Experiences with an Innovative Approach to CAD/CAE System Teaching at Secondary Vocational Schools

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ABSTRACT

Aim. In the paper the authors briefly describe a methodology they proposed to innovate engineering education at secondary vocational schools in the field of CAD/CAE systems, and subsequently in a more detail they analyse teachers´ experiences and opinions on the use of the proposed methodology, and to it designed teaching materials, in their teaching practice.

Methods. The proposed innovative way of the CAD/CAE system teaching is based on inverting the ratio of the time allowance between teaching technical drawing, and teaching modelling and simulation from 2:1 to 1:2. The stated inverting enables on the one hand to reduce by half the number of teaching lessons allocated to creation of technical documentation, and on the other hand to double the number of teaching lessons devoted to modelling and simulations.

Results. As a main output of the proposed innovative approach of the CAD/CAE system teaching two textbooks were created which can be used in teaching the subjects focused on technical drawing knowledge and skills acquisition at secondary vocational schools according to the newly proposed alternative way of teaching methodology of CAD/CAE systems.

Conclusion. The created teaching materials supporting the teaching of CAD/CAE systems according to the proposed methodology undergone through an experimental implementation process at a selected sample of vocational schools in conditions of real pedagogical practice. Evaluation of the obtained experiences was done in a frame of a panel discussion.

Keywords: CAD/CAE systems, vocational education and training, technical subject teaching, innovations in IT teaching, new trends in branch didactics

Introduction

During the last twenty years engineering for products has been changed to product lifecycle management. This change was influenced mainly by the continuous development in computer aided design, manufacturing, and engineering (CAD/CAM/CAE) systems and some other engineering areas during the last third of the past century. Application of Computer Aided Design and Computer Aided Engineering (CAD/CAE) tools have been used more and more often in industrial practice, as they considerably contribute to shorten the period which is necessary for a new product entrance to the market as well as to decrease financial expenses related to its development. In a consequence of these facts, courses in CAD, CAM and CAE systems have been introduced in a lot of educational programmes, including study programmes of secondary vocational schools. Although in Slovak vocational education and training a lot of different guides and manuals, supporting familiarisation with the systems and contributing to mastering their utilisation, are available, an efficient inclusion of them into the teaching processes at the relevant secondary vocational schools is missing. That is why at the Faculty of Education, Constantine the Philosopher University in Nitra, an innovated way of teaching CAD/CAM systems at Slovak upper secondary vocational schools was proposed (Kuna et al., 2018; Kuna et al., 2019). After several years after the alternative way was proposed, a colloquium was organised to assess experiences and satisfaction with the proposed methodology of CAD/CAE systems teaching, of the schools in which it has been used. Hereinafter, the particular questions, which were to be answered, together with the main findings resulted from them are discussed in more detail.

Current State of Tendencies to Innovate CAD/CAE System Teaching

Despite the increasing importance of CAD/ CAE systems teaching and a broad scope of publications dealing with CAD/CAE systems issue, only a limited scope of the publications is dedicated to the issue of teaching this topic (Asperl, 2005; Berselli et al., 2020; Lantada et al., 2013; Sapidis & Kim, 2004; Tang et. al., 2011; Xie et al., 2018). As Xiuzi Ye et al. (2004) emphasise, the issue of CAD/CAE systems teaching has to be solved from the point of view that today´s students are tomorrow´s engineers, i.e., it has to be taken into consideration what roles these systems will play in their future (their future as users, technology and software developers, CAD/CAE managers). Some researches point out on the fact that there is no consensus about the optimal time duration of the courses and trainings devoted to CAD/CAE issue teaching, neither about the desirable number of their participants to achieve the best possible learning outcomes (García et al., 2005). However, despite the aforementioned, during the last decade the number of studies dealing with the issue of CAD/CAE systems is increasing. On the other hand, the majority of them is focused on teaching these software tools in higher education institutions, and not within secondary vocational education.

In higher education, CAD/CAE systems teaching is based on the use of a combination of techniques including live demonstrations, printed and online tutorial guides and textbook activities. This way of acquiring relevant new knowledge and skills is efficient in small groups of students. In large groups, this way becomes less effective and additionally to that, it leads students to superficial learning and their poor abilities to apply usefully the obtained knowledge and skills within the context of practical design activities. This is linked with two interconnected facts. The first of them is that the traditional higher education CAD/CAE systems teaching uses explanation of system commands, user interface tutorials, and best practices, all aimed at operating the relevant software system. And the second fact is that in this way of CAD/CAE systems teaching the main attention is paid to teaching „the positive knowledge“, i.e. students are learning what they have to do, and less, or even no attention is paid to teaching „the negative knowledge“, which means that students are not familiarised with what they have not to do. Acquisition of the negative knowledge is paradoxically very important, as not being familiar with the negative knowledge may result in applying inappropriate strategies in design processes which may lead to modelling situations which would have been better avoided (Otto & Mandorli, 2018). According to Ivan Chester (2007) this “positive” and “negative” knowledge can be called ”command knowledge” and “strategic knowledge”. Command knowledge represents knowledge of tools provided by the relevant software application, and knowledge of their using or application. Strategic knowledge represents knowledge of the methods how to use the acquired commands or tools provided by the given software application to achieve the most efficient solution of a particular specific task, and the knowledge how to choose one of them. So, learning of the particular CAD/CAE systems should not be focused only on students´ learning knowledge on modelling, and developing to it relevant maths skills. It should take into consideration also development of students´ skills to utilise all information which they have at disposal either to design something new, or to innovate a given, already constructed product. As examples of introducing new innovative approaches to CAD/CAE systems teaching at higher education institutions we mention works of Rafael Sola-Guirado et al. (2022), Mohammed Abdullatif Almulla (2020), Giovanni Berselli et al. (2020), Richard Lie et al. (2019), A. M. M. Sharif Ullah and Khalifa Harib (2018), Charles Xie et al. (2018), Basilio Ramos Barbero et al. (2017), Andres Diaz Lantada et al. (2013), Ferruccio Mandorli and Harald Otto (2013), Shana Daly et al. (2012), Hector Lorenzo-Yustos et al. (2010), Derek Covill et al. (2008).

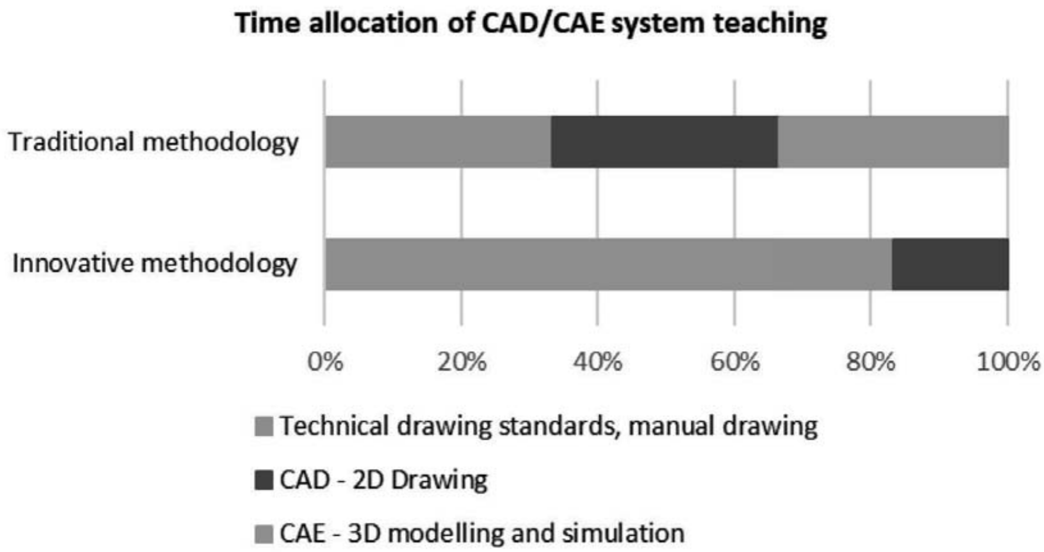
Proposed Innovation of CAD/CAE System Teaching

Common practice at vocational schools in Slovakia (ISCED3) is that students are taught at first basics and rules of technical drawings while practicing all this knowledge in a manual way. This means that they are given assignments to create different schemes and technical documentation by means of manual drawing. Only after this stage the second one starts, in frame of which the students are taught to do the same things, to prepare the same drawings, but based on the use of relevant software applications. The main purpose of the first stage is to provide students with basic knowledge regarding technical drawing creation, while the second stage is focused on development of their practical computer based skills to produce technical documentation. The whole process ends by assignments in frame of which the students produce by the means of computer assisted design technical documentation of different machine elements and integrate them into required complete constructions.

As the above mentioned shows, the key focus of education is on the theory of technical drawing and manual drawing. This is proved also by the fact that according to the State Education Programs (ŠIOV, 2022) two thirds of the total time are devoted to teaching principles of drawing and training of manual drawing, while only one third of it is devoted to teaching CAD/CAE systems. So, the distribution of the time allowance between teaching technical drawing, and teaching modelling and simulation is in the ratio of 2:1, while the given topics are taught in the stated order. As part of the two-year project Teaching Materials Supporting a Progressive Form of Teaching CAD/CAE Systems (2020—2021), the Faculty of Education of the Constantine the Philosopher University in Nitra dealt with a possibility to teach the given topics by an alternative way, based on the opposite ratio 1:2 (Kuna et al., 2018; Kuna et al., 2019). By inverting the ratio 2:1 to 1:2, on the one hand, the number of teaching lessons allocated to creation of technical documentation was reduced by half, and on the other hand, the number of teaching lessons devoted to modelling and simulations was doubled (Figure 1).

Figure 1

Time allocation breakdown graph



Source. Own research.

The curriculum stayed in line with the State Education Program. Necessary changes have been introduced only into the time-topical plan of the relevant subjects, and topical units taught within them. According to the new time-topical plan, students start immediately by designing and modelling machine elements, in the next phase they create their simulations, and only at the end they create technical documentation for the designed 3D model of the constructed elements. While the traditional way of teaching technical drawings has followed the historical technical development of the field of CAD systems, the proposed aforementioned unconventional alternative method of teaching technical drawings (CAD/CAE systems) is based on copying the sequence of individual steps of the design process applied currently in every day technical practice. But to reflect these requirements at schools by increasing the total time allocation for CAD/CAE system teaching would result in necessity to modify relevant school documentation (both State Education Programs and School Education Programs).

In frame of the above-mentioned project Teaching Materials Supporting a Progressive form of Teaching CAD/CAE Systems teaching materials were developed supporting the presented alternative way of CAD/CAE system teaching. As the main output of the project, two publications can be considered, and these are textbooks containing teaching tasks covering the given subject matter.

Teaching Materials Supporting Teaching CAD/CAE Systems According the Proposed Methodology

While designing the teaching materials which could be used at teaching the subjects focused on technical drawing knowledge and skills acquisition at secondary vocational schools according to the newly proposed teaching methodology of CAD/CAE systems, the possibilities of their intervention application in the practice of different secondary vocational schools, where the relevant subject matter is taught (in frame of different particular subjects), were considered. Due to the practical application, the created teaching materials were not conceived as a separate module of teaching texts and an accompanying module of practical exercises, but instead of that two "hybrid" modules were created (hybrid in the sense of the connection of teaching/learning texts with practical activities), one with a narrower thematic focus on technical graphics (Kuna & Skačan, 2021):

- Peter Kuna - Miloslav Skačan: *Technická grafika : Zbierka úloh pre stredné odborné školy* [Technical Graphics : Collection of Tasks for Secondary Vocational Schools]. Nitra, PF UKF, 2021. ISBN 978-80-558-1826-9,

And the other one with a narrow thematic focus on programming the Arduino microcontroller (Kuna & Palaj, 2021):

- Peter Kuna - Miloš Palaj: *Programovanie vývojovej dosky Arduino : Zbierka úloh pre stredné odborné školy* [Arduino Microcontroller Programming : Collection of Tasks for Secondary Vocational Schools]. Nitra, PF UKF, 2021. ISBN 978-80-558-1827-6.

Both textbooks are available at the same link stated in references.

Collection of Tasks *Technical Graphics*

The collection of tasks, or the textbook *Technical graphics : Collection of Tasks for Secondary Vocational Schools* of the authors Peter Kuna and Miloslav Skačan (Figure 2) is oriented on practical solutions of tasks in the Autodesk Inventor environment, which is a tool for designing of new products. This tool continues the tradition of using AutoCAD in education and provides an effective and easy-to-use tool for modelling. Intuitiveness of the use of the particular functions and their options takes parametric, adaptive and interactive modelling, and its use in teaching, on a higher level. The publication contains a detailed description of 20 complexly solved tasks, from the task assignment through compilation of the production documentation of the product even to the creation of the proposed product. The tasks allow the student to master gradually the work in the Autodesk Inventor environment. They are processed in such a way as to proceed from the simple to the more complex, and to gradually increase the difficulty of the solutions. The chapters Introduction of the Autodesk Inventor Program and Basic work with the programme provide basic information about the use of modelling in the Autodesk Inventor environment and about the setting of environment parameters for creating a project — the design of a machine element, or the machine. An integral part of the teaching texts Technical Graphics are also methodological instructions for teachers including notes on solving the particular tasks, definitions and descriptive explanations to the meaning of the basic terms (as e.g., specification of drawing formats, description of the screw principle, explanation of technical drawing scale, etc.). Some tasks are oriented to explanation and practical use of the given elements (machine parts) and functions of the environment, others to knowledge fixation or to solutions of more demanding tasks, where it is necessary to use Autodesk Inventor. Totally the textbook contains assignments and solutions of the following 19 tasks:

- Basic work with the programme;
- Tool *Circle*;
- Polygon as a screw;
- Hammer;
- Pad with holes;
- Fidget spinner;
- Hole template;
- Copying;
- Special flange;
- Brake disc;
- Plastic mat;
- Strengthening pad;
- Shaft;
- Pad;
- Handle with a semicircular cutout;

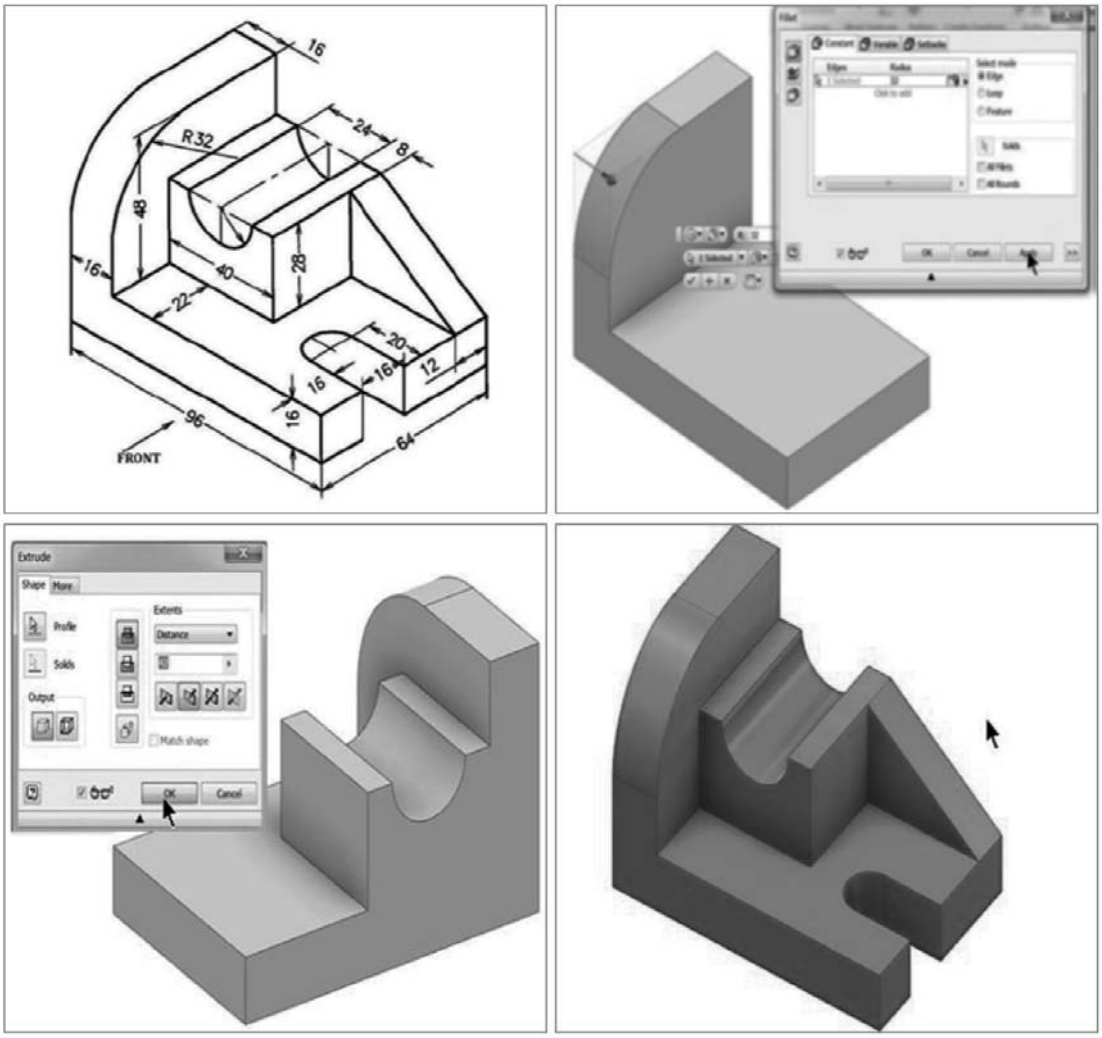
- Pipeline;
- Shaft flange;
- Configuration;
- Modelling plasticine.

Figure 2
Textbook Technical Graphics cover

Source. Technical Graphics: Collection of Tasks for Secondary Vocational Schools (Kuna & Skačan, 2021). Published with the agreement of the author of the cover design Miroslav Šebo graphics.

Figure 3

Example of one of the tasks from the textbook Technical Graphics



Source. Technical Graphics: Collection of Tasks for Secondary Vocational Schools (Kuna & Skačan, 2021).

Collection of Tasks
Arduino Microcontroller Programming

The collection of tasks, or the textbook *Arduino Microcontroller Programming : Collection of Tasks for Secondary Vocational Schools* of the authors Peter Kuna and Miloš Palaj (Figure 4) is focused on the practical solution of tasks oriented on the use of the Arduino microcontroller. The processed issue of the practical use of programming the Arduino microcontroller is highly topical also because of the significant lack of textbooks in the given area. Totally the textbook contains assignments and solutions of following 11 tasks:

- Technical means of Arduino;
- Programming simple applications with LED;
- Programming simple applications with push-button key;
- Programming of analogue inputs;
- Programming LCD and more complex applications;
- Arduino, relay and transistor switching elements;
- DC motor control;
- Servomotor control;
- Stepper motor control;
- Arduino and wireless device NFC;
- Arduino and wireless device Wi-Fi.

The first task is aimed at familiarisation with the technical tools of the Arduino microcontroller. The other tasks contain a description of the task, theoretical knowledge necessary to solve the task, schematic wiring diagram (in two forms) and a programme that is used to control the created circuit. In the case of a more complex task also the connection procedure, the principle of operation of the connected component, or for the user´s inspiration (teacher and student) links to solving similar tasks freely available on the Internet are presented. In the case of some tasks, there are also topics to broaden the given task or to solve another similar problem.

Example solutions of the tasks enable gradual mastering of the use of different possibilities offered by the Arduino UNO microcontroller (its functions, connection of various standard and non-standard components, external functional units, sensors and peripheral devices). As in the case of the teaching texts *Technical Graphics*, the tasks are processed in such a way that they proceed from the simple to the more complex, and the difficulty and difficulty of their solutions gradually increases.

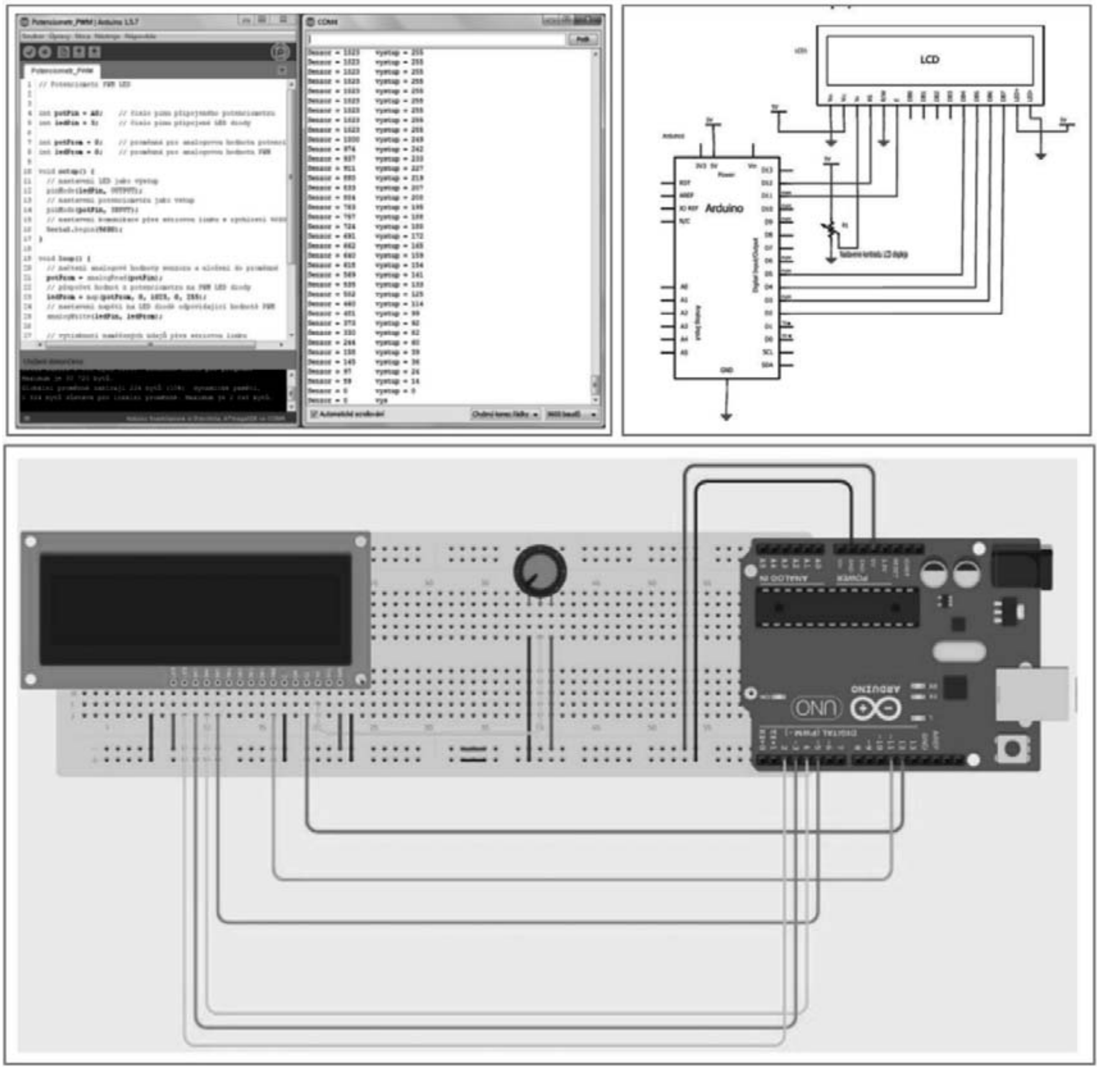
Figure 4

Cover of the Textbook Teaching texts Arduino Microcontroller Programming

Source. Teaching texts Arduino Microcontroller Programming: Collection of Tasks for Secondary Vocational Schools (Kuna & Palaj, 2021). Published with the agreement of the author of the cover design Miroslav Šebo.

Figure 5

Examples of the tasks from the textbook Arduino Microcontroller Programming



Source. Teaching texts Arduino Microcontroller Programming: Collection of Tasks for Secondary Vocational Schools (Kuna & Palaj, 2021).

Evaluation of the Proposed Innovative CAD/ CAE System Teaching

Already in 2020, several secondary vocational schools in Nitra region accepted the proposed innovative CAD/CAE system teaching and started to teach the relevant subjects according to the described methodology. After several years of the use of the proposed way of CAD/CAE teaching at these schools a panel discussion was held to evaluate what are its pros and cross, how effective is this way of teaching and what are the teachers´ experiences with its use in practice.

Methodology of the Carried Panel Discussion

In the years 2020—2022 the proposed new model of teaching CAD/CAE systems have been gradually applied in 7 different secondary vocational schools:

- Secondary Technical School of Mechanical Engineering and Electrical Engineering in Nitra;
- Industrial Construction Secondary School in Nitra;
- Secondary Vocational School of Construction in Nitra;
- Polytechnic Secondary School in Zlaté Moravce;
- Secondary Technical School of Mechanical Engineering and Electrical Engineering in Levice;
- Secondary School of Electrical Engineering in Nové Zámky;
- Secondary Vocational Technical School in Vráble.

Implementation of the proposed model of teaching CAD/CAE systems and teaching of the relevant subjects according to the new methodology was carried out under the auspices of the Department of Technology and Information Technologies of Faculty of Education, Constantine the Philosopher University in Nitra. While applying the proposed procedure in conditions of real pedagogical practice, the above-presented teaching materials (*Technical Graphics* and *Arduino Microcontroller Programming*) were used. To create a common platform for evaluation of the experiences achieved at all these schools with the use of the new model of CAD/CAE system teaching, a panel discussion was held with the participation of representatives of all the given schools.

In our case, there were three "natural" groups of panellists:

- The first group consisted of representatives of different companies and enterprises that apply CAD/CAE systems in their technical practice. From the point of view of technical practice, they are therefore target users of CAD/CAE systems. At the same time, they are employers of graduates of secondary technical vocational schools and therefore, in a figurative sense, "consumers" of the outputs of the secondary vocational education system. A particular group of panellists consisted of representatives of the companies Muehlbauer, Constellium, Eaton and Kompositum;
- The second group consisted of academics dealing with branch didactics of technical subjects teaching, i.e., here were included authors of the proposed innovative methodology together with the authors of the related teaching materials, and for ensuring objectivity and broad view portfolio of the particular discussions also representatives of other academic workplaces. At particular representatives of University of Trnava in Trnava, SK, Comenius University in Bratislava, SK, Masaryk University in Brno, CZ, Palacký University in Olomouc, CZ, University of Technology and Economy in České Budějovice, CZ, and The Kibbutzim College of Education, Technology and the Arts in Tel Aviv, IL;
- The third group consisted of the secondary vocational school teachers, who implemented the new methodology into teaching their subjects. This was the key group of the panel-

lists, as they were its direct first-hand users in pedagogical practice. Moreover, we have perceived them as "suppliers" of adequate work forces for technical practice.

From the stated "natural" groups of panellists three mixed focus groups were created, and the panel discussion was led in the form of the focus group interview. In each of the focus groups was more or less the same number of the representatives from each of the "natural" groups of the panellist, i.e. there were more or less the same numbers of the representatives of the industrial practice, academic environment and secondary vocational schools. While the panel discussion with the whole group of the panellists required intensive inputs of the moderator into the led discussion (i.e., the discussion is dominantly influenced by the moderator and it is led as a debate between the moderator and the panellists), the panel discussion in the form of focus group interview is dominantly based on mutual debates of the panellists. As Mike Watts and Dave Ebbutt (1987) state, the focus group interview is a form of interview in which a group of people spend some time together debating a given problem, while it is important that the participants in this debate focus on what the other members of the group are saying.

The key questions, discussed during the panel discussion, were the following:

- Opinions on the content of the newly created secondary school programme of CAD/CAE system teaching;
- Experience with the organisation of this way of CAD/CAE system teaching at secondary vocational schools;
- Evaluation of the created teaching materials to support the newly proposed way of CAD/CAE system teaching;
- Own observations and ideas of the panellists related to the discussed issue,
- Analysis of errors and problematic parts of the proposed new way of CAD/CAE system teaching.

In the first phase of the panel discussion, the key questions were discussed separately in each of the focus groups, while each of the groups had to come to its own answers to each of the given questions (topics). At the second part of the panel discussion, each of the focus groups presented the conclusions, to which they came. Subsequently all panellists in mutual debate had to come to common conclusions.

Findings and Conclusions Resulting from the Panel Discussion

In each group, the discussion in each of the focus groups took place in a very constructive, direct, and honest dialogue. This was also due to the fact, that most of the panellists (including the moderator) already knew each other personally from the previous different kinds of cooperation.

From the common debate led in the second part of the panel discussion, following findings and conclusions resulted:

- All participants appreciated the idea of changing the content structure and time allocation of the particular topics of CAD/CAE systems in secondary school curricula. It was clearly stated, and verified in pedagogical practice, that the newly created and implemented teaching model more accurately reflects the needs of industrial practice;
- Mainly the secondary vocational school teachers pointed out on some problems with organising this type of teaching at schools. The key problem results from the status of the new methodology, i.e., with its status of "experimental" teaching. Content of the experimental teaching had to be aligned with prescribed teaching. There was general agreement with the opinion that if this teaching is approved as a "standard model", almost all the organisational problems that occurred and were discussed will be deemed irrelevant;
- Despite a long and content-rich discussion about the content of the created teaching material, these were evaluated by high credit. The selected example solutions were evaluated very positively, as well as the presented work procedures themselves, as well as the expertise and topicality of the content. A broad discussion was led on the selection of the particular topics. Each of the industry representatives had another idea about the importance or significance of the particular topics. This can be to a high measure influenced by the application expertise and experiences of the industry representatives. There was an unequivocal consensus that it would be appropriate to expand the given topics and possibly publish another sequel to the created textbook.

Results and Conclusions

The primary goal of the carried discussion was to get feedback on the newly designed and experimentally verified way of teaching CAD/CAE systems, and from different points of view. Implementation of the new methodology was based on the assumption that the successful experimental verification of the benefits of the proposed methodology from the point of view of didactics does not automatically mean also confirmation of its general usefulness and benefit across secondary vocational education and training, technical practice and academic research. The discussion formed by the panellists — partners from the given branches brought evaluations, opinions and ideas with a high degree of objectivity.

The conclusions of the discussion described in detail in the previous points can be summarised as follows. The newly created methodology of teaching CAD/CAE systems is applicable in the environment of secondary vocational education. From the point of view of the expertise, it more thoroughly reflects the requirements of technical practice, which is considered as its main benefit. Didactic materials to support the new teaching system are excellent from both a pedagogical and professional point of view. The wide range of types of CAD/CAE systems used at secondary vocational schools necessarily places demand on the creation of such materials for other types of CAD/CAE systems as well.

An unplanned topic of the discussion was the expression of the importance of the creation and long-term use of a communication framework between the environment of technical practice, vocational education and universities. All parties involved agreed that such discussions should be organised in a targeted, long-term manner under the state supervision of the Ministry of Education, Science, Research and Sport or the Ministry of Economy. However, the very positive evaluations stated within the discussion, including the evaluation of our own panel discussion was overshadowed by the absence of further continuation or systematicity of the entire process. All participants of the panel discussion expressed their opinion in support of organising such discussions also in the future (what could be done also in an electronic form), as the exchange of opinions across the academic environment and technical practice brings new knowledge to the improvement of vocational education.

Acknowledgements

This research was supported by the Cultural and Educational Grant Agency of the Ministry of Education, Research, Development and Youth of the Slovak Republic, within the project no. 009UKF-4/2023 Virtual Reality in PLC System Programming.

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