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On the development of course interconnections within a mechanical engineering training programme via single CAD/CAM/CAE software

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ABSTRACT: This article presents an investigation of a modern education practice: introducing a common computer design tool within different semester courses in a mechanical engineering undergraduate programme. Recently, at the Department of Mechanical Engineering of the Technological Educational Institute of Western Greece, considerable effort has been devoted to the development of a cohesive training structure concerning, especially, the Design and Construction division. The aim was to create interrelations between courses by utilising, from the first semester to the last semester, a single software tool capable of combining computer aided design (CAD), and computer aided manufacturing (CAM) and computer aided engineering (CAE) technologies. This research is to identify and analyse the influence of such a training tactic on preparing future mechanical engineers for the road ahead in the field of manufacturing design. The continuity and cohesion enhancement of the eight-semester educational programme due to the interlinkages, which arose between courses, has been evaluated by conducting an appropriate questionnaire.

INTRODUCTION

There is an increasing demand in the engineering sector for skilled and experienced mechanical engineering graduates. Academics are continuously searching for new programmes that will allow students to gain an appreciation of what industry is really like [1]. Today, a cohesive training programme, which offers spherical and up-to-date knowledge, as well as the experience required by the manufacturing sector has become fundamental. Graduate mechanical engineers should already be aware of any industrial machine or new product development process. It is common truth that the traditional lecturing approach to education presents serious limitations, because it places students in a passive role. The arrival and implementation of computational technologies has led to the replacement of pens, paper and drawing boards with CAD, CAM and CAE applications and, thus, design and consequently design education has been significantly improved. The adoption of these technologies has greatly changed and still modifies the methods of design and education of design. Nowadays, candidate engineers have gained a more energetic and active role in their studies due to computer oriented courses.

CAD could not exist without commercial CAD software tools, which have been developed to systematise and simplify product design. Manufacturing developments are the driving force behind the improvement of CAD systems. Frequently, new advances in CAD systems are sponsored by key companies. In the last three decades, CAD systems have progressed from computer assisted drawing to computer aided design, while the design techniques have evolved from wire-frame modelling, to surface modelling [2], to solid modelling [3][4] and to parametric based modelling [5]. Initially, CAD programs were installed in proprietary computer systems and later in UNIX-based systems. Nowadays, simple Windows-based systems provide support for such software tools. In addition, the development of commercial CAD systems have been progressed from simple 2D and 3D design to the incorporation of CAM and CAE facilities. These improvements have led to the initiation of relevant professional and academic training activities. Future mechanical engineers should be able to apply effectively the CAD, CAM and CAE technologies, which are so highly valued by modern industry. Thus, it becomes evident that the teaching methodology concerning the mechanical engineers of the future should incorporate innovative approaches focused on CAD/CAM/CAE systems [6]. Apart from the basic knowledge and competencies offered by the CAD courses, students should learn effective CAD/CAM/CAE applications in order to be able to improve design productivity, to deploy automatic design and to create parametric design [7].

Despite the popularity and importance of computer-based design courses within undergraduate engineering programmes, there has been little discussion about the improvement of relevant training techniques. Abdulrasool et al have presented two blended teaching learning models concerning a CAD/CAM/CNC module and compared them with traditional teaching-learning processes [8]. Aberšek and Popov have presented an intelligent tutoring system for education on design, optimisation and the manufacturing of gears and gearing [9]. Candal and Morales have presented two experiences based on the use of computer tools for teaching courses about the design and analysis of plastic pieces and moulds [10]. The purpose was to offer students the opportunity to handle software by combining knowledge about plastics, metals, processing, mechanising, marketing, stresses, costs and design. Chowdhury and Mazid have attempted to uncover excellent teaching, learning and research facilities concerning computer integrated design and manufacturing within the Bangladesh University of Technology [11]. Lorenzo-Yustos et al have presented a student learning scheme through projects concerning the design and manufacturing of complete products and showed that students may benefit greatly from the use of CAD, CAM and CAE tools, which are held in high esteem by companies dedicated to the development of machines and products [12]. Spence and Doyle have proposed a product centric training perspective that progressively builds skills and knowledge from mechanical dissection and solid modelling fundamentals towards original product design, prototyping and testing [13].

In the present study, a cohesive training programme is presented, which seems to be appropriate for producing skilful future mechanical engineers in the field of product and machine design. The proposed undergraduate programme includes professional CAD, CAM and CAE courses, which are based on the adoption of a unique professional design tool, i.e. SolidWorks [4]. In order to prove the benefits that arise and the established connections between different courses due to the utilisation of a common software design tool, a special questionnaire was conducted in the Mechanical Engineering Department of the Technological Institute of Western Greece. In particular, the effects of using a commercial software package with CAD/CAM/CAE capabilities in a variety of courses including the final thesis and practical exercise were evaluated and confirmed by an appropriate student-oriented questionnaire survey. According to this survey, a comparison between an old training schedule consisting of independent courses and the current SolidWorks based unified course structure is attempted. The outcome is thoroughly discussed.

SINGLE DESIGN SOFTWARE-BASED MECHANICAL ENGINNERING PROGRAMME

The Mechanical Engineering Department of the Technological Institute of Western Greece aims to produce experienced and highly skilled graduates to enter the work force. Particularly, the aforementioned Department continues to demonstrate its commitment to enhanced education by providing extensive resources in CAD/CAM/CAE software, hardware and training in order to provide to its students the education and experience desired by the design and construction sector. For the last few years students of the Design and Construction Division have been using the same advanced mathematics-based engineering and design tools provided by SolidWorks for courses, such as CAD, FEM, CAM, CNC and Mechanical Formations - Die Design [4][14]. In this way, students learn to design, engineer and validate products in a virtual world and are therefore prepared to address real-world engineering challenges and increased productivity demands. Figure 1 depicts the SolidWorks-based training procedure followed in the Division of Design and Construction starting from the CAD course and ending with the final thesis study and practical exercise.

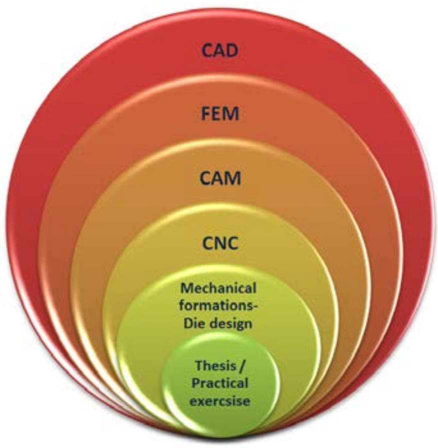

Figure 1: Basic course structure associated with SolidWorks regarding the Design and Construction Division of the Mechanical Engineering Department of the Technological Educational Institute of Western Greece.

SolidWorks [4][14] is a popularly known solid modelling CAD and CAE software program that runs with Microsoft Windows and was developed by Dassault Systemes [4]. The advantage of using a commercial CAD modeller like SolidWorks is that product model of the part can be used as an input, and outputs may be directly utilised for further downstream applications like die manufacturing. SolidWorks solutions cover all aspects of the product development process with a seamless, integrated workflow - design, verification, sustainable design, communication and data management. SolidWorks users can span multiple disciplines with ease, shortening the design cycle, increasing productivity and delivering innovative products to the market faster.

During CAD courses (Figure 2a), students are initially introduced to SolidWorks. They learn the use of sketching and constraints. The main aim is to develop all the required CAD skills, so that students may create working drawings, design specific parts, overview assemblies and use of parametric modelling in creation of parts. The FEM course (Figure 2b) goes beyond the relevant theoretical and mathematical background and includes numerous lessons on simulating real mechanical engineering problems via SolidWorks. Specifically, students learn to create finite element models, and to evaluate designs for non-linear and dynamic response, dynamic loading and composite materials with the powerful tools of SolidWorks. During the CAM and CNC courses (Figure 2c) SolidCAM features are adopted.

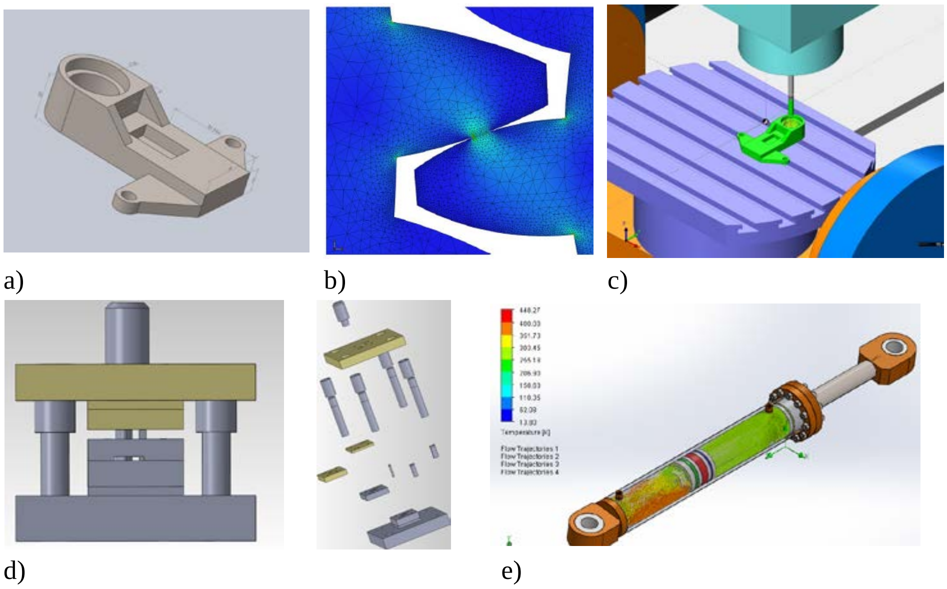

Figure 2: Representative uses of SolidWorks during a) CAD course (design of a metal part); b) FEM (study of gear coupling); c) CAM-CNC courses (manufacturing of a metal part); d) mechanical formations - Die Design course (design of a cutting die); and e) thesis (study of a hydraulic press).

SolidCAM provides seamless single-window integration and full associativity with the SolidWorks design model, so that the CNC may be programmed directly inside SolidWorks in a way that the toolpaths may be automatically updated when the design model changes. Using the specific software, students are educated in CNC programming by utilising easy, fast, efficient and profitable techniques done directly inside SolidWorks. Regarding the Mechanical Formations - Die Design course (Figure 2d), students learn to design dies and moulds, validate final relevant products and to incorporate design changes easily throughout the development process, right up to final manufacturing.

The students are provided with training in various utilities of the software, which are provided for plastic, cast, stamped, formed and forged designs. Students learn to validate that parts can be moulded successfully, including checking for draft, thickness and undercuts to ensure the correct geometry for moulding. Additionally, students learn to use SolidWorks to simulate die kinetics and overall mechanical behaviour, if required. Finally, it has to be mentioned that the SolidWorks software contribution does not stop at the aforementioned courses. Due to its efficiency in providing integrated solutions for mechanical design and manufacture, it has been proved to be a significant and valuable numerical tool for the thesis of many students during the final period of their studies (Figure 2e), as well as their practical exercise that takes place in the final semester.

SURVEY DESCRIPTION

The effectiveness of a recent teaching process in the Design and Construction Division has been compared with the traditional one, which was followed by the Department of Mechanical Engineering five years ago. In the new training tactic, courses, such as CAD, FEM, CAM, CNC and Mechanical Formations - Die Design are based on the use of the same design software, i.e. SolidWorks.

The programme finishes with the thesis study and practical exercise which, frequently, are also strongly associated with SolidWorks. Furthermore, each course aims to prepare students for the courses in the next stage through the adoption of appropriate project exercises. On the other hand, traditional training, which was followed in the past, did not utilise a common computer design tool for all courses which did not present interconnections between them. This study, in particular, reports on *old* and *new* students' views about various facets of the learning process under the traditional and new training mode, respectively.

Data were collected by distributing questionnaires to postgraduate students of the Department of Mechanical Engineering of the Technological Institute of Western Greece. Students completing the survey studied at the Design and Construction Division and one of the two available course programmes; namely, the old traditional programme and new cohesive training programme. The questions that have been set are shown in Figure 3. In response to the difficulty of measuring character and personality traits, a Likert scale has been adopted for measuring attitudinal scales [15]. The Likert scale that has been used here for a series of questions has five response alternatives: a) absolutely no; b) mostly no; c) neither yes nor no; d) mostly yes; and e) absolutely yes.

No of question	Design software helped you:	Absolutely no	Mostly non	Neither yes nor no	Mostly yes	Absolutely yes
1	In 3d designing	○	○	○	○	○
2	In mechanical parts perception	○	○	○	○	○
3	Using FEM	○	○	○	○	○
4	Using CAM	○	○	○	○	○
5	Using CNC	○	○	○	○	○
6	In die design	○	○	○	○	○
7	In your thesis	○	○	○	○	○
8	In your practical exercise	○	○	○	○	○
9	To develop products	○	○	○	○	○
10	To develop as an engineer	○	○	○	○	○

Figure 3: The questionnaire that has been distributed to *old* and *new* students.

The survey explored students' perceptions of the benefits of the use of a unique professional design software in various courses. The questionnaires were intended to permit an examination of the effectiveness of SolidWorks in improving learning objectives for the CAD/FEM/CAM/CNC modules, as well as for the thesis and the practical exercise. Participation in the survey was voluntary. The questionnaires were filled in via an on-line application developed for the purpose. The questionnaires had been formulated in order to gain an understanding of the mechanism of the learning process from the student's perspective. The data presented below correspond to a sample size over 100 students for each category. The students participating in the survey may be categorised into the two following groups:

- *Control group 1*: Traditional training process followed by *old* students.
- *Experimental group 2*: New training process based on a single design software followed by *new* students.

ANALYSIS OF RESULTS

In this section, the output of the survey has been analysed via suitable charts and statistical procedures. The responses of the control group 1 and experimental group 2 are set in contrast in order to investigate the influence and contribution of SolidWorks software adoption in the new programme. Figure 4a and 4b summarise the students' responses regarding the assistance, which design software provided to them during their studies considering the old traditional (control group) and the new cohesive training mode (experimental group), respectively. It becomes obvious that there are more positive responses from experimental group for all kinds of questions. The students seem to be positively influenced by using a single design software for a variety of significant courses. The single design software-based training mode has helped them considerably in the understanding of CNC technology, CAM technology, in increasing their ability to develop new products, and in unfolding their engineering skills by 20.1%, 16.7%, 16.2% and 16.0%, respectively. Corresponding percentages regarding control group 1 were lower: 17.4%, 14.1%, 11.0% and 14.0%, respectively. Nonetheless, according to the students' perspectives, the new training programme has not had a very significant impact on their educational activities regarding FEM course, the thesis study and practical exercise. Generally, according to the presented results, the use of SolidWorks seems capable of effectively combining CAD, CAM and CAE technologies, as well as creating interrelations and positive interactions between courses.

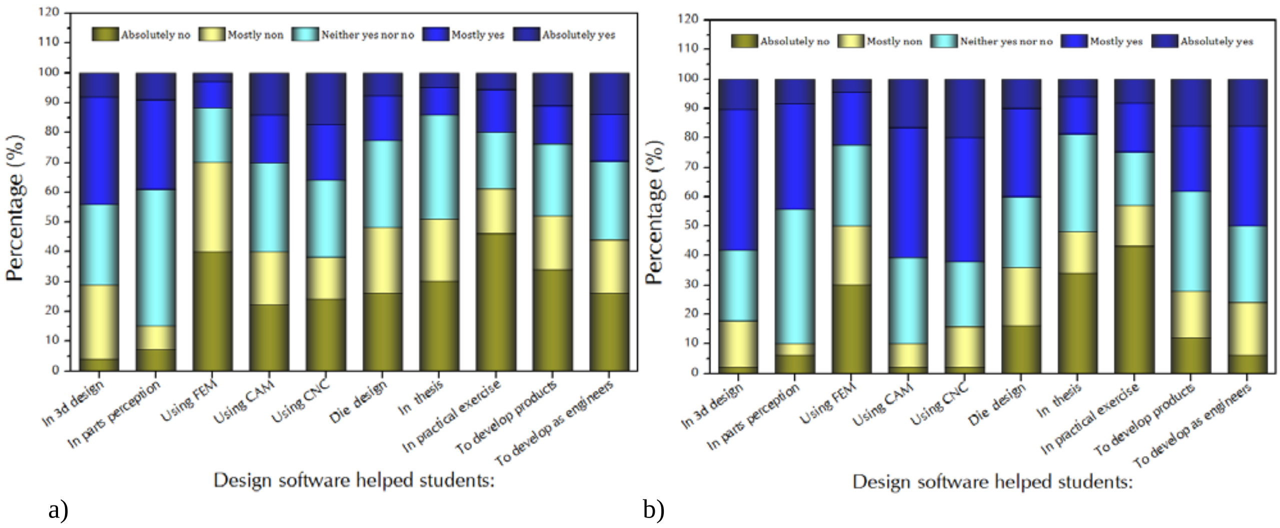

Figure 4: Benefits obtained by the training program according to a) control and b) experimental group's answers.

In order to emphasise the advantages of the new cohesive training mode, Figure 5 compares the positive answer percentages (*mostly yes* plus a*bsolute yes* answers) between the two groups. According to the students' opinion, new learning mode may serve specific educational goals with more success.

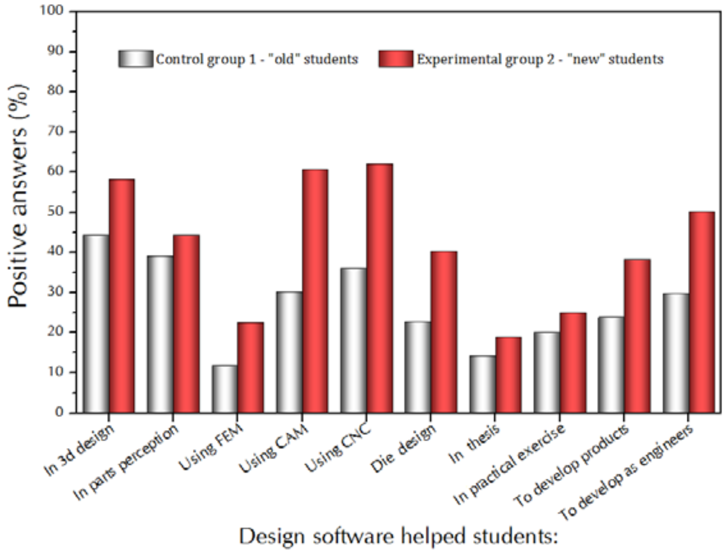

Figure 5: Control group versus the experimental group concerning the benefits received during studies.

In order to prove statistically the fact that the experimental group 2 has extra benefited during their studies, a one-way analysis of variance (ANOVA) [16] was carried out. In order to conduct an ANOVA analysis, Table 1 was constructed.

Table 1: ANOVA table for the statistical analysis of the data depicted in Figure 5.

	Positive answers (%)	
Group $j \rightarrow$ Question $i \downarrow$	Control group 1	Experimental group 2
1	44.2	58.2
2	39.1	44.3
3	11.7	22.5
4	30.1	60.7
5	36.0	62.1
6	22.7	40.2
7	14.1	18.8
8	20.0	24.9
9	23.8	38.2
10	29.8	50.1
Sample mean $\overline{x}_j$	27.2	42.0
Grand mean $\overline{\overline{x}}$	34.6	

Assume the null hypothesis H_0 that the positive answer means between the control and experimental group are statistically equal. Evidently, the alternative hypothesis H_a is that the corresponding population means among groups differ statistically. The two hypotheses may be summarised as follows:

$$\begin{aligned} H_0 &: \mu_1 = \mu_2 \\ H_a &: \mu_1 \neq \mu_2 \end{aligned} \tag{1}$$

where μ_1 and μ_1 are the population means of the control group 1 and the experimental group 2. The sample means $\overline{x}_j$ and the grant mean $\overline{\overline{x}}$ (Table 1) may be calculated by the following equations, respectively:

$$\overline{x}_j = \frac{\sum_{i=1}^{n} x_{ij}}{n}; \quad \overline{\overline{x}} = \frac{\sum_{j=1}^{g} n\overline{x}_j}{N} \tag{2}$$

where x_{ij} is the positive answers percentage (%) for question i =1,2,3,…,10 of group j = 1,2 while n = 10 is the sample size of each group, g = 2 is the total number of groups and, finally, N = 20 is the total number of measurements.

The sum of squares among groups *SSA* and sum of squares within groups *SSW* may be calculated as follows, respectively:

$$SSA = \sum_{j=1}^{g} n(\overline{x}_j - \overline{\overline{x}})^2 ; \qquad SSW = \sum_{j=1}^{g}\sum_{i=1}^{n}(x_{ij} - \overline{x}_j)^2 \tag{3}$$

The corresponding mean squares are:

$$MSA = \frac{SSA}{g-1}; \qquad MSW = \frac{SSW}{N-g} \tag{4}$$

Finally, the F ratio is calculated as:

$$F = MSA / MSW = 239.5 \tag{5}$$

Given the numerator degrees of freedom g-1 = 1, the denominator degrees of freedom N-g = 18 and by adopting the significance level a = 1%, the critical value F_{cr} of F distribution is [17]:

$$F_{cr} = F(g-1, N\text{-}g, a) = 8.285 \tag{6}$$

Since $F >> F_{cr}$, one may safely conclude that the alternative hypothesis H_a is true, which means that the experimental group corresponding to the *new* students who follow the proposed training programme, according to their answers, are statistically better trained.

CONCLUSIONS

Nowadays, the rapid development of engineering education aims to promote education modernisation by utilising new computer-based technologies, especially, in the field of design and construction.

In the present study, a survey was conducted in the Department of Mechanical Engineering of the Technological Educational Institute of Western Greece with the help of an on-line questionnaires sent to a) students who followed an old traditional training mode; and b) students who followed a modern training mode, which is based on the adoption of a common professional design software package as a learning tool in most of the courses.

The results have demonstrated the ability of the proposed programme to assist students in adapting to a rapidly changing educational environment, as well as improving their basic design and engineering skills. Furthermore, the adoption of a single design software package as the medium to familiarise students with CAD, CAM and CAE technologies, combined with appropriate projects, may lead to the development of effective interconnections and compatibilities between courses and, thus, to a cohesive course structure.

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