Title:
CAD Teaching and Learning through Team Projects: Addressing Future Trends in the Product Development

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Introduction:
This paper focuses on the preparation of a curriculum for a practical course dealing with CAD in mechanical engineering. The course is entitled "Methods of Development and Design of Components in Transport Technology" and it is taught during the second term of Master studies at the Faculty of Mechanical Engineering, Slovak University of Technology in Bratislava. The main objective is to guide students towards being more than just traditional designers and therefore to think out of box. Apart from previous courses, team projects intent to prepare not only designers, but future inventors. Four main levels of the development process are demonstrated for such goals – theory review; concept preparation; design, manufacturing, and testing; economy and marketing. Reproducing demands in the industry, the teams had to fulfil criterions such as price, weight, assembling and sustainability of the design. Finally, the most interesting student's work is presented.

Academic and industrial contexts:
Mechanical engineering design has been an important part of the mechanical engineering discipline as one of its oldest fields. The way and tools of design went through a significant change for several times in the history. An important development step was the invention of CAD, which led to work with actual 3D data enabling fast modifications. However, the field of mechanical engineering has been struggling with lack of interest of promising students. Technical fields in general are difficult, and also informatics became markedly popular compared with other disciplines. These and other reasons may cause lack of specialists when artificial intelligence is not yet ready to replace the humans in designing work. Some discouragements may even be caused by teachers. Curricula are not refreshed based on modern material properties, fabrication technologies, CAD tools or industrial demands.

Various studies focused on CAD teaching and learning differ significantly. Authors' intention is affected by field of CAD application or level of knowledge of students within CAD, [1-3,11]. In [9], it is explained how a game, as an important part of software, may stimulate students' interest. Authors of [5] promote competition as follows: "By positioning the groups as competing design bureaus, students pro-actively aim for the best product possible, thus the project aim as providing realistic circumstances." These are only a few claims of the successful link between education and competition, which authors of the presented work have decided to integrate into the new course curriculum.

Figure 1. shows an approximate learning curve of a random sample of three students presenting a different process of their professional growth. In contrast to a common learning curve [8], axis y corresponds to proficiency, which may be described as $proficiency \approx \frac{1}{t_T}$, where t_T is the time needed for

a task. It involves earning proficiency in CAD from basics through understanding principles, exploring tools possibilities and finishes at the level of a proficient user. An optimal preparation for career means the student graduate when leaving the progressive part of the curve. If the time of graduation was moved on the curve to an earlier stage, the graduate may not be suitable to be hired by a company, as he lacks significant knowledge to adapt to professional conditions. On the other hand, CAD programs widen their functionality from year to year and it is difficult to set up the courses so that students are prepared for any possible designer position. Hence a neutral assignment for team projects was created and is described in the following section.

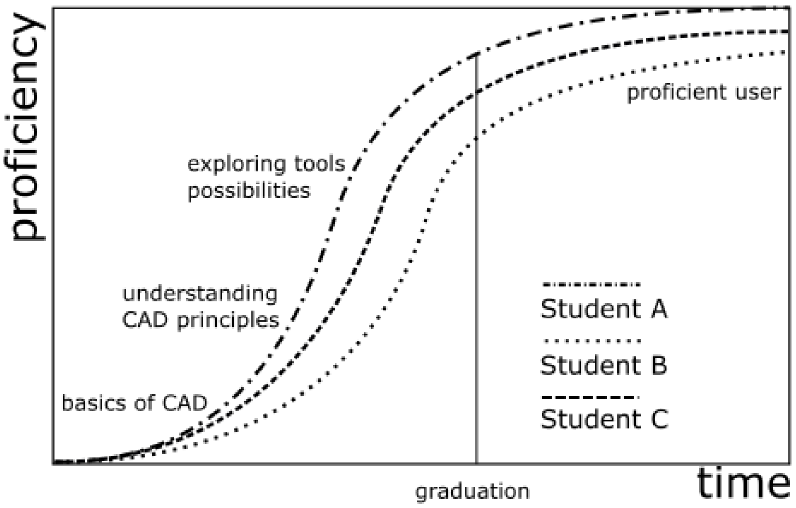


Fig. 1: Learning curve, [7].

Experimental study:
The observed cohort was 35 master students, which consisted of 2 females and 33 males. Before this course, they all had finished 3 terms of CAD lectures specialized in Transport Technology Design. They could thus be considered intermediate CAD users. Their state within the learning curve (Fig. 1) was near exploring tools possibilities. Curriculum of the presented course supposed to be about an advanced use of CAD and involve students in authentic projects simulating industrial conditions.

Traditional CAD assignments are quite specific. Students directly model the assembly based on an existing original or a drawing. Then he has to validate it, check its functionality, strength of certain parts and also its kinematics. Even though the result should be original, its form is already defined by its nomenclature. Once the assembly is named a clutch, it misleads the student from original idea since he has already seen a clutch, and therefore it is visually connected with an existing assembly. The presented course is prepared differently. The machinery has no specific nomenclature. It is merely described via its function and boundary conditions. Therefore, the clutch could be defined as a mechanism for interrupting the torque transmission.

A particular assignment for student teams was to design, verify, manufacture and test a unique mechanism. It would be controlled by one hand ready for a final competition, which was about carrying all the balls from one bin to another, placed 3 meters from each other (Fig. 2). The number of balls was 140 and the operator only had 60 seconds for the transfer. Since the real product competition is never only about meeting the functionality, the designers always have to minimize costs and weight, while attracting customers with something unique. Teams of students had to adhere to seven criterions described in Tab. 1. The different percentage of severity in final evaluation is based on significance of each criterion, similarly to real product projects. Weight, price and number of parts are important elements of lightweight designing. Despite it is difficult to set durability as a criterion, it was expected not to risk a possible failure in the competition. Therefore, all abovementioned criteria had a higher severity compared to dimensions, drawings, and presentation. Presentation of student works has a high importance, however, it was not a part of curriculum here and it is expected to be supported by other departments in the real company. To motivate students to design for modern technologies with strong focus on sustainability, university 3D printers were offered to build their designs free of charge. On the other hand, here the theoretical price was higher in comparison to hand-made solutions. To make the competition more realistic, it is necessary to predefine the labor costs for all teams, so that the gap between additive manufacturing and other technologies will be smaller.

Fig. 2: Competition set-up.

	Criterium	*Description*	*Severity in evaluation*
1	Weight	Less is better	20 %
2	Dimensions	Distance from balls to hand, minimum 180 mm	10 %
3	Price	Less is better	15 %
4	Number of components	Less is better, minimum 3	15 %
5	Drawings	Technical documentation with GD&T	10 %
6	Presentation	Process, kinematics and strength, sustainability	10 %
7	Competition	60 s for carrying balls in the 3 m distance	20 %

Tab. 1: Design demands.

Methodology

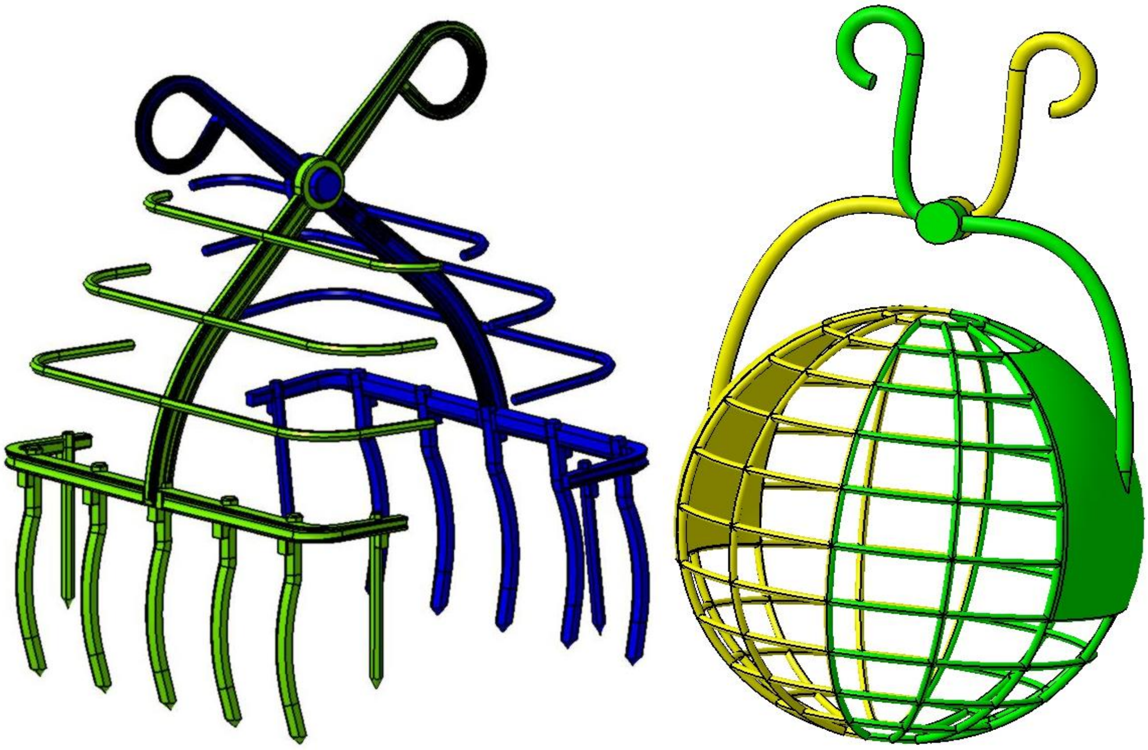
Important steps of the process, which the students learn:

- <u>Theory review</u> – browsing existing mechanisms, inspiration from nature;
- <u>Concept preparation</u> – each student proposes his conceptual design;
- <u>Design, manufacturing, and testing</u> – CAD, kinematics, FEA, Additive Manufacturing, assembling, real tests;
- <u>Economy and marketing</u> – costs calculation or estimation, brand design and presentation.

A part of the preparation of students was learning the TRIZ methodology described in [4]. They had to understand the contradiction matrix and use it to find at least one principle to resolve the design contradiction. These principles were applied for designs and affected their selection since teams had to work with more than two versions. Two compared mechanisms of the winning team are shown in Fig. 3.

An example of the use of TRIZ methodology:

- <u>Find worsening and improving parameters in contradiction matrix</u> – in this case improving is no. 14 strength and worsening no. 1 weight of moving object;
- <u>Find appropriate column of this situation</u> – means raw 14 and column 1, where 4 numbers – 1, 8, 40, 15 – are written;
- <u>Find appropriate principles of TRIZ</u> – no. 1 is segmentation, no. 8 is counterweight, no. 15 is dynamics and no. 40 is composite materials;
- <u>Choose a principle to apply</u> – in this case students chose a combination of 2 principles – they apply a composite material and minimize dynamic loads while operating the mechanism.



a) b)

Fig. 3: Two of proposed designs of the winning team.

Results and discussion:

There were several edifying experiences in the final competition. Students who wished to carry all the balls at once failed, since they always missed one or few balls which were then impossible to re-collect using mechanisms that were too robust and thus had difficulties to fit into a bin. Such models were also quite heavy compared to those, which only carried few balls at once. The best teams used exact time to deliver all balls since they had practiced before designing to find out how many times they can run between two positions. These experiences are applicable in real conditions.

An essential part of any professional growth is a relevant feedback, and university teaching process is no exception. After the competition, most of the students claimed that it was the best course they had during their master studies. Four students filled in an anonymous survey giving the course the best evaluation possible. Another important result of a new course will be after a professional involvement of the graduates. It is expected to be observed by industrial partners. Only a few companies in Slovakia employ the best design students and they also give a feedback once in a while.

The next step in preparation of a curriculum would be to enter or create an appropriate international competition of design projects of student teams. After the first year of this course, it would be too easy for students to design a mechanism for the same assignment, therefore the competition needs to be updated every year. Inspired by the jumping mechanism in [10], it may be a task for the next term to compete in jumping the longest distance or to jump over a predefined obstacle.

The final enhancement proposed for the presented course may be the involvement of modern CAD software tools such as Generative Design from Autodesk or a collaborative and multifunctional 3D Experience platform [6].

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