A Framework for Technology Enhanced Education in Orthopaedics: Knee Surgery Case Study

G. Devedzic\textsuperscript{1}, S. Petrovic\textsuperscript{1}, A. Matic\textsuperscript{2,3}, B. Ristic\textsuperscript{2,3}, V. Devedzic\textsuperscript{4}, Z. Asgharpour\textsuperscript{5}, S. Cukovic\textsuperscript{1}

\textsuperscript{1} University of Kragujevac, Faculty of Engineering, Sestre Janjic 6, 34000 Kragujevac, Serbia
\textsuperscript{2} University of Kragujevac, Faculty of Medical Sciences, Svetozara Markovića 69, 34000 Kragujevac, Serbia
\textsuperscript{3} Clinical Centre Kragujevac, Clinic for Orthopedics and Traumatology, Zmaj Jovina 30, 34000 Kragujevac, Serbia
\textsuperscript{4} University of Belgrade, Faculty of Organizational Sciences, Jove Ilića 154, 11000 Belgrade, Serbia
\textsuperscript{5} Materialise HQ, Technologielaan 15, 3001 Leuven, Belgium

Abstract—The paper presents a framework for technology enhanced education (TEE) in orthopaedics aimed at employment of ubiquitous information and communication technology (ICT) and digital technologies in order to compensate for an unaffordable learning environment. On the other side, the concept involves both (bio)engineers, ICT specialists, and orthopaedic surgeons in an interprofessional collaboration, leveraging multidisciplinary approaches to improve the quality of clinical-oriented education. Preliminary results indicate increased motivation and satisfaction of both the learners and educators.

Keywords—Technology enhanced education, 3D modeling, Augmented reality, Orthopaedics, Bioengineering.

I. INTRODUCTION

Traditional approaches to medical education have two stages: formal "classroom" knowledge (with clinical experience), and hospital apprenticeship. These involve theoretical classes and lab exercises and training aimed at gaining practical clinical-oriented knowledge. However, big discrepancies exist, in terms that students are not sufficiently exposed to different clinical settings during training and are not well equipped to identify essential health problems and provide solutions.

In order to overcome underlying deficiency and provide better education for real-world health problems, schools of medicine employ different kinds of simulators, mannequins and partial- and full-body task trainers, patient-simulation rooms and laboratories, sophisticated training stations for surgical skills, and other advanced digital equipment [1-3]. These are oriented towards efficiently gaining additional knowledge and experience through studying hypothetical patient cases. Combined with interaction with real patients and assistance with treatment throughout clinical practice, students have supervisory guidance in gaining competences for addressing real clinical problems. Such a combination of meaningful and instructive clinical experiences and academic learning is interwoven throughout medical education. Additionally, it fully complies with the objectives set in European and worldwide strategies and standards [4-6].

However, in some cases availability of these advanced learning aids, approaches and facilities is highly dependent on national and institutional economic capabilities. Consequently, educators, learners and trainees are facing a lack of adequate facilities required for a proper response to the challenge of paradigms of contemporary medical education. In order to partially overcome these deficiencies, we propose systematic employment of ubiquitous information and communication technology (ICT) and digital technologies, which provide a good ground for compensation when a sophisticated, but expensive, learning environment is not affordable.

The paper presents preliminary results obtained through in-progress comprehensive action at the University of Kragujevac (Serbia) aimed at quality improvement of medical education through the substitution of one part of the unaffordable equipment with virtual contents. This is a follow-up study of the actions undertaken within Tempus project 530423: "Studies in Bioengineering and Medical Informatics – BioEMIS", funded by the European Commission (EC).

II. RELATED WORK

Contemporary medical education has used digital technology and corresponding sophisticated equipment for years in order to gain additional knowledge, improve skills, and accelerate medical progress. It is used to facilitate education at both undergraduate and graduate levels. As Tarpada et al. summarize, in the field of orthopaedics different e-learning approaches are applied, combining virtual patient cases, digital modeling, online tutorials, as well as video recordings of surgical procedures, which are proved to provide greater score improvement than standard teaching methods in both knowledge and clinical skills [7]. Pei and Yan present the multidisciplinary concept of Digital orthopaedics.
that embraces digital anatomy, navigational, virtual and robotic surgery, 3D printing, and finite elements analysis (FEA) [8]. Obviously, this concept synthesizes both hardware and software components, and the knowledge stemming from medicine, engineering, medical physics and materials science. Although the majority of the underlying systems are aimed at performing real surgery, in terms of education and training, these provide the ability for clinical residents to learn basic skills and techniques, and conduct pre-operative planning [2], [9-11]. Among them, a special class of devices is designed for training and simulation only and usually offers haptic functionalities.

In addition to simulation systems dedicated to surgery skills and techniques, contemporary orthopaedics also uses software systems based on computational methods [12-13]. Even though, based upon a number of assumptions and simplifications, these systems help to give deeper insight into the behavior of bones, joints and implants under loads in a non-invasive manner.

Technology enhanced learning and training systems and approaches mainly rely on 3D virtual models of patients [1-2] and anatomical structures (both healthy and pathological) [14]. Basically, virtual patients may be created in dedicated software packages, while creation of anatomical structures assumes the application of reverse engineering technology to the corresponding datasets generated by various imaging and scanning modalities, e.g. X-ray, CT, MRI, ultrasound, optical. Nowadays, the growing technology of 3D printing, also based on 3D virtual models, provides plenty of opportunities for simulation based and discovery learning [14-17].

These examples, as well as a plethora of others, demonstrate the value of TEE approaches and techniques, contributing to an increased satisfaction of learners and their educators in the field of orthopaedics. Thereby, multidisciplinarity appears as a basis of all the underlying concepts, systems, and methodologies.

Finally, Tempus project BioEMIS basically provided twofold benefits. Firstly, in the Western Balkan region, there are now several accredited study programs in bioengineering and medical informatics with qualification identification, as the result of joined action of the nine state universities [18]. Secondly, initially equipped laboratories encouraged new ideas and collaboration axes, launching a comprehensive action towards essential improvements in the ways in which knowledge in the field of orthopaedics (and more generally, in medicine) is communicated and skills are achieved.

III. FRAMEWORK OUTLINE

In our approach we propose a blend of dedicated systems, simulation techniques, and technology-enhanced learning (TEL) and e-/m-/blended learning (EMBL) approaches. In order to compensate for the part of unaffordable systems, yet providing undergraduate students with easily accessible learning contents required for gaining practical clinical-oriented knowledge, we designed a set of collaborative laboratory projects in the course of Geometrical modeling (in medicine) for the students of bioengineering. Each project has the generic structure shown in Fig.1.

![Fig. 1 Generic structure of the projects in Geometrical modeling (in medicine)](image)

As a result, each project brings an anatomical structure, healthy or pathological. It is stored in the repository of 3D virtual models, ready for further use, e.g. augmented reality (AR), 3D printing, FEA analysis, and digital mock-up (DMU) analysis, in the form of TEL materials.

Combining it with easily electronically accessible virtual 3D models, simulation and computational tools, students and learners have the abilities to perform problem-based, collaborative, what-if study approaches that are safe and protected from harmful substances, specimens and organisms. Unlike traditional off-shelf learning objects, these innovative models bring additional suitability for promotion of collaborative interprofessional education among the different student groups, clinical educators and/or healthcare professionals.

Learning materials and other resources are delivered in the form of Open Educational Resources (OER). They include different multimedia content, such as textbooks, course readings, simulations, games, and other learning applications that can be used in orthopaedics. They are
released under a Creative Commons or similar license that supports open or nearly open use of the content. They are typically stored in repositories on shared servers, and teachers and researchers can include more resources over time. Students can browse and use these resources from various devices (desktop, mobile), anytime and anywhere. In addition, discussion forums and learning analytics techniques enable resource authors and students alike to have a better insight into the usability and usefulness of resources in such a resource ecosystem. Institutions that build, maintain and use these resources can, in principle, impose restrictions on using the resources, but in practice more and more institutions rather enjoy the benefits of openly sharing their resources.

As the number of resources in orthopaedic OER repositories grows over time, tools to search for and filter resources become a necessity for instructors and individual learners to navigate the content, to assess its accuracy and credibility, and ensure its high-level quality, especially when they are used in for-credit courses. All this is a prerequisite for developing orthopaedics massive open online courses (MOOCs) on top of such OER repositories.

Finally, our framework involves both EMBL and Digital orthopaedics in a scalable manner, allowing for employing as many elements of these two concepts as available or needed.

IV. CASE STUDY – TOTAL KNEE ARTHROPLASTY

Taking into account efforts, achievements and evident research results, as the effect of the systematic introduction of the bioengineering study programs in Serbia and Western Balkan countries through the BioEMIS project, the Faculty of Engineering (University of Kragujevac, Serbia) proposed further development in the field. Considering well-rooted collaboration and the amount of research results jointly achieved by teams of the Faculty of Engineering and Faculty of Medical Sciences [19-21], it was decided to promote our initiative in the field of orthopaedics. At undergraduate level, for which we mainly intend our TEE methodology, orthopaedic surgery is taught within a much wider course of surgery. Since students do not always have the opportunity to attend all representative orthopaedic surgeries, TEL materials are designed to fulfill that shortage on one side, and to provide easily accessible additional learning aids for problem based and discovery learning, on the other.

Augmented reality (AR) technology is the link between real and virtual worlds that provides interactive coexistence of virtual objects in a real world environment. A part of the innovative TEL materials uses this technology to bring deeper interactive insight into the orthopaedic surgeries while using traditional learning resources. Preliminary results have been achieved for the surgery of gonarthrosis (knee joint arthrosis).

![Fig. 2 The workflow of development of AR supported TEL material](image)

A male patient, aged 70, suffering from left knee gonarthrosis, underwent knee surgery. An x-ray of the left knee proved arthrotic changes over the whole joint and was classified as III/IV grade by Kellgren-Lowrence classification. After typical preoperative preparation, the patient underwent surgery during which a cruciate retaining total condylar knee prosthesis was implanted.

In order to acquire images needed for the development of innovative TEL materials, we performed optical scanning in the operating theater using an Artec Spider® 3D scanner. For the reconstruction of the scans we used Artec Studio 11®, Geomagic Design X®, and Catia V5 R21®. Marker-based AR application was developed using Unity® and Vuforia development platform. The workflow of the development of AR supported TEL material for gonarthrosis caused total knee joint replacement is shown in Fig.2.

The Artec Spider scanner enables the recording of the object’s texture, which contributes to a more realistic visualization of the TEL materials. After reconstruction in Artec Studio 11 accompanying software, a textured surface model is exported into .obj format, which is required for further processing in Unity software for AR application development. Depending on further application (FEA, 3D printing, DMU, ...) the surface model may be additionally processed to a 3D solid model. This is a challenging task for students of (bio)engineering, which promotes collaborative team work. All 3D models generated through the described pro-
cess are stored in the OER repository for browsing and usage.

V. CONCLUSIONS

Principles of contemporary education in the field of orthopaedics promote intensive utilization of both hardware and software systems to improve the quality of learning outcomes and the quality of training of the students and clinical residents. In the cases when a sophisticated learning environment is not affordable for any reason, we propose a framework that enables compensation to a feasible extent by employing technology enhanced education methodology. The key feature is providing users with learning materials delivered in the form of Open Educational Resources. At this moment they include Augmented Reality supported frameworks, but the whole framework is building towards accessing various multimedia contents, course readings, simulations, games, and other learning applications. Linking real and virtual worlds, AR technology provides students and trainees with better perception and understanding of what is not perceived or experienced directly by the use of their own senses, imaging modalities or involvement, such as experience with total knee arthroplasty (TKA). Moreover, thanks to the multidisciplinary approach, besides teachers and students of medicine (surgery, orthopaedics), an essential contribution is collaboratively provided by teachers and students of (bio)engineering and ICT. Future enhancements are directed towards upgrading the current AR applications to support a markerless tracking mode, more intensive application of 3D printing technology, and improvement of simulation capabilities.

ACKNOWLEDGMENT

This work is a part of the project “Application of Bio-medical Engineering in Preclinical and Clinical Practice”, supported by the Serbian Ministry of Education and Science (III-41007).

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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Corresponding author:
Goran Devedzic
University of Kragujevac, Faculty of Engineering, Sestre Janjic 6, 34000 Kragujevac, Serbia
Email: devedzic@kg.ac.rs