writing down as many pros and cons of both approaches as possible.

Table 4. Pros and Cons of Classic and New approach

Classic approach (only 2nd year students)		New approach (both 1st and 2nd year)	
Pros: • Well structured • Answer right or wrong is very clear • Knowledgeable lecturer • Purely individual, so no "free riders"	Cons: • Often boring classes; low general motivation • Hard to keep up for slow students • Slow students frustrate fast students • Poor interaction with lecturer • Poor applicability of acquired skills • Difficult exam	Pros: • Application of knowledge in professional practice very clear • You can't do wrong • Provokes steady work pace; less stress for assessment • Feedback well accessible during class • Very dynamic classes • Motivating assignments • Team learning is stimulating	Cons: • Uncertainty about progress made • Classes are too chaotic for some • Free riding occurs occasionally

The first (elder) group (N = 42) of evaluated students was additionally asked a question concerning the use they had made of their acquired knowledge in their 5-month internship period, of which they had recently returned. The youngest 1st year student group (N = 78) was asked for their appreciation for the new approach, while having no experience with the classic approach. In order of comparable answers counted, the main findings are shown in Table 4.

9 DISCUSSION

9.1 Applicability

All students appreciate the new approach as connecting more to professional practice. This is confirmed by answers of students who returned from internships.

9.2 Safety

Here we find mixed results. For some, the new approach feels safer because of increased interaction with lecturers, enabling them to gradually gain insight and knowledge. Others appear to miss the structure of the classic approach and its “right / wrong” clarity. What we do see is an increased appreciation for the new approach with students progressing. 1st year students generally feel more uncertain about the effectiveness of the new approach than 2nd year students. We suspect the causes mainly in former secondary education practice, which is generally closer to the classic approach in the Netherlands. Probably, the new approach takes some time and explanation to get used to. As for the experienced safety of “fast” students, our findings are not clear at this moment.

9.3 Stepwise learning

Students generally appreciate the increased dynamics in classroom atmosphere, student-teacher interaction, practical assignments and team learning. Increased pass rates and class attendance (without obligations for attending) indicates an increased student motivation. As for the actual knowledge gained, conclusions cannot be drawn, because of substantial differences in assessment methods used.

10 CONCLUSIONS

Although data have been gathered over a relatively short period after implementation of the new approach on a relatively small number of students, findings strongly suggest that the new approach:

- Increases pass rates dramatically
- Increases classroom dynamics
- Increases experience applicability of knowledge gained
- Increases motivation of students during the entire class-period

Attention should be paid to:

- Intensively explaining the aims of the new approach to new students
- Increasing opportunities for fast students to speed up or deepen their learning
- Provide a quieter classroom atmosphere for some students

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