



TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 65, Issue Special I, February, 2022

ENHANCED LEARNING MATERIAL FOR MECHANICAL ENGINEERING STUDENTS

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Abstract: This paper describes a case study of a project guide that uses digital learning materials enriched with physical learning materials, created for mechanical engineering students that learn computer aided design for the first time. The digital learning material details the systematic process in which a five degree-of-freedom robotic arm is designed. The purpose of this research is to highlight the advantages of combining the digital learning materials with the physical learning materials. The digital learning materials are useful in the modeling, assembly and simulation of 3D models, while the physical learning materials help students to grasp the scale and the shape of the digital 3D components. The physical learning materials are obtained via 3D printing the 3D modeled components. This approach has the potential to make both teaching and learning more effective.

Key words: computer aided design, mechanical engineering, interactive learning material, 3D printing.

1. INTRODUCTION

In higher education, students have the opportunity to engage in evidence-based learning activities, and to manage their learning on their own [1]. As presented by R. J. Kapadia [2], there are several learning styles which can be matched with different types of teaching styles. These teaching styles are dependent on the subject matter, but also on the teacher. Several authors have addressed the introduction of 3D printing components into the teaching process, to create a hands on learning experiences. The authors Y. H. Chien and P. Y. Chu [3] studied the ability of high school and college students to use 3D modeling applications to create a car form. L. Cheng et al. [4] conducted a study that examined the influence of teacher's beliefs and 3D printing integration in science classrooms or student's science, technology, engineering, and mathematics motivation (STEM). S. Ford and T. Minshall [5] investigate the application of 3D printing in schools, universities, libraries and special education settings, where they identified six categories: teach students about 3D printing, teach educators about 3D printing, support

technology during teaching, produce artefacts that aid learning, create assistive technologies, and support outreach activities. L. Cheng et al. [6] studied the influence of 3D printing in STEM integration on students' interest in STEM careers, which is essential for students to participate in STEM disciplines.

Several universities created manufacturing laboratories, or makerspaces, where students can learn on the "do it yourself" and "learning by doing" principles, where all the software and manufacturing tools are available [7]. Some researchers investigate the impact of makerspaces to the additive manufacturing field, and to highlight how individual users can benefit in order to gain access to 3D printing technologies in the best way possible [8].

Teaching computer-aided design is more focused on the practical use of a computer aided design software, where students have to learn the software's commands, to be able to create 3D models, assemblies, drawings and simulations.

Most of the students from Romania that enroll at the Technical University of Cluj-Napoca have attended high schools focused on Mathematics and Computers programming, therefore they have a limited experience

regarding technical drafting drawings and manufacturing engineering.

For students that attend their first computer aided design software course and practical project it is very helpful for both the teacher and students, if the learning experience makes use of tangible components that the students can analyze and manipulate within the classroom. Figure 1 presents one of the classrooms used to teach Computer Aided Design within the Technical University of Cluj-Napoca. The classroom has 15 individual desks, each suited with a workstation and plenty of room on the desk if the students want to use their own laptops, having access to a dedicated power outlet on the side of the desk. The teacher's desk makes use of a digital projector so that the students can follow the teacher's screen with ease.



Fig. 1. Computer Aided Design laboratory.



Fig. 2. Makerspace laboratory from Technical University of Cluj-Napoca.

3. THE LEARNING MATERIAL

Since the struggle with the global pandemic that started in 2019 some changes had to be made in teaching, and adapting to an online environment, some changes had to be done to the teaching materials as well. Thus, the teaching materials had to be digitized, to be able to be sent via the internet to the students. This opened up

The practical project is focused on the 3D modeling of a five degree-of-freedom robotic arm using the SolidWorks software solution.

2. RELATED WORK

The authors have identified several problems that some mechanical engineering students encounter, with no or lesser technical background [9], thus the authors created a printed version of this student's guide, which they enriched with an augmented reality application. This example of learning material is useful in a face-to-face style teaching, where students can use the computers in the classrooms to follow the steps from the printed version of the student's project guide. This example has its limitations, regarding that, students cannot grasp the size of the 3D modeled components, since the printed version and the augmented reality application does not present the models in their real scale.

On the other hand, our faculty has a makerspace, where several 3D printer types are installed, from different manufacturers that students can use. There are also a few machines, on which they can carry out different tasks. A wide screenshot of the makerspace can be seen in Fig. 2.

new possibilities, but also created some challenges.

The authors have identified the need to create the teaching documents in a globally known format that can be easily opened on every smart device, without specialized or paid software. This was an important factor, to increase the availability of the teaching materials for students.

To meet all the above-mentioned criteria the *.PDF (Portable Document Format, created by Adobe) format was chosen for the student's guide. This format allows the integration of 3D models into the document, in the text body, to exemplify the components of a five degree of freedom robotic arm. Students are guided with

step-to-step instructions to create the components and then the assembly of the robotic arm. At the beginning of every chapter is presented the location, an integrated 3D model and a drafting drawing of the component that is going to be 3D modeled, as shown in the Fig. 3.

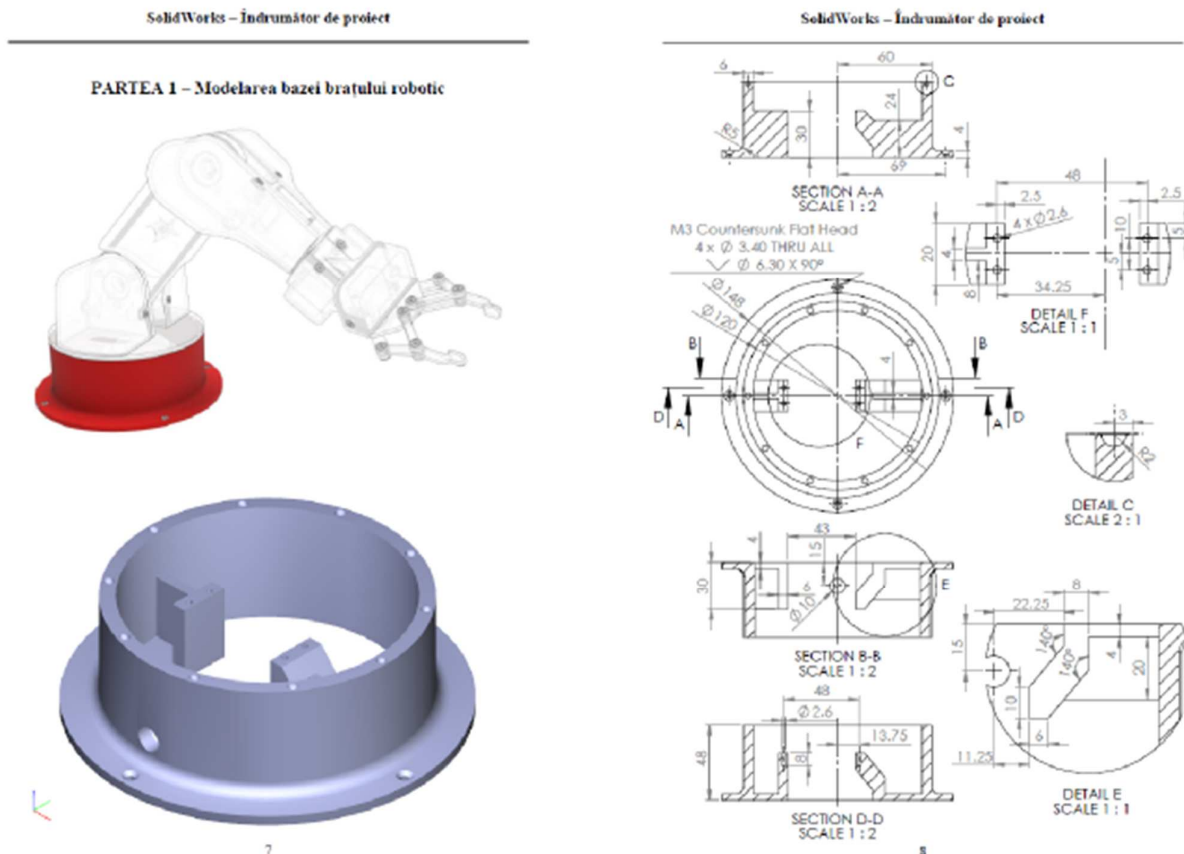


Fig. 3. The 3D model (left) and the 2D drawing (right).

Moreover, the *.PDF format facilitates the integration of 3D models in *.STP or *.STEP formats, by attaching them to the document. Students who already know how to 3D model and need to practice the assembly of components can really benefit of this feature, by skipping the 3D modeling part of the components.

The student's guide is available at the Technical University of Cluj-Napoca's online library website at [10] for free and can be accessed by anyone who wishes to learn SolidWorks. The file size of this document is less than 30 Mb.

The five degree-of-freedom robotic arm was designed around some existing components that can be bought on the market, like MG996R servomotors, Micro 9g servomotors, M3 Countersink Flat Head screws, and Ø4 mm bearing balls. From the beginning, the robotic arm was designed to be functional, because of this; the design of the robotic arm was affected by some limitations that 3D printed components have (fragility of components, wall thickness, component's size, etc.).

Having the components 3D printed, students can experience the real size of components, and understand the need of using the correct

dimensions in the 3D modeling process. During the 3D modeling process, they can check the shape of the real components, if they have difficulty reading the drafting drawings from the student's guide.

4. THE WORKFLOW

To create the learning materials, the authors used the following software: SolidWorks, Microsoft Word, Adobe Acrobat Pro, and PrusaSlicer. The above-mentioned software applications should be accessible in every university. The workflow has a straightforward approach. The methodology is presented in the Fig. 4.

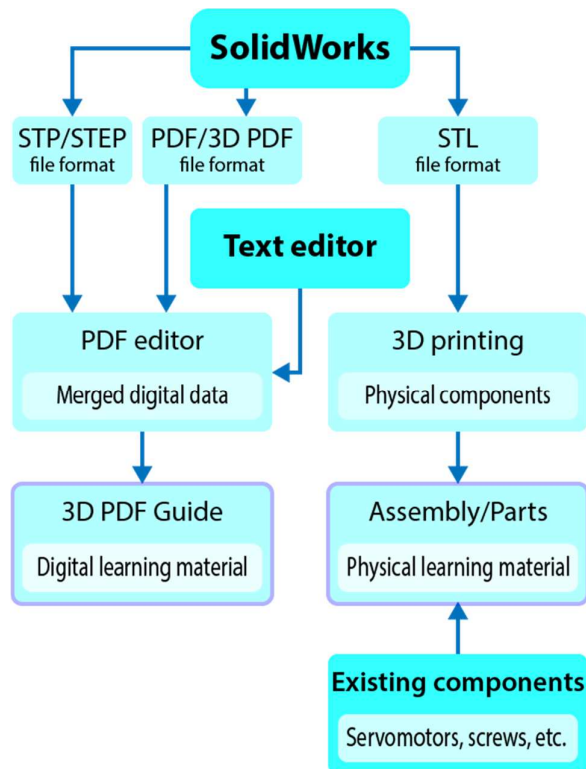


Fig. 4. The proposed workflow

The workflow starts with the 3D modeling of the five degrees-of-freedom robotic arm's components. After the final design is finalized, the creation of every single component is detailed using text and screenshots in a text editor. The text document is saved as a *.PDF file as well, to be further used in the final version of the digital student's guide.

At the same time, every single 3D modeled component is exported in three different formats

from the SolidWorks software application, in addition, the drafting drawings as well in one specific format:

- *.PDF – for the 2D drafting drawings;
- *.PDF (3D) – for the interactive 3D models;
- *.STEP – for the embedded 3D models;
- *.STL – for 3D printing the components.

The *.PDF and *.PDF (3D) file formats are combined using a PDF editor software, to achieve the final layout of the digital student's guide, after which the *.STP / *.STEP files are included as attachments. This way, all the necessary digital learning materials are in one place and can be easily shared. This final document will constitute the digital learning material part.

The *.STL file formats are used to create the robotic arm's physical components, using additive manufacturing technologies. The authors used a widely known Prusa i3 MK3S printer to create the physical learning materials. In the image below are presented the digital 3D model and the 3D printed model of the robotic arm's second arm.

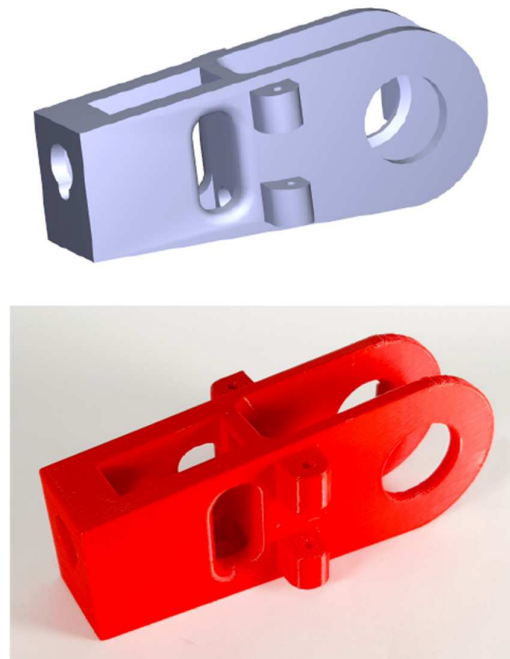


Fig. 5. The robotic arm's second arm 3D model (top) and 3D printed component (bottom).

The robotic arm's components were 3D printed with black and red colored PLA (Polylactic acid) type materials, as rendered on the project's guide cover, presented in Fig. 6.



Fig. 6. Cover of the project's guide (left) and 3D printed components (right).

The code for the Prusa 3D printer was generated using the printer's software, PrusaSlicer, version 2.3.3, from the *.STL files saved from SolidWorks. A 30% infill was selected for the components of the robotic arm. An Ø0.4 mm nozzle was used, with a Ø1.75 mm PLA filament. In Fig. 7 is presented the robotic arm's second arm in the slicer software.

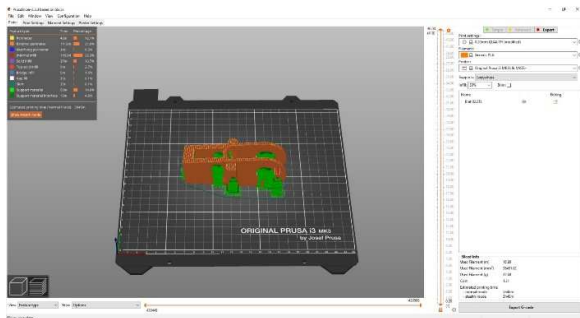


Fig. 7. 3D printing setting within PrusaSlicer

This workflow can be used to create other similar learning materials that use different CAD software, but if the used CAD software cannot export *.PDF (3D) file formats, a third-party application is needed, like Deep Exploration, which can convert *.STP file formats into *.PDF (3D) file formats.

5. CONCLUSION

Using this type of combination of digital and physical learning materials, students can easily work on their projects in either an online or a face-to-face environment.

Using a 3D PDF document, which has all the documentation and additional files in one place for a project for mechanical engineering

students, makes the digital learning materials more accessible.

The digital student's guide can be opened on any smart device, but in order to have the ability to interact with the embedded 3D models, the document must be opened with an Adobe PDF reader on a personal computer.

Combining the intangible and tangible learning materials, mechanical engineering students have a better understanding of the tasks that they need to complete on a project.

The presented workflow uses commonly used software applications for CAD users and should represent an easy method to create digital learning materials for different type of educational projects, that are used mainly in higher education.

6. FUTURE WORK

In the moment, the student's guide is available only in Romanian language, but the authors want to create an English version as well, useful for ERASMUS students that learn in our university.

In addition, the student's guide can be extended for multidisciplinary use, by adding a new chapter that tackles the programming of the Arduino board that controls the robotic arm's movements.

The authors would like to extend the number of 3D printed components, to include section views, to help students who have issues reading drafting drawings. In addition, 1:1 scale drawings will be printed, to be used together with the sectioned real components, for a better visualization of the sections.

The authors would like to create a survey for the students that use the proposed learning method in this article, in order to evaluate the usefulness of this approach, and to be able to improve it.

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MATERIAL DE ÎNVĂȚARE ÎMBUNĂȚIT PENTRU STUDENȚII DE INGINERIE MECANICĂ

Rezumat: Această lucrare descrie un studiu de caz al unui material de învățare digital îmbogățit cu materiale de învățare fizică, creat pentru studenții de inginerie mecanică, care învață pentru prima dată proiectarea asistată de calculator. Materialul digital de învățare detaliază procesul sistematic în care este proiectat un braț robotizat cu cinci grade de libertate. Scopul acestei cercetări este de a evidenția avantajele combinării materialelor digitale de învățare cu materialele fizice de învățare. Materialele de învățare digitale sunt utile în modelarea, asamblarea și simularea modelelor 3D, în timp ce materialele de învățare fizică îi ajută pe studenți să înțeleagă scara și forma componentelor digitale 3D. Materialele de învățare fizică sunt obținute prin imprimarea 3D a componentelor modelate 3D. Această abordare are potențialul de a face atât predarea, cât și învățarea mai eficiente.

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