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Integrating 3D printing in project based learning for future healthcare- and medical engineering professionals

Introduction

The already well-established application of 3D printing in various industries has shown a multifaceted potential in education, especially for students of medical and medicine-related courses. The module "Medical Imaging" within the Mechatronics/Medical Engineering bachelor program at Munich University of Applied Sciences consists of a lecture, an interactive seminar and a practical lab course. After learning theoretical concepts (physical principles of X-rays, CT, MRI, cross-sectional imaging including positions and orientation, image reconstruction and algorithms) in the lecture, students are invited to participate in an interactive lab course where they are asked to perform a modeling exercise to create printed models from real CT or MRI DICOM datasets, thus enhancing students' practical skills and professional motivation.

Material and Methods

The didactic framework of this practical course includes all steps from the reconstruction of an image from a DICOM dataset to the collaborative construction of a fully assembled skeleton (see Figures 2 - 9). This enriches the lecture with elements of a "cooperative game" according to the EPAMOS method, which incorporates mechanics derived from games in order to increase the motivation in a non-gaming context [5][6]. In the conceptualization of this course, open source or free software and open hardware platforms were used to minimize financial costs, reduce dependency on manufacturers, and prioritize the principle of sustainability (e.g., reasonably priced tools that can be repaired, assembled, or replicated). The software used for 3D reconstruction from the DICOM dataset included 3D Slicer [1][2], Autodesk® Meshmixer [3], and PrusaSlicer [4]. The hardware setup consisted of a Prusa i3 MK3S, an enclosed housing, a camera, and a filter. Printer networking, including camera integration and connection to the RaiseCloud remote monitoring service, was established using the OctoPrint platform. Tools (e.g. files, sandpaper, precision drill grinder) were used for mechanical post-processing.
The visual and textural outcomes, as well as the anatomical accuracy of the 3D printed models, are then evaluated by the instructors using a grading scale developed specifically for this application to ensure comparability between students. In addition, the success of the lab is also determined by student evaluation, observation of student communication (frequency, use of technical and anatomical terminology), and the impact of participation in the non-mandatory lab course on exam results.

Figure 1: Mechanically post-processed and assembled model of a left foot and ankle.
The individual bones are connected by wires and springs to resemble the physiological range of motion of the various joints. The printed model bone of the tibia shows the remnants of the triangular mesh previously used for the 3D model (see Figure 4).

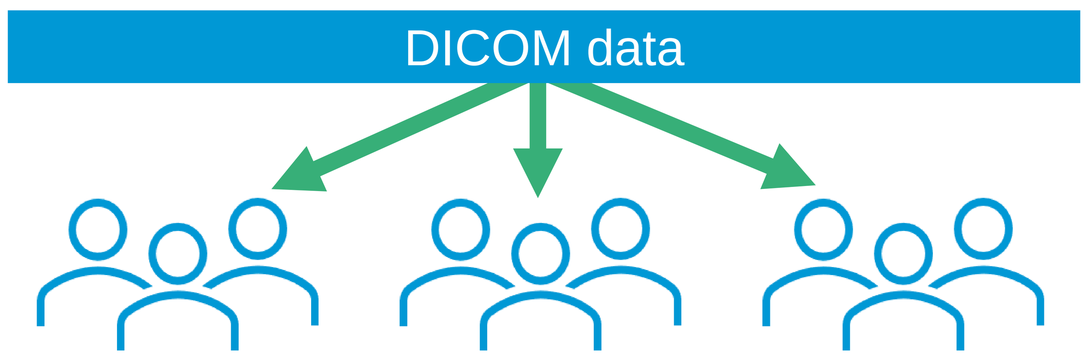

Figure. 2: Provision of a medical dataset:
Different body parts, in this case bones, are assigned to students to be extracted from a whole-body medical dataset (DICOM). The source data are anonymized CT or MRI scans. Students whose bones form a common macrostructure (e.g. arm, leg, skull) group now and collaborate later in the process (See Figure 9).

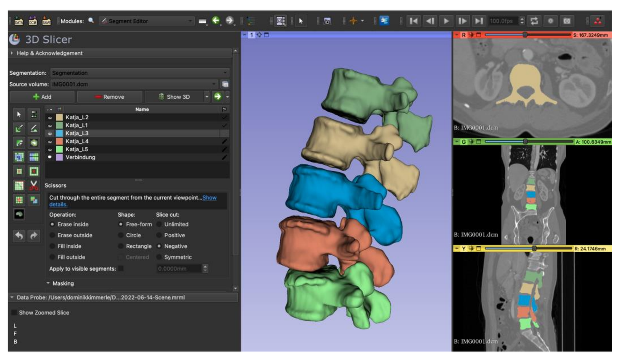

Figure 3: Segmentation:
The open-source software 3D Slicer is used to extract the bone structures from the surrounding tissue in each layer and export the resulting 3D object as an STL file. The use of several image processing tools such as thresholds and pen tools is required. The process of segmentation improves the spatial imagination in medical images and therefore improves anatomical understanding.

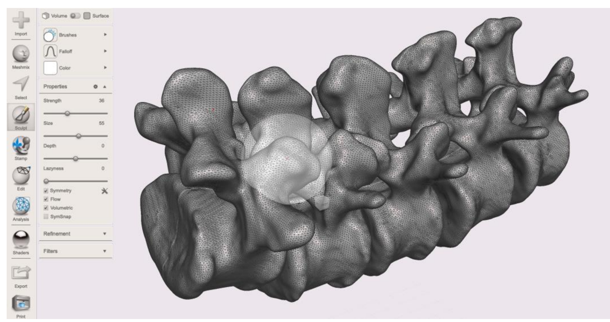

Figure 4: Digital post-processing:
Since the model is now defined by its surface (triangular mesh) this step typically involves mesh manipulation such as refinement, mesh repair, interpolation and slight structural deformation within the free software Autodesk® Meshmixer.

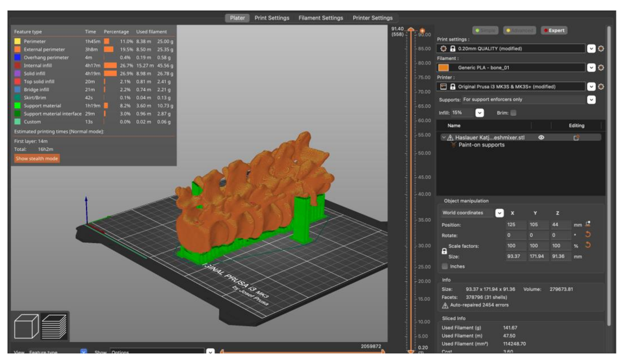

Figure 5: Printing preparation:
Under the personal guidance of experienced tutors, students are introduced to the beginner-friendly Prusa i3 MK3S printers in the lab and learn how to set up a print job. This includes preparation in the open source software PrusaSlicer for positioning, support structure placement and machine code export. It includes explanations of the parameters, materials and machinery.

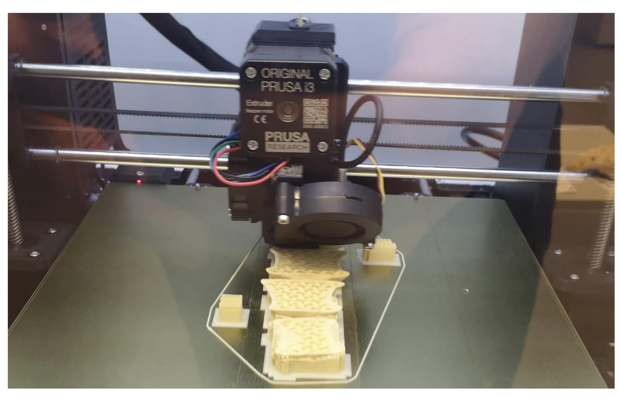

Figure 6: Printing process:
During the printing process, students have remote access to their printers through the RaiseCloud service. The monitoring features, including a real-time video stream of the printing process of their personal model, allow them to register incidents in an early stage and intervene if necessary.

Figure 7: Mechanical postprocessing:
In order to remove support structures, improve surface quality and in preparation for assembly of individual joints, students are provided with a variety of necessary materials and tools.

Figure 8: Individual assembly:
Part of the problem-solving aspect is finding ways to integrate joint connections into the model. In this spine section (lumbar spine, L1-L5), anatomically correct joint cavities are combined with an artificial but elastically flexible connecting rod to provide realistic flexibility. See Figure 1 for details. This exercise is designed to help students identify where articular surfaces are located on different bones and the consequences of damage, such as arthrosis or fractures.

Figure 9: Group assembly
The cooperative game element of the task requires the students at the end of the course to combine their individual bones first to separate limbs and further into a full skeleton (also see Figure 11). The student were required to constantly exchange ideas and find solutions through teamwork.

Results

Figure 10: Finished print of a cranium
The model with still attached support material is ready to be removed from the print bed and postprocessed by the student.

Figure 11: Fully assembled skeleton
By trying to build an anatomically correct skeleton the students also gained a deeper understanding of the importance and biomechanics of stabilizing connective tissues and ligaments.

Conclusion

In addition to lectures and seminars, the practical course in the Medical Imaging module can more effectively convey the application of additive manufacturing in the medical field.
As shown in the literature [7] and in our own research [8], students benefit significantly from learning with models rather than relying solely on lectures and literature. The innovation of combining this with materials science and additive manufacturing, as well as adding a gamification aspect, has proven to be extremely beneficial. This is evidenced by increased student participation, reduced dropout rates and increased motivation.
This instructional method enables students to specialize in specific areas such as medical engineering simulations and training, additive manufacturing, material sciences, patient education, and the education of new generations of medical professionals and engineers. This encompasses challenges such as point-of-care applications, osteosynthesis materials, intra-surgical manufacturing, and personalized medicine (e.g., customized implants and prosthetics).
The utilization of low-cost and open-source hardware has also proven to be beneficial. This significantly reduces the barriers to entry for students and ensures easy maintenance.
The success of this project offers valuable insights into novel teaching methods and concepts that have the potential to contribute to the sustainable improvement of education for future medical engineers.

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