Project Number	621668-EPP-1-2020-1-ES-EPPKA2-KA
Project Title	Mixed Reality in medical Education based on Interactive Applications (MIREIA)

PEDAGOGICAL NEEDS

Dissemination Level	Public
Delivery Date	Aug. 2021
Responsible	UPM
Authors	Carmen Guzmán García, Manuel Rodriguez Matesanz, Ignacio Oropesa García, Enrique J. Gómez Aguilera, Patricia Sánchez González, Magdalena K. Chmarra, Jenny Dankelman, Thomas Lango, Jan-Magne Gjerde, Calin Tiu, Juan A. Sánchez Margallo, Francisco M. Sánchez Margallo

Co-funded by the Erasmus+ Programme of the European Union

Version control

Version	Date	Comment
01	13/09/2021	First version of the report
02	14/09/2021	Format and partners contributions
03	15/09/2021	Approved version

Summary

Deliverable 3.1 presents the process of identifying and defining a list of pedagogical needs of the solutions to be developed in the MIREIA project. The pedagogical needs are a result of (1) the analysis of the state of the art, (2) past research projects and experiences, and (3) the knowledge elicitation process. The methodology followed for the review of the state of the art and the knowledge elicitation are described within this deliverable, together with main findings.

All knowledge summarized in this deliverable lays out the pedagogical roadmap of the MIREIA project. This roadmap is going to be used to set the guidelines for 3D models' design, ensuring that the learning resources facilitate the development of all the needed skills.

Table of contents

1. Introduction

Medical education is a long and demanding process, requiring the learning of extensive theoretical knowledge as well as a set of technical and non-technical skills[1]. Traditionally, during the early stages of education, training methods are often based on static learning content and sometimes far removed from actual clinical practice[2]. Currently, these methods are being replaced by new approaches based on the use of information and communication technologies (ICTs)[2]. New technologies, such as extended reality (which include virtual (VR), augmented (AR) and mixed reality (MR)) and three-dimensional (3D) printing, are being applied in different aspects of the medical field, including education[2].

Despite the popularization of these methods and technologies, several challenges remain to be addressed in order to extract the full didactic potential of virtual models: (1) there are no existing technologies for quick and automatic generation of 3D models, which means that models must be obtained from third parties with limited personalization; (2) there are no accepted standards to exploit these novel immersive technologies with methodological guidelines in medical training, and (3) scientific evidence to support the validity of personalized models as learning and training tools is scarce.

MIREIA is a unique Knowledge Alliance involving Higher Education Institutions (HEIs) and companies that will combine the use of cutting-edge technology in immersive virtual technology and 3D printing with personalized learning content to promote the student-centered learning process of medical students and residents. This Alliance proposes the development of an innovative methodology and tools to provide interactive pedagogical content for customized training based on 3D models, such as anatomical models (with and without pathologies) built from real-patient cases (e.g. medical imaging studies) and/or virtual scenarios for basic training in minimally invasive surgery (MIS).

Contents will be accessible anytime and anywhere using portable devices, extended reality (XR) visualization technologies, and/or printed with 3D printing technology. This will allow students to train through immersive virtual environments or in physical simulators that use personalized 3D printed models. Mentors will also be able to create and share any clinical experiences as learning content for students. These clinical experiences can include medical imaging studies, 3D anatomical models based on preoperative studies, or video sequences of surgical procedures, following specific methodological guidelines. In addition, innovative tools will be implemented for the semi-automatic creation of customized 3D models for educational purposes.

Deliverable 3.1 (D3.1) focuses on identifying pedagogical needs, which we have defined as everything that has to be taken into account while creating the 3D models, so that they have a firm pedagogical basis. For that, the consortium gathered knowledge from (1) the state of the art on the application of 3D models in training and the learning assets available, (2) past research projects and experiences, and (3) interviews, workshops, and discussion groups with medical stakeholders. The gathered knowledge was used to make a roadmap to set the guidelines for instructional design to create 3D models and print them guided by pedagogical sustainment.

In this deliverable, we will present the methodology and results for knowledge elicitation that has been employed in Work Package 3 (WP3). Within the MIREIA project, the knowledge elicitation phase has served for the definition of the pedagogical needs. Knowledge elicitation process and its results (including pedagogical needs) are presented in this deliverable - D3.1 - , while D3.2

will focus on the methodological guidelines to create learning contents from 3D models, and D3.3 on the methodological guidelines for 3D printing with training purposes.

2. State of the art

For this task, we covered the existing range of commercial and research solutions within 3D model creation and printing, existing for medical training.

2.1. Methodology

In order to carry out the analysis of research solutions within 3D model creation and printing focused on medical training, a systematic literature search was carried out following the PRISMA statement in Web of Science, Scopus and Pubmed [3,4]. The specific search strategy was "(Medical OR surgery OR surgeon OR surgical OR healthcare) AND (3D model OR tridimensional model) AND (learning OR training OR education)". The last search was conducted in March 2021 and filtered for the last 5 years. All the retrieved titles and abstracts were screened for relevant manuscripts and duplicates. Then, full-text articles were assessed for eligibility. Of the articles retrieved, only those meeting at least one of the following criteria were included:

1. Studies on the potential of 3D models in medical learning.
2. Studies including data on how to create and/or print 3D models for other medical applications.
3. Studies involving training methodologies for medical skills making use of 3D models.

Only articles in English were included. Reviews and conference reviews were excluded, since the aggregated data from these articles did not fit the requirements for this review. Once articles were deemed to be included or excluded, all included articles were analyzed. The tools to create and print 3D models used by each article were disclosed, as well as whether they proved their validity. Since 2014[5], validity must be established in a specific context by gathering supporting evidence[6]. In fact, this approach has been removed altogether from subsequent revisions of the consensus standards[5], and replaced by a unified model, in which different sources of validity are explored; i.e., Messick validity framework[7]. Messick framework consists of 5 different sources of validity evidence:

- Content. Represents the relevance of the assessment method with its intended use (e.g. if the intention of a test is to measure preparedness to operate appendectomies in the operating room (OR), the requirements of the test content are different than if the intention is to simply say something about surgical psychomotor skills in general)[8].
- Response process (i.e., quality control). Represents "the data integrity and the extent to which the understanding and performance of those assessed aligns with the expectations and interpretations of whomever or whatever is making the assessment"[9]. For instance, if some participants have trained far more than others on the simulator before it is tested, this might bias the interpretation of the results. Additionally, the rater (or scoring technology) should consider external factors that can influence the obtained test scores[10].
- Internal structure (e.g., reliability). Relates to reliability (i.e., consistency) and reproducibility of the tested entity. [11]

- Relationships with other variables. Analyses statistically associated assessment scores with specified theoretical relationships (e.g. variations in simulator scores against number of laparoscopic procedures performed[12] or assessment scores against a previously validated gold standard[10]). This validity evidence is in consonance with the construct and criterion validity types of the 1985 standards.
- Consequences of the assessment. Explores whether desired results have been achieved and unintended effects avoided[9]. A test investigating consequences can be whether an assessment method that is used to select candidates for residency programs, selects well suited candidates (i.e., a positive consequence would be if the candidates that are selected are well suited, while a negative consequence could be that the method is too strict and good candidates are not allowed to enter)[10].

In addition to this, we have also studied the commercial solutions found in the market. Based on a study, the annual growth rate of VR applications between 2017 and 2025 is profiled to be about 30.7%, worth about 6.5 billion dollars[13]. The potential of VR technology in healthcare appears as business way for those with the resources to invest in a company that offers either hardware, software, or both. Taking into consideration the amount of money needed to start up a technology company, we researched some funding process such as invention competitions and partnership relations in the last decade. Furthermore, we found some companies that are making into the industry with an extended budget. This will be extended on the result section.

2.2. Results

The search strategy after exclusion of the duplicates yielded 299 articles. Of those, 130 were further excluded after title and abstract screening. Out of the remaining 169 articles, 48 were excluded for not being focused on 3D models (i.e., they used commercial models and applied them), and 25 of them were excluded for not being focused on medical training (i.e., they focused on other healthcare applications, such as patient familiarization with their diseases). Finally, 77 articles were included in the review. The workflow of the selection process can be found in Figure 2.1.

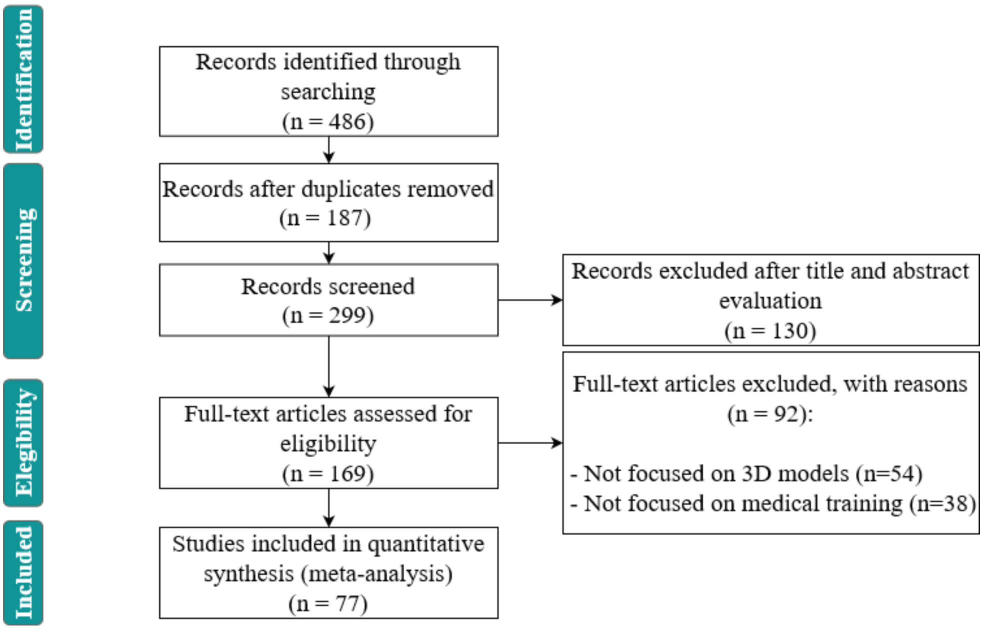


Figure 2.1. Workflow of the review of the state of the art.

The distribution of specialties in those articles are depicted in Figure 2.2, being the most common urology, traumatology and internal medicine and neurology.

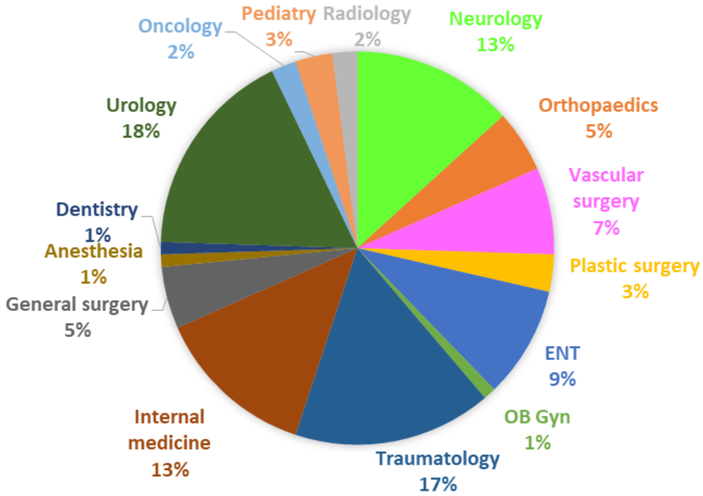


Figure 2.2. Distribution of specialties within the articles of this review. ENT (Ear-Nose-Throat): otorhinolaryngology. OB Gyn.: Obstetrics and Gynecology.

1.1.1. 3D model creation

According to this literature review, 3D models of human tissues or organs can be created from different sources as depicted in Figure 2.3 (i.e., Computed Tomography (CT)[14–65], Magnetic Resonance Imaging (MRI)[14,21,30,32,35,39,47,50,66–74], X-rays[45,75–77], Ultrasound (US)[30,50,78], microscopic sample images[61,79,80], and 3D photographs of the organs or tissues to be modelled[81,82]). The most used one is CT.

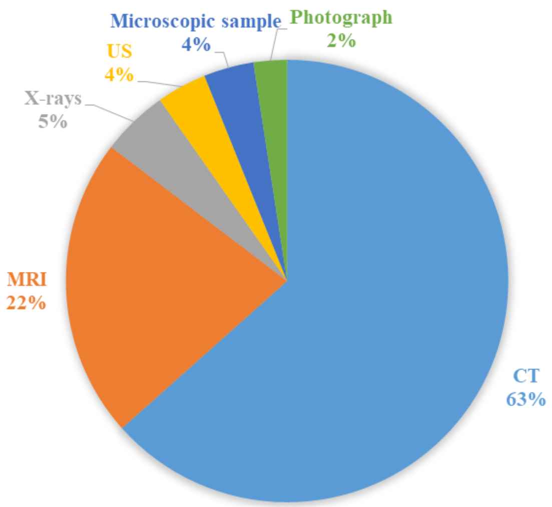


Figure 2.3. Distribution of data sources for 3D model creation.

If more than one source is used for the creation of the 3D model, the image sources should be registered (i.e., alienated to make sure that all consequent images are taken from the same angle and create a realistic view of the tissue or organ to be modelled)[83]. Then, the source images are segmented (i.e., anatomical structures are differentiated from the images). This segmentation can be manual (made by experts, such as radiologists), automatic (made by computer algorithms), or semiautomatic (made by computer algorithms which need one or more inputs from an expert)[83].

Within this review, we have found that the automatic methods for segmentation aimed at 3D model creation are based on deep learning methodologies[63,69,75,76]. Specifically, most methods make use of 3D convolutional neural networks. In addition, deep learning methodologies can also be used for the 3D reconstruction of the models, with an end-to-end methodology (i.e., training networks both for segmentation and reconstruction).

Regarding manual or semiautomatic methods, there are several software tools available in the market that allow to segment images for further model creation, being the most common 3D slicer[16,22,23,25,31,34,39,42,44,52,71,77,79,84] (36%), followed by Mimics[36,43,45,47,49,50,57,85] (17%), ITK snap[22,27,38,52] (11%) and Photoshop[60,67,80,86] (8%). Other tools were used, although in fewer articles (i.e, Amira[21,53], Hisense computer assisted surgery system[54,87], 2D Xtra vision[41], Stealthviz[88], Seg3D[89], Intellispace portal[61], Alma3D[17] , Artec Eva[90] and Synapse[35]).

Once images are segmented, 3D reconstructions techniques are applied to merge all images into a unique 3D model and add meshes that can be used in VR to deform the tissue realistically. The most common software solutions found in the literature are Meshmixer and Meshlab[18,23,27,31,36,38,40–43,78,79] (20%), Mimics[20,29,45,47,49,50,57,77,85] (18%), Cura[16,17,22,25,27,57,91] (10%), Osirix[28,60,67,86,91] (7.5%), 3D slicer[39,52,63,71,84] (7.5%) and Blender[28,38,42,81] (5%). Other tools were used in individual articles (i.e., Amira[53,66,80], Autodesk[60,86,92], Google Sketch up[64,65], InVesalius[93], Geomagic[90], CAD[34], Seg3D[89], Synapse[35], Stealthviz[88], Vitrea[40], Hisense computer assisted surgery system[54,87], 3D coat[94], Zprint[56] and Netfabb[43]).

1.1.2. 3D model printing

Within this review we found that 3D printing is done by Fused Deposition Modelling (FMD) most of the times[16–19,22,24,25,27–29,31,40–42,46,47,49,54,56,57,60,67,71,72,77,86,90,93,95] (72%), followed by material jetting [34,36,45,52,53,85](17%) and laser sintering[61,78] (10%). As for the materials: PLA [22,28,31,42,95](24%) and ABS [24,25,38,40,41,43,49,53](27%) are the most common ones (obtaining also good results when studied for realism). Other articles used polyamide[60,67,86], resin[29,95], PVA[42,61], TangoPlus[21,36], PC[16,77], PETG[16,26], Glycol-modified filament[26,96], silicone[95], GA[28], and polyurethane[27].

1.1.3. Application of 3D models in medical training

Out of the 77 included articles, only 31 studied the applications in medical training. The main conclusions of each article can be found in Table 2.1.

All in all, most 3D models were found useful and realistic in most of the articles studying content validity. Both virtual and printed 3D models were considered most useful when used for surgical planning. With respect to its relationship with other variables, in most cases the use of 3D printed models was perceived as more useful for training than the use of virtual model. However, when compared with 2D images, both types of models proved to bring about better outcomes (e.g., decision making confidence, performance time, number of errors, etc.). Interestingly, medical students (and surgical residents) found 3D printed models more useful in their training, while experienced doctors and surgeons perceived virtual models as the best tool to complement training[45,51,52,55,56].

1.1.1. Commercial solutions

Between the numerous companies found in the study of commercial solutions for 3D models usage in Extended Reality (AR, MR and VR simulations, 18 companies are focused on Table 2.2.

Table 2.1. Summary of the articles studying applications in medical training, including the specialty and number of participants, the validity type, the main purpose of the study and its main findings. ENT:

Authors	Specialty (No. participants)	Validity type	Main purpose	Main conclusions
Grillo et al. (2019)[93]	Neurology (17)	Content	Design and validity test of virtual and printed 3D models	Both realism and usefulness were considered high.
Haffner et al. (2018)[16]	ENT (15)	Content	Design and validity test of virtual and printed 3D models	Different printing materials were tested for realism, obtaining that PETG was the most realistic, followed by PLA and ABS.
Jacobo et al. (2018)[19]	Traumatology (NA)	Content and relationships with other variables	Design and validity test of virtual and printed 3D models	Quantitative assessment of the model realism resulted effective. Model was designed to be used for surgical planning, and procedure time was reduced. Teachers and residents were satisfied with the use of models for planning and the advantages of manipulating physical models were highlighted.
Barber et al. (2018)[34]	ENT	Content	Design, validity test and guidelines for VR application of virtual and printed 3D models	A navigation tracking system utilizing a 3D-printed endoscope was designed as a trackable VR controller and validated the accuracy on VR and 3D-printed skull models.
Boedecker et al. (2021)[35]	Internal medicine	Content	Design, validity test and guidelines for VR application of virtual and printed 3D models	"System Usability Scale" (SUS) score of 76.6%.
Condino et al. (2018)[38]	Orthopedics and Traumatology	Content	Design, validity test and guidelines for VR application of virtual and printed 3D models	Designed a MR HoloLens-based training system using 3D printed model, and tested it for usability and realism by clinicians and engineers. The perceived overall workload was low, and the self-assessed performance was considered satisfactory.
Awan et al. (2019) [40]	Radiology (22)	Relationships with other variables	Study of transfer learning with 3D model	Found that the test taken before using the 3D model obtained lower scores than after using it.
Bairamian et al. (2019)[41]	Neurology (10)	Relationships with other variables	Study the perception of models in training	Virtual model showed advantages in its resolution, ease of manipulation, durability, and educational potential. VR angiogram had a higher questionnaire total score than 3D models. 3D printed models had a statistically significant advantage in depth perception and ease of manipulation.

Bati et al. (2020) [71]	Internal medicine (NA)	Content	Study the perception of models in training	3D model was perceived more useful than 2D when training (with a simulated patient), especially the printed version.
Chee et al. (2021)[42]	Internal medicine (17)	Content	Comparison of virtual and printed 3D models in training	3D model was better or much better for airway inspection when compared with Broncho-Boy.
Cherkasskiy et al. (2017)[43]	Traumatology (10)	Relationships with other variables	Study of transfer learning with 3D model	3D model in surgical planning with actual patient reduces procedure time.
Gillis et al. (2020)[95]	Urology (64)	Relationships with other variables	Study of transfer learning with 3D model	Participants increased their confidence in the procedure after training with 3D printed model (perceived as realistic).
Hyde et al. (2019)[44]	Urology (25)	Relationships with other variables	Study of transfer learning with 3D model	Participants increased their confidence in decision making after training with 3D printed model (perceived as realistic).
Jacquesson et al. (2020)[82]	Neurology (195)	Content	Study of transfer learning with 3D model	A stereoscopic model was used as the main aid for a lecture. It turned out to be well-accepted by the residents in the class.
Kang et al. (2019) [45]	Traumatology (102)	Relationships with other variables	Study of transfer learning with 3D model	86% of inexperienced surgeons wanted to use 3D models for complex fractures but only 18% of experienced did.
Li et al. (2018)[46]	Internal medicine (20)	Relationships with other variables	Study of transfer learning with 3D model	3D printed model was perceived better than virtual one.
Lim et al. (2018)[77]	Traumatology (41)	Relationships with other variables	Study of transfer learning with 3D model	3D model and CT scans decreased the number of misclassifications of fractures as compared to X-rays.
Lin et al. (2018)[47]	Oncology (42)	Relationships with other variables	Study of transfer learning with 3D model	Found that the test taken before using the 3D model obtained lower scores than after using it.
Lobb et al. (2019)[49]	Plastic surgery (6)	Relationships with other variables	Study of usefulness in surgical planning	3D models improved the efficiency of surgical planning as compared to previous cases.
Loke et al. (2017)[50]	Pediatry (35)	Relationships with other variables	Study of transfer learning with 3D model	The test taken before using the 3D model obtained similar scores than after using it, but participants declared higher satisfaction in the training using 3D models.
Low et al. (2019) [51]	ENT + Radiology (41)	Relationships with other variables	Study of transfer learning with 3D model	The test taken before using the 3D model obtained similar scores than after using it. ENT preferred 3D models over 2D models while radiologists preferred 2D models.

Marconi et al. (2017)[52]	Internal medicine (10), General Surgery (10), Radiology (10)	Relationships with other variables	Study of transfer learning with 3D model	3D printed models yielded better results than 2D images or virtual models. 3D printed models were perceived as more relevant in the training by students as compared to surgeons and radiologists.
Mashiko et al. (2017)[53]	Internal medicine (6)	Content	Study of transfer learning with 3D model	3D printed model to perform aneurysm surgery was found feasible.
Tang et al. (2018) [54]	Internal medicine (1)	Relationships with other variables	Study of transfer learning with 3D model	3D printed model to perform choledoscopy was found feasible.
Uygur et al. (2020)[55]	Orthopedics and Traumatology (28 students, 10 surgeons)	Content	Study the perception of models in training	Beginners found 3D printed models more useful while experts found virtual models more useful.
Wong et al. (2019) [56]	ENT (19)	Content	Study the perception of models in training	A simulation with 3D printed bone model was implemented (while capturing performance metrics). Performance differences were found between experts and nonexperts. Simulation was perceived by participants to improve surgical performance, comfort with actual patients, and operative speed.
Zheng et al. (2019) [84]	Traumatology (11)	Relationships with other variables	Study of transfer learning with 3D model	A simulation coupled with gaze tracking was implemented with 3D virtual and printed model to find differences between them. Less fixations were found when using 3D models, with higher fixation duration. Results confirmed the value of the printed 3D model on improving the clinical judgement on patient anatomy. Confidence in collecting information from the physical world and the cross-model sensor integration may explain why participants performed better with the printed model compared to the virtual model.
Zheng et al. (2018) [57]	Traumatology (100)	Relationships with other variables	Study of transfer learning with 3D model	A simulation with 3D printed Pilon fracture model was implemented and compared to conventional training. 3D printing group showed significantly shorter operation time, less blood loss volume, higher rate of anatomic reduction and rate of excellent and good outcome than conventional group.

NA: Not Available.

Table 2.2. Summary of the companies that use Extended Reality applications in the medical training field, the year of foundation, the milestones and key clients, and the devices they use.

Company name	Initial Budget ($)	Key Clients and Milestones	Devices	Developed applications with 3D models
Fundamental VR (2012)	9.6 M	Time Magazine's best invention (2018). They have a joint development agreement with Mayo Clinic.	VR headsets and MR Hololense.	Simulations for surgeons which allows them to rehearse, practice and improve their surgical techniques in a controlled environment that includes haptic elements for tactile feedback.
Karuna Labs (2016)	3 M	HIPAA-compliant and FDA-registered	VR headsets.	Simulations to treat chronic pain.
Oxford VR (2016)	13.2 M	United Kingdom's National Health Service and Mc Pin Foundation.	VR headsets.	Simulations to relieve the symptoms of mental disorders and fears, such as the fear of heights.
Augmedics (2014)	15 M	FDA 501 (k) clearance	VR headset and own MR headset	Simulations where the surgeons can see the patient's anatomy through the skin as if they had x-ray vision.
Sugar-Theater VR (2010)	9.6 M	The Mayo Clinic, UCLA School of Medicine, St. Joseph's Children's Hospital and the Stanford School of Medicine	VR Headset.	Platform for neurosurgical procedures based on preoperative planning and process guidelines in real time.
Echo Pixel (2012)	14.3 M	Received the FDA clearance. Partners with institutions like Cincinnati Children's Hospital, Primary Children's Hospital, C.S. Mott Hospital, Lucile Packard Children's Hospital	AR and MR devices.	Platform that facilitates visualizing and interacting with organs of a patient displayed as holograph-like images over the patient.
Medivis (2016)	2.5 M	Partners with Microsoft, Verizon and Magic Leap	VR and MR headsets + AI.	Simulation using MR with artificial intelligence that provides presurgical information and details related to the patient's anatomy.
Health Scholars (2017)	17 M	Partners with EMS agencies and hospitals like Arvada Fire & Rescue, Cedars Sinai, Mount Sinai New York, New York City Health & Hospital	VR headsets.	Simulations with performance assessment designed for first responders and clinicians in pediatric scenarios, general care, perioperative and obstetrical scenarios.
Vicarious Surgical (2015)	30 M	FDA Clearance	VR headsets.	Simulations where a physical robot is mixed in VR to manipulate 3D models while performing minimally invasive surgery procedures.

Touch Surgery (2013)	19.5 M	Amazon Web Services Hot Startups Award, Brandon Hall Silver Award in 2014. Residency programs at the Cleveland Clinic, Stanford School of Medicine, Harvard Medical School Teaching Hospital	VR headsets.	Simulations where 3D anatomy models are used in immersive VR surgical procedure assessment.
Propio Vision (2016)	30 M	Partners with Seattle Children's Hospital and the University of Washington's Department of Neurological Surgery	VR and MR headsets.	Holographic anatomy model visualization in AR where the rendered image floats over the patient during interventional procedures with visual guides.
Osso VR (2016)	2 M	Vanderbilt University Medical Center pilot program, and was a DocsF18 Innovation Award Winne	VR headsets + Haptic devices.	Simulations for surgical training and procedure assessments in fully immersive VR experiences with haptic feedback.
SentiAR (2017)	7.4 M	Named one of the Top 10 Cardiovascular Device Companies in 2019 by Med Tech Outlook	AR and MR devices.	Holographic anatomy model visualization in AR where the rendered image floats over the patient during interventional procedures.
Medical Augmented Intelligence (2016)	500 K	Partners with Beijing University of Chinese Medicine, Kiang Wu Nursing College of Macau, and the Davao Medical School Foundation are some of the company's clients. Medical Augmented Intelligence counts Intel, NVIDIA, and Vive	VR headsets.	Simulation based on training for anatomy and acupuncture, plus model visualization for patient education.
SyncThink (2010)	3.6M	FDA Clearance. Partners with Massachusetts General Hospital, Children's National Medical Center, and Georgia Tech University	Custom VR headset.	Anatomy model visualization in their custom VR headset called Eye-Sync and simulations where the patient's eye movements are tracked to determine if they have a concussion.
HoloAnatomy (2016)	3 M	2016 Jackson Hole Wildlife Film Festival Science Media Awards	MR headset.	Interactive visualization of anatomy 3D models where the user can modify and display information in realtime.
XR Health (2016)	15.M	Relations with Sheba Medical Center, Stanford Sports Medicine, Spaulding Rehabilitation Network, Hoag Hospital Network, and Mass General Hospital's Sports Medicine Center	VR headsets.	Simulations for therapy that provides scenarios where patients with similar conditions can connect anonymously and remotely with leading physicians moderating the group.

Some of these companies use more than one headset, changing the experience between them. Others like ThinkSync use their own headset but all of them make use of 3D models for either assessment, training or helping in the learning process.

2. Knowledge elicitation

2.1. Methodology

In this project we proposed the following steps for the knowledge elicitation process (Figure 3.1):

Figure 3.1. Steps followed for the knowledge elicitation process.

The idea was to carry out a series of local workshops at clinical partner sites (Spain, Romania, Norway) as well as with the European Association for Endoscopic Surgery (EAES; https://eaes.eu/) (Figure 3.2). To provide a safe space and encourage participation, focus groups were limited to 7-8 participants maximum. Additionally, we did not mix participants with different expertise all the time to avoid domination of the discussion on behalf of more experienced subjects. When possible, the workshops were carried out in native languages (EAES workshop – in English), and the key findings were translated into English.

Before the workshops, we sent participants a list of questions to reflect upon and prepare for the session (Appendix A). Each workshop included two parallel sessions: one for experts & teachers, the other one for residents & students. At the end of each session, all participants came together to pool the ideas given by both groups and draw the final conclusions for that country.

The conclusions extracted from each workshop were rounded up in a final workshop with representatives from the clinical sites.

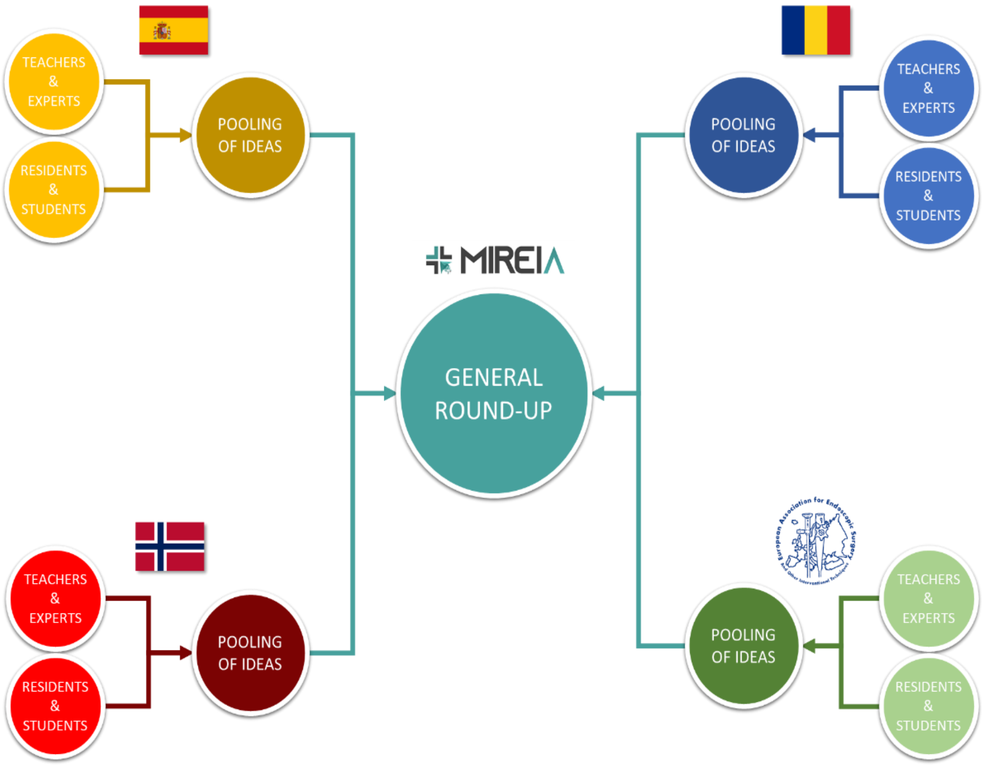


Figure 3.2. Diagram of the workshop functioning.

Each workshop session was attended by at least two members of the Consortium. A local staff member acted as director of the session, presenting different questions for debate to the participants and ensuring that everybody gets to participate. On the other hand, a secretary from the Consortium was present to take minutes.

Based on the conclusions extracted from the workshops, a brief, focused questionnaire was prepared and distributed online across the surgical community (Appendix B). This allowed us to ratify or discard some of the ideas discussed during the workshops.

2.2. —----------------------------Results: workshops

2.2.1. Number of participants

- Spain: 13 experts, 7 residents
- Norway: 5 experts, 3 non-experts
- Romania: 3 experts, 5 residents
- EAES: 5 experts
- Final workshop: 5 experts

2.2.2. Previous experience

Participants from Romania and EAES had previous experience with 3D models. However, participants in Spain claimed to have rather little experience with both virtual and 3D printed models and experts at Norway mentioned to have experience with 3D models for clinical applications but not so much for training systems. They express their interest in prediction and planning actual procedures, rather than for training.

2.2.3. Skills

From the workshops, we found that the skills for which 3D models can be most beneficial are (ordered by the number of times they were mentioned during the workshops at different sites):

1. Cognitive (specifically mentioning anatomy, pathology, steps of the procedure, and instruments)
2. Technical (specifically mentioning hand-eye coordination)
3. Decision making (specifically mentioning surgical planning)
4. Stress management
5. Teamwork

Within the final workshop, a differentiation was made between **virtual models** (used both for **technical and nontechnical skills** depending on the environment in which they are integrated) and **3D printed models** (used mostly for **technical skills**, although teamwork skills were also mentioned especially for **team surgical planning**). They also remarked that 3D models can be especially useful to understand 2D anatomical images.

2.2.4. Integration

Regarding the integration of 3D models within the learning program, participants reinforced the potential of 3D models to replace animal models and cadavers, but they stated this replacement should be gradual (i.e., not forcing an immediate replacement) and it should always be done before human practice.

In the final workshop, a new idea surfaced with respect to the optimal model (either virtual or printed) for each learning target. More specifically, the experts identified three learning targets:

undergraduate, graduate and postgraduate students. Hence, virtual models would be preferred for undergraduate students (since the main focus is to engage them into medical practice and virtual simulations are indeed eye-catching), graduate students would make use of both virtual and printed models depending on the task complexity (i.e., they would start with simple models and require more complex ones as they advance in their residency), and so would postgraduate students (specifically, the study of pathological models obtained from actual patients could be beneficial for them).

Both experts and non-experts suggest that 3D models should be used for surgical planning, and specify the usefulness of 3D printed models to train for surgical actions in conjunction with VR (including sutures and resections).

Experts in particular, mentioned that ideally, each center should have a laboratory with 3D printers to use the resulting 3D models for training.

2.2.5. Creation

In general, participants suggested that the creation of 3D models should be (1) realistic, (2) reproducible, (3) adaptable to the needs of trainees and trainers, and (4) shareable. On the other hand, experts stated that models should respect normal anatomy but allow to add modifications (e.g., anatomical variants). In the final workshop, the importance of these modifications was stressed, implying that pathological models could be more relevant for overall training. They suggest that CT images (or any other imaging technique) could be used to create patient-specific models.

Specifically for printed models, participants suggest the materials used to print the models should be flexible (similar to actual tissues).

Concretely for virtual models, participants encourage the creation of models with different levels of complexity and layers of information, and reinforce the need to move, rotate and scale the models according to the needs of the task.

During the final workshop, when asked about the possibility to use creation tools, surgical or medical experts were not eager to learn (and train students) to use them, while those with technical background saw great advantages in these creation tools, which would allow them to design models from 2D images from actual patients without extra expenses.

2.2.6. Barriers

We have identified 3 main barriers, which actually may deter participants from using 3D models: (1) logistic (e.g., lack of space to place the 3D printed models, lack of printers, lack of coordination between training bodies…), (2) financial (e.g., lack of financial resources to buy equipment, lack of personnel specialized in 3D model creation…), (3) technical (e.g., lack of personnel trained in 3D model creation and printing, long time required to create and print the models…). Some other barriers mentioned in the workshops were regulatory aspects (e.g., issues with privacy from patients, difficulties to adapt the learning program to include innovative models…), lack of pedagogy associated to the models, lack of repositories in which models are stored.

In the final workshop, technical and financial barriers were agreed as the most limiting ones, although experts recognize virtual models to have less barriers than printed ones. In addition, experts remarked that virtual models account for multiple possible virtual scenarios (varying in complexity and skills trained), while printed models' applications are more limited from its design.

2.2.7. Interaction

Participants suggested that the interaction with printed models should be done directly with the hands.

As for the interaction with virtual models, it was proposed to use hand tracking, head-set visualization with haptic feedback, or even interacting the same way as with a gaming console. One of the participants suggested to leave the interaction method to the wishes of the trainer/trainee. A different participant suggested to interact with the virtual model directly from the computer or the smartphone to make it more accessible.

During the final workshop, experts were asked about the usefulness of immersive and non-immersive environments. They agreed that immersive environments are interesting due to their ability to train different skills and variability, while non-immersive ones are usually less expensive and quicker to implement. In conclusion: none of the environments is preferred over the other and they should be applied depending on the trainee's needs.

2.3. Results: questionnaires

A total of 85 people participated in the questionnaire (62.8% male, 37.2% female). 58.1% of participants were from Spain, 24.4% from Norway, 2.3% from Romania, and the remaining 15.2% from different Latin American countries (i.e., Argentina, Colombia, Mexico, Ecuador, Peru and Brazil). The age of participants was distributed between 22-30 (5%), 31-45 (42%), 46-60 (29%) and over 61 (9%). The specialties of participants were varied, with the greatest amount of participants having specialty in general surgery (30.2%), followed by urology (17.4%) and obstetrics and gynaecology (14.1%).

2.3.1. Skills

Basic technical skills are considered the most beneficial for training using virtual and printed 3D models, followed by cognitive skills (both related to anatomy and procedure) in the case of virtual models, and advanced technical skills and anatomical cognitive skills for printed models (Figure 3.4). Soft skills (stress management, leadership, interpersonal skills) were considered to benefit less from training with virtual and printed models.

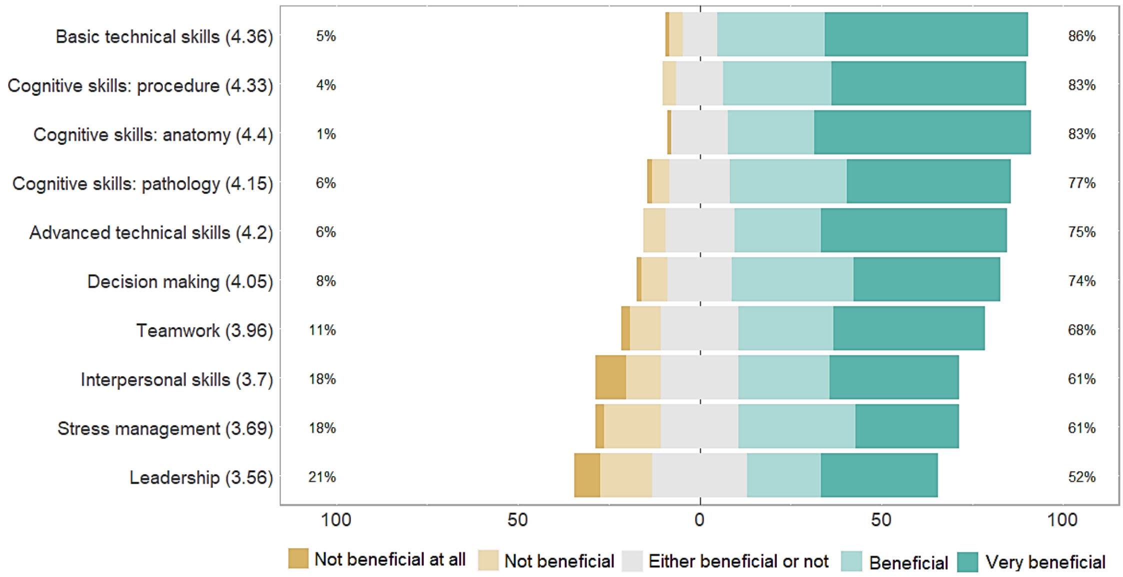


Figure 3.3. Frequency (%) of negative responses (oranges), neutral responses (gray) and positive responses (blues) for the question on the benefit of training with virtual 3D models for each skill. Average importance score is shown between brackets next to the corresponding skill.

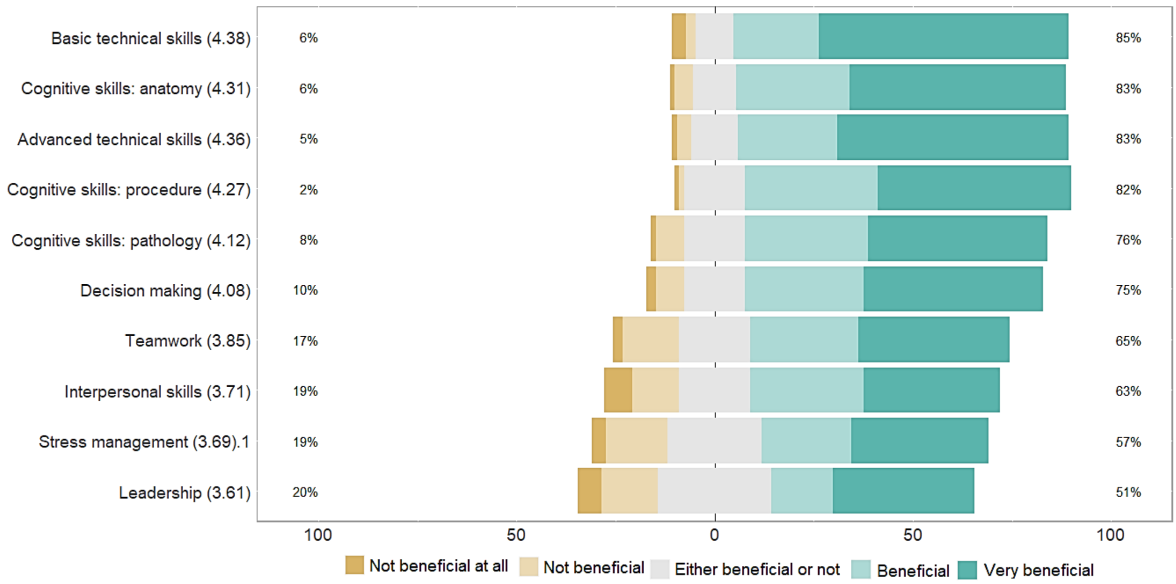


Figure 3.4. Frequency (%) of negative responses (oranges), neutral responses (gray) and positive responses (blues) for the question on the benefit of training with printed 3D models for each skill. Average importance score is shown between brackets next to the corresponding skill.

2.3.2. Integration

Participants agreed more on the statement that "virtual models should be used as an aid to learn anatomical and procedural competencies", closely followed by using it "as a complement to current learning programs" (Figure 3.5). In the case of printed models, "printed models should be used as an aid to learn anatomical and procedural competencies" received highest agreement scores, followed by using them as a complement to current hands-on programs. However, using them as a replacement of animal models was not considered so agreeable.

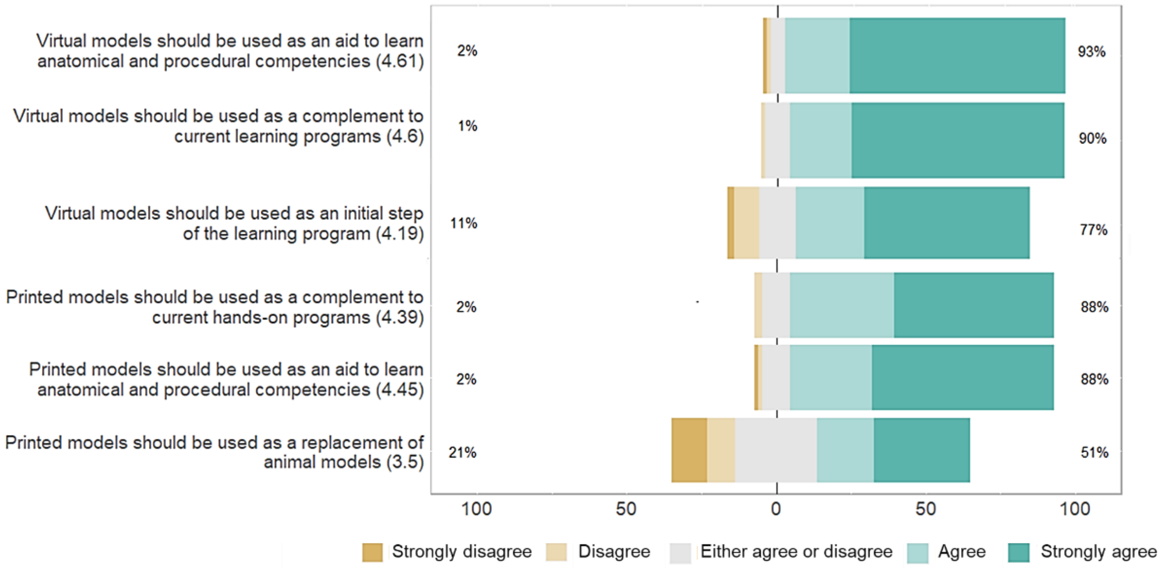


Figure 3.5. Frequency (%) of negative responses (oranges), neutral responses (gray) and positive responses (blues) for the question on the level of agreement with the statements regarding integration of virtual and printed 3D models within training programmes. Average agreement score is shown between brackets next to the corresponding statement.

2.3.3. Creation

When creating 3D models (both virtual and printed), the most important features to consider according to participants are the possibility to include different levels of complexity and layers of information and the ability to interact with those models in real time (Figure 3.6).

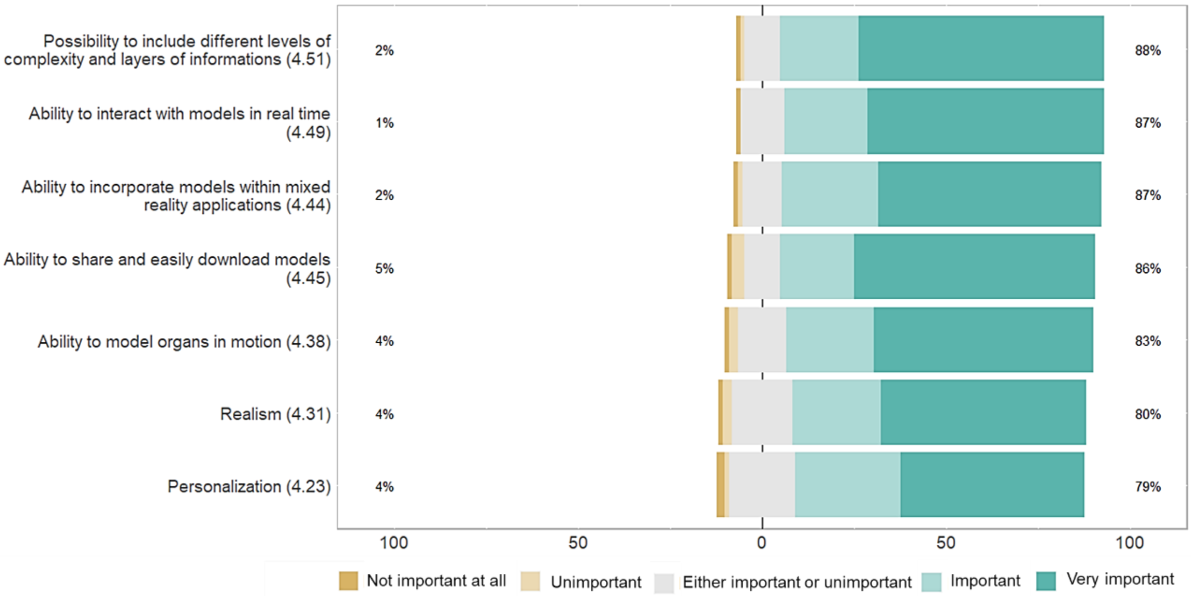


Figure 3.6. Frequency (%) of negative responses (oranges), neutral responses (gray) and positive responses (blues) for the question on the importance of virtual 3D models' features to be incorporated within medical training. Average importance score is shown between brackets next to the corresponding feature.

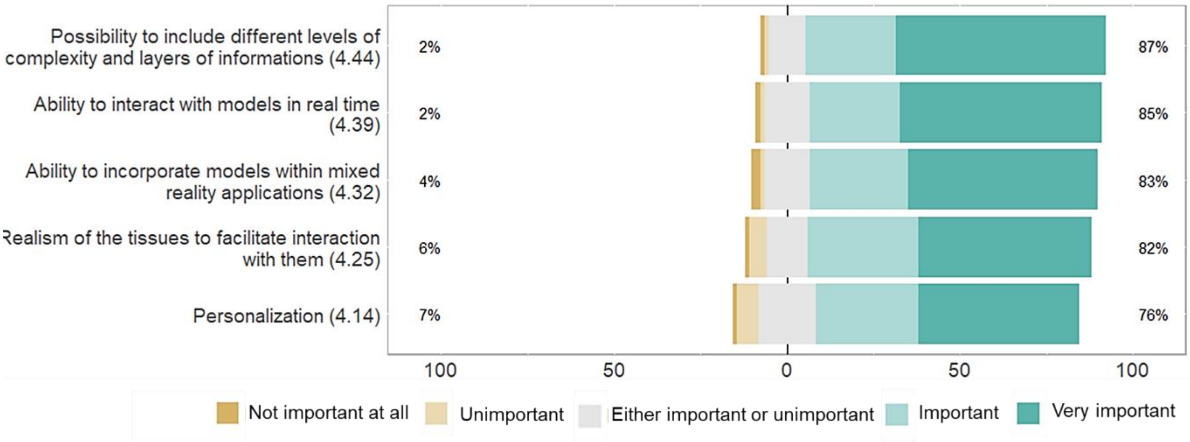


Figure 3.7. Frequency (%) of negative responses (oranges), neutral responses (gray) and positive responses (blues) for the question on the importance of printed 3D models' features to be incorporated within medical training. Average importance score is shown between brackets next to the corresponding feature.

Some participants suggested that the possibility to include gamification features should be taken into account when creating 3D models, as well as the creation of models of organs of people with different ages and focused on different procedures.

2.3.4. Barriers

Financial and logistic (e.g., low accessibility, limited personnel to create models, limited coordination between model creators and hospitals, etc.) issues were selected as the most limiting barriers for the use of 3D models (both virtual and printed). The next issue in the case of virtual models is technical (e.g., lack of familiarization with technology, lack of resources, etc.) while for printed models, the long time required to create the model is the next great issue.

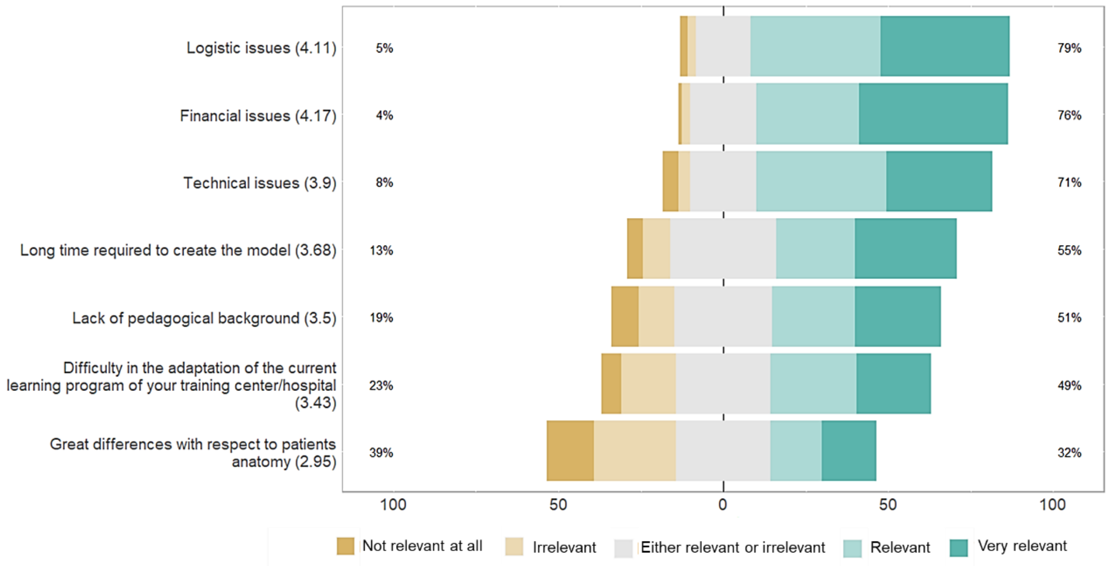


Figure 3.8. Frequency (%) of negative responses (oranges), neutral responses (gray) and positive responses (blue) for the question on the relevance of 3D virtual models' barriers for their incorporation within medical training. Average relevance score is shown between brackets next to the corresponding barrier.

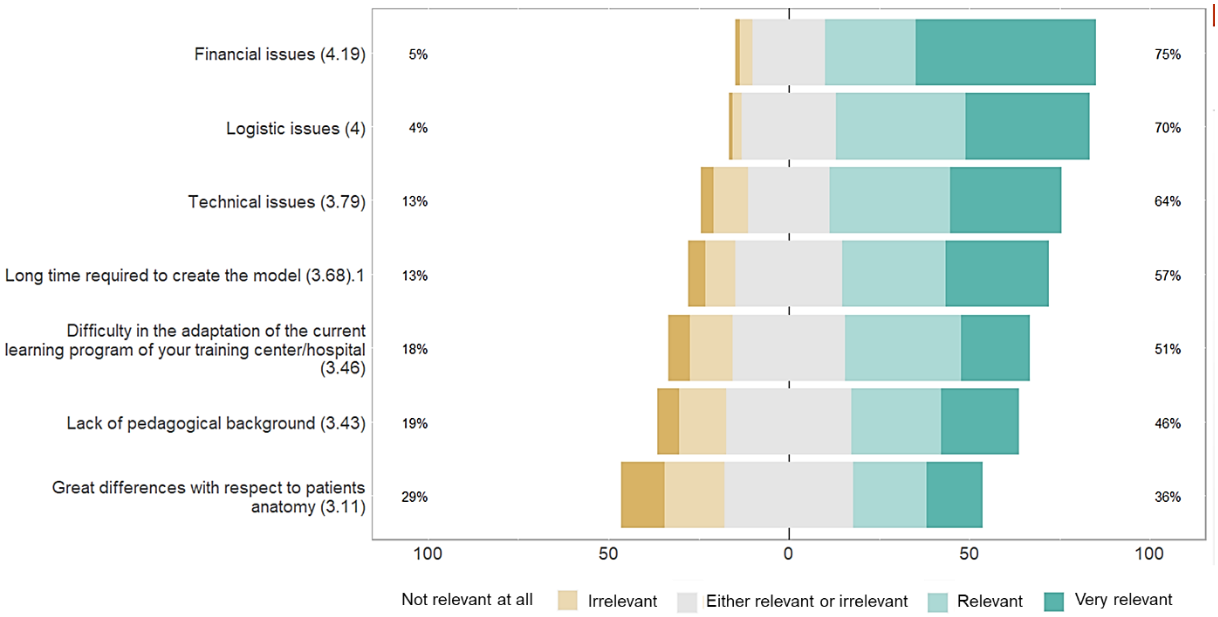


Figure 3.9. Frequency (%) of negative responses (oranges), neutral responses (gray) and positive responses (blues) for the question on the relevance of 3D printed models' barriers for their incorporation within medical training. Average relevance score is shown between brackets next to the corresponding barrier.

Access to 3D printers was considered a critical barrier for two participants, while for 4 participants the difficulty to access to virtual models was considered detrimental towards the use of these models.

2.3.5. Interaction

The interaction with virtual models was found more suitable using haptic devices, followed by hand tracking (Figure 3.10).

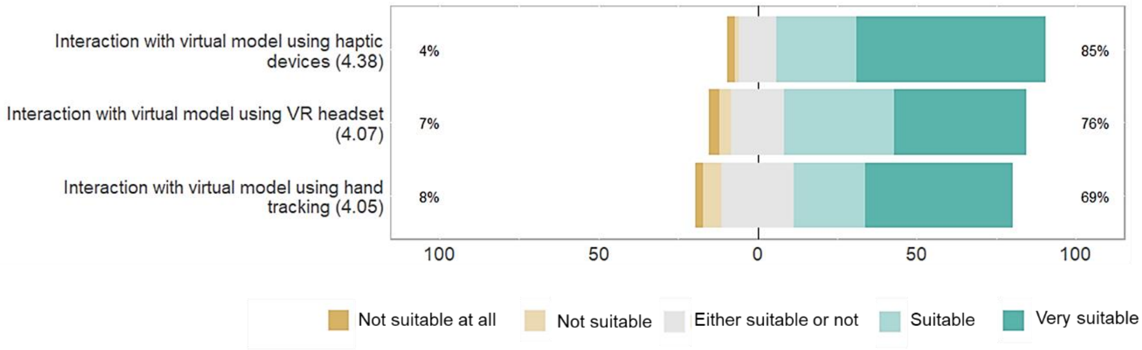


Figure 3.10. Frequency (%) of negative responses (oranges), neutral responses (gray) and positive responses (blues) for the question on the suitability of methods to interact with 3D virtual models. Average relevance score is shown between brackets next to the corresponding method.

2.4. Pedagogical needs

Taking all the information extracted from the knowledge elicitation process, 16 pedagogical needs were detected (9 common to virtual and printed models, 5 exclusive for virtual models and 2 exclusive for printed models). These needs are summarized in Table 3.1.

Table 3.1. Pedagogical needs.

ID	Detected pedagogical needs
Common to virtual and printed models	
U1	Ability to personalize contents
U2	Ability to access to realistic contents
U3	Ability to incorporate models within MR applications
U4	Ability to include different levels of complexity and layers of information
U5	Ability to interact with models in real time
U6	Ability to access models at reduced prizes
U7	Ability to incorporate models within AR applications
U8	Ability to access to creation tools
U9	Ability to adapt models to training needs
Exclusive to virtual models	
U10	Ability to model organs in motion
U11	Ability to share and easily download models
U12	Ability to interact with different tools (e.g., hand tracking, VR headset, haptic devices)
U13	Ability to incorporate models within VR applications
U14	Ability to freely move, rotate and scale models
Exclusive to printed models	
U15	Ability to reduce printing times
U16	Wide range of materials for printing according to tissues' needs

2.5. Discussion and conclusions

D3.1 presents a list of pedagogical needs that has been derived based on Consortium know-how, state of the art analysis, and knowledge elicitation process. Specifically, the analysis of the state of the art of 3D models allowed to elucidate the highest perceived features of 3D models and the pedagogical value in medical training. The knowledge elicitation process was highly based on the knowledge gathered from this analysis.

From this knowledge elicitation process we confirmed that 3D models were considered most useful for cognitive and technical skills. This is consistent with the literature, being most of the research lines focused on the training of cognitive or technical skills. However, participants in the questionnaire and the workshops also considered soft skills (e.g., stress management, teamwork, leadership…) to benefit from training with virtual and printed models, although to a lesser extent.

The results of the questionnaire suggest that 3D models may not be a good replacement for animal models. However, participants in the workshops agreed that it could eventually replace them. This shows that further research should be done as to how to best incorporate 3D models to medical training programs. This research should be carried out while considering the main barriers of 3D models (i.e., financial and logistic issues, as per participants in the questionnaire and workshops).

Workshop participants believed the most important feature of 3D models was its realism while participants in the questionnaires highlighted the ability to include layers of complexity and to interact in real time as the most relevant features. Specifically for the latter, participants in the questionnaire selected haptic devices as the most suitable interaction method, followed by hand tracking. All of these features were taken into account for the creation of the pedagogical needs.

The list of pedagogical needs will serve as a roadmap to define the guidelines to create learning contents from 3D models that will be presented in D3.2. Moreover, they will become a key part for defining functional requirements for the MIREIA solution (D4.1), ensuring its proper pedagogical foundations.

Pedagogical needs can be considered as a subgroup of user needs. However, every user need in a learning environment is going to impact the learning experience, so in a sense all user needs may also be considered as pedagogical needs. For the sake of clarity, we include in this deliverable only user needs that are related to actions that have emerged from the knowledge elicitation process. The complete set of user needs, including those with weaker pedagogical base and, as such, not incorporated here, will be considered in WP4. This complete and exhaustive definition of user needs is essential for developers, who must translate them into technical (functional and non-functional) requirements to be implemented.

The field of learning sciences is an interdisciplinary one, and the creation of pedagogically sound learning 3D models needs to be built upon evidence-informed criteria that come from (1) scientific research on cognitive, developmental, educational and social psychology, pedagogy and sociology of education among others, (2) professional expertise on those areas and on IT and learning technology, and (3) field-specific knowledge. Therefore, gathering every pedagogical need for a field such as surgery requires input from clinical, educational and technical experts. The knowledge elicitation process has tried to fulfil these requirements by bringing together the appropriate expertise from the MIREIA Consortium in medicine, higher education, technology and educational psychology. The results presented in this deliverable draw from them all to ensure that they provide evidence-informed guidelines for the construction of the MIREIA solution.

- References

1. Yule S, Flin R, Paterson-Brown S, Maran N. Non-technical skills for surgeons in the operating room: A review of the literature. *Surgery*. 2006. doi:10.1016/j.surg.2005.06.017
2. Hammond M. Learning through practice: models, traditions, orientation and approaches. *Teach Dev*. 2011. doi:10.1080/13664530.2011.608521
3. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. In: *Journal of Clinical Epidemiology*. ; 2009. doi:10.1016/j.jclinepi.2009.06.006
4. Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Med*. 2009. doi:10.1371/journal.pmed.1000097
5. Joint committee on Standards for Educational and Psychological Testing APA, American Educational Research Association, National Council on Measurement in Education. *Standards for Educational and Psychological Testing*.; 2014.
6. Hatala R, Cook DA, Brydges R, Hawkins R. Constructing a validity argument for the Objective Structured Assessment of Technical Skills (OSATS): a systematic review of validity evidence. *Adv Heal Sci Educ*. 2015. doi:10.1007/s10459-015-9593-1
7. Borgersen NJ, Naur TMH, Sørensen SMD, et al. Gathering Validity Evidence for Surgical Simulation: A Systematic Review. *Ann Surg*. 2018. doi:10.1097/SLA.0000000000002652
8. Downing SM, Haladyna TM. Validity threats: Overcoming interference with proposed interpretations of assessment data. *Med Educ*. 2004. doi:10.1046/j.1365-2923.2004.01777.x
9. Cook DA, Beckman TJ. Current concepts in validity and reliability for psychometric instruments: Theory and application. *Am J Med*. 2006. doi:10.1016/j.amjmed.2005.10.036
10. Goldenberg M, Lee JY. Surgical Education, Simulation, and Simulators—Updating the Concept of Validity. *Curr Urol Rep*. 2018. doi:10.1007/s11934-018-0799-7
11. Cook DA, Brydges R, Zendejas B, Hamstra SJ, Hatala R. Technology-enhanced simulation to assess health professionals: A systematic review of validity evidence, research methods, and reporting quality. *Acad Med*. 2013. doi:10.1097/ACM.0b013e31828ffdcf
12. Cook DA, Zendejas B, Hamstra SJ, Hatala R, Brydges R. What counts as validity evidence? Examples and prevalence in a systematic review of simulation-based assessment. *Adv Heal Sci Educ*. 2014. doi:10.1007/s10459-013-9458-4
13. MarketsandMarkets. *Virtual Reality Market with COVID-19 Impact Analysis by Offering (Hardware and Software), Technology, Device Type (Head-Mounted Display, Gesture-Tracking Device), Application (Consumer, Commercial, Enterprise, Healthcare) and Geography - Global Forecast T*.; 2020.
14. Ammanuel S, Brown I, Uribe J, Rehani B. Creating 3D models from Radiologic Images for Virtual Reality Medical Education Modules. *J Med Syst*. 2019;43(6):166. doi:10.1007/s10916-019-1308-3
15. Arand C, Wagner D, Richards RG, et al. 3D statistical model of the pelvic ring - a CT-based statistical evaluation of anatomical variation. *J Anat*. 2019;234(3):376-383. doi:10.1111/joa.12928
16. Haffner M, Quinn A, Hsieh TY, Strong EB, Steele T. Optimization of 3D Print Material

for the Recreation of Patient-Specific Temporal Bone Models. *Ann Otol Rhinol Laryngol*. 2018. doi:10.1177/0003489418764987

17. Herrero Antón de Vez H, Herrero Jover J, Silva-Vergara C. Personalized 3D Printed Surgical Tool for Guiding the Chisel during Hump Reduction in Rhinoplasty. *Plast Reconstr surgery Glob open*. 2018;6(2):e1668. doi:10.1097/GOX.0000000000001668

18. Higgins GC, Thomson SE, Roditi G, Riehle MO, Murnaghan C, Hart AM. Anatomically accurate 3D modelling and printing in a case of obstetric brachial plexus injury. *JPRAS open*. 2020;24:7-11. doi:10.1016/j.jpra.2020.02.003

19. Jacobo OM, Giachero VE, Hartwig DK, Mantrana GA. Three-dimensional printing modeling: application in maxillofacial and hand fractures and resident training. *Eur J Plast Surg*. 2018. doi:10.1007/s00238-017-1373-0

20. Latorre CJ, Arang ML, Nino LSP, et al. Pipeline of anatomical models generation. Experience of surgical planning and medical personal training by means of virtual environments and physical prototyping. In: *Proceedings - 2020 IEEE Conference on Virtual Reality and 3D User Interfaces, VRW 2020*. ; 2020. doi:10.1109/VRW50115.2020.00030

21. Madurska MJ, Poyade M, Eason D, Rea P, Watson AJM. Development of a Patient-Specific 3D-Printed Liver Model for Preoperative Planning. *Surg Innov*. 2017. doi:10.1177/1553350616689414

22. Mashari A, Montealegre-Gallegos M, Jeganathan J, et al. Low-cost three-dimensional printed phantom for neuraxial anesthesia training: Development and comparison to a commercial model. *PLoS One*. 2018. doi:10.1371/journal.pone.0191664

23. Moreta-Martinez R, García-Mato D, García-Sevilla M, Pérez-Mañanes R, Calvo-Haro JA, Pascau J. Combining augmented reality and 3d printing to display patient models on a smartphone. *J Vis Exp*. 2019. doi:10.3791/60618

24. Nakayama M, Yamamoto S, Kaneko N, Mato N, Suzuki T, Hagiwara K. Use of low-cost three-dimensional printer to simulate grasping of bronchial foreign body. *Respirol case reports*. 2018;6(7):e00351. doi:10.1002/rcr2.351

25. Piles L, Reig MJ, Seguí VJ, Pla R, Martínez F, Seguí JM. Reverse engineering applied to biomodelling and pathological bone manufacturing using FDM technology. In: *Procedia Manufacturing*. ; 2019. doi:10.1016/j.promfg.2019.09.065

26. Barón V, Guevara R. Three-dimensional printing-guided fenestrated endovascular aortic aneurysm repair using open source software and physician-modified devices. *J Vasc Surg cases Innov Tech*. 2019;5(4):566-571. doi:10.1016/j.jvscit.2019.08.006

27. Rivero Belenchón I, Congregado Ruíz CB, Gómez Ciriza G, et al. How to obtain a 3D printed model of renal cell carcinoma (RCC) with venous tumor thrombus extension (VTE) for surgical simulation (phase I NCT03738488). *Updates Surg*. 2020. doi:10.1007/s13304-020-00806-6

28. Rynio P, Falkowski A, Witowski J, Kazimierczak A, Wójcik Ł, Gutowski P. Simulation and Training of Needle Puncture Procedure with a Patient-Specific 3D Printed Gluteal Artery Model. *J Clin Med*. 2020;9(3). doi:10.3390/jcm9030686

29. Schmidt M, Holzbauer M, Kwasny O, Huemer GM, Froschauer S. 3D Printing for scaphoid-reconstruction with medial femoral condyle flap. *Injury*. 2020;51(12):2900-2903. doi:10.1016/j.injury.2020.02.102

30. Wagner M, Werther T, Unger E, et al. Development of a 3D printed patient-specific neonatal brain simulation model using multimodality imaging for perioperative management. *Pediatr Res*. 2021. doi:10.1038/s41390-021-01421-w

31. Cheng K, Mukherjee P, Curthoys I. Development and use of augmented reality and 3D printing in consulting patient with complex skull base cholesteatoma. *Virtual Phys Prototyp*. 2017. doi:10.1080/17452759.2017.1310050

32. Karner F, Gsaxner C, Pepe A, et al. Single-Shot Deep Volumetric Regression for Mobile Medical Augmented Reality. In: *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. ; 2020. doi:10.1007/978-3-030-60946-7_7

33. Lee D, Yi JW, Hong J, Chai YJ, Kim HC, Kong HJ. Augmented reality to localize individual organ in surgical procedure. *Healthc Inform Res*. 2018. doi:10.4258/hir.2018.24.4.394

34. Barber SR, Jain S, Son YJ, Chang EH. Virtual Functional Endoscopic Sinus Surgery Simulation with 3D-Printed Models for Mixed-Reality Nasal Endoscopy. *Otolaryngol - Head Neck Surg (United States)*. 2018. doi:10.1177/0194599818797586

35. Boedecker C, Huettl F, Saalfeld P, et al. Using virtual 3D-models in surgical planning: workflow of an immersive virtual reality application in liver surgery. *Langenbeck's Arch Surg*. 2021. doi:10.1007/s00423-021-02127-7

36. Chen SA, Ong CS, Malguria N, Vricella LA, Garcia JR, Hibino N. Digital Design and 3D Printing of Aortic Arch Reconstruction in HLHS for Surgical Simulation and Training. *World J Pediatr Congenit Heart Surg*. 2018. doi:10.1177/2150135118771323

37. Błaszczyk M, Jabbar R, Szmyd B, Radek M. 3D Printing of Rapid, Low-Cost and Patient-Specific Models of Brain Vasculature for Use in Preoperative Planning in Clipping of Intracranial Aneurysms. *J Clin Med*. 2021;10(6). doi:10.3390/jcm10061201

38. Condino S, Turini G, Parchi PD, et al. How to build a patient-specific hybrid simulator for orthopaedic open surgery: Benefits and limits of mixed-reality using the Microsoft hololens. *J Healthc Eng*. 2018. doi:10.1155/2018/5435097

39. Grillo FW, Rondinoni C, Filho ACSS, et al. Virtual surgical planning: Patient-specific imaging segmentation. In: *IFMBE Proceedings*. ; 2019. doi:10.1007/978-981-13-2119-1_114

40. Awan OA, Sheth M, Sullivan I, et al. Efficacy of 3D Printed Models on Resident Learning and Understanding of Common Acetabular Fracturers. *Acad Radiol*. 2019. doi:10.1016/j.acra.2018.06.012

41. Bairamian D, Liu S, Eftekhar B. Virtual Reality Angiogram vs 3-Dimensional Printed Angiogram as an Educational tool - A Comparative Study. *Neurosurgery*. 2019. doi:10.1093/neuros/nyz003

42. Chee A, Sierra-Ruiz M, Parikh MS, Majid A. Comparison of Flexible 3D Printed Stenotic Airway Model Versus Standard Model for Therapeutic Bronchoscopy Training a Proof of Concept. *J Bronchology Interv Pulmonol*. 2021;28(2):124-129. doi:10.1097/LBR.0000000000000701

43. Cherkasskiy L, Caffrey JP, Szewczyk AF, et al. Patient-specific 3D models aid planning for triplane proximal femoral osteotomy in slipped capital femoral epiphysis. *J Child Orthop*. 2017;11(2):147-153. doi:10.1302/1863-2548-11-170277

44. Hyde ER, Berger LU, Ramachandran N, et al. Interactive virtual 3D models of renal cancer patient anatomies alter partial nephrectomy surgical planning decisions and increase surgeon confidence compared to volume-rendered images. *Int J Comput Assist Radiol Surg*. 2019;14(4):723-732. doi:10.1007/s11548-019-01913-5

45. Kang HJ, Kim BS, Kim SM, et al. Can Preoperative 3D Printing Change Surgeon's Operative Plan for Distal Tibia Fracture? *Biomed Res Int*. 2019.

doi:10.1155/2019/7059413

46. Li A, Tang R, Rong Z, et al. The Use of Three-Dimensional Printing Model in the Training of Choledochoscopy Techniques. *World J Surg*. 2018;42(12):4033-4038. doi:10.1007/s00268-018-4731-6

47. Lin QS, Lin YX, Wu XY, Yao P Sen, Chen P, Kang DZ. Utility of 3-Dimensional–Printed Models in Enhancing the Learning Curve of Surgery of Tuberculum Sellae Meningioma. *World Neurosurg*. 2018. doi:10.1016/j.wneu.2018.01.215

48. Chen J, Prem A, Yang G, Cui D. Use stereoscopic model in interventional and surgical procedures. In: *Advances in Experimental Medicine and Biology*. ; 2019. doi:10.1007/978-3-030-31904-5_2

49. Lobb DC, Cottler P, Dart D, Black JS. The Use of Patient-Specific Three-Dimensional Printed Surgical Models Enhances Plastic Surgery Resident Education in Craniofacial Surgery. *J Craniofac Surg*. 2019;30(2):339-341. doi:10.1097/SCS.0000000000005322

50. Loke Y-H, Harahsheh AS, Krieger A, Olivieri LJ. Usage of 3D models of tetralogy of Fallot for medical education: impact on learning congenital heart disease. *BMC Med Educ*. 2017;17(1):54. doi:10.1186/s12909-017-0889-0

51. Low CM, Morris JM, Matsumoto JS, Stokken JK, O'Brien EK, Choby G. Use of 3D-Printed and 2D-Illustrated International Frontal Sinus Anatomy Classification Anatomic Models for Resident Education. *Otolaryngol - Head Neck Surg (United States)*. 2019. doi:10.1177/0194599819860832

52. Marconi S, Pugliese L, Botti M, et al. Value of 3D printing for the comprehension of surgical anatomy. *Surg Endosc*. 2017;31(10):4102-4110. doi:10.1007/s00464-017-5457-5

53. Mashiko T, Kaneko N, Konno T, Otani K, Nagayama R, Watanabe E. Training in Cerebral Aneurysm Clipping Using Self-Made 3-Dimensional Models. *J Surg Educ*. 2017;74(4):681-689. doi:10.1016/j.jsurg.2016.12.010

54. Tang R, Ma L, Li A, et al. Choledochoscopic Examination of a 3-Dimensional Printing Model Using Augmented Reality Techniques: A Preliminary Proof of Concept Study. *Surg Innov*. 2018;25(5):492-498. doi:10.1177/1553350618781622

55. Uygur E, TÜrkmen İ, Özturan B, Poyanli O. The Role of 3D Modeling in Education of Orthopedic Trainees for the Treatment of Foot Deformities. *Acta Chir Orthop Traumatol Cech*. 2020;87(5):346-349.

56. Wong V, Unger B, Pisa J, Gousseau M, Westerberg B, Hochman JB. Construct Validation of a Printed Bone Substitute in Otologic Education. *Otol Neurotol*. 2019. doi:10.1097/MAO.0000000000002285

57. Zheng W, Chen C, Zhang C, Tao Z, Cai L. The Feasibility of 3D Printing Technology on the Treatment of Pilon Fracture and Its Effect on Doctor-Patient Communication. *Biomed Res Int*. 2018. doi:10.1155/2018/8054698

58. Zheng B, Wang X, Zheng Y, Feng J. 3D-printed model improves clinical assessment of surgeons on anatomy. *J Robot Surg*. 2019. doi:10.1007/s11701-018-0809-2

59. Chou PY, Hallac RR, Shih E, et al. 3D-printed models of cleft lip and palate for surgical training and patient education. *Cleft Palate-Craniofacial J*. 2018. doi:10.1177/1055665617738998

60. Javan R, Rao A, Jeun BS, Herur-Raman A, Singh N, Heidari P. From CT to 3D Printed Models, Serious Gaming, and Virtual Reality: Framework for Educational 3D Visualization of Complex Anatomical Spaces From Within—the Pterygopalatine Fossa. *J*

Digit Imaging. 2020. doi:10.1007/s10278-019-00315-y

61. Tejo-Otero A, Lustig-Gainza P, Fenollosa-Artés F, Valls A, Krauel L, Buj-Corral I. 3D printed soft surgical planning prototype for a biliary tract rhabdomyosarcoma. *J Mech Behav Biomed Mater*. 2020;109:103844. doi:10.1016/j.jmbbm.2020.103844
62. Coles-Black J, Bolton D, Chuen J. Accessing 3D Printed Vascular Phantoms for Procedural Simulation. *Front Surg*. 2021. doi:10.3389/fsurg.2020.626212
63. Fan G, Liu H, Wang D, et al. Deep learning-based lumbosacral reconstruction for difficulty prediction of percutaneous endoscopic transforaminal discectomy at L5/S1 level: A retrospective cohort study. *Int J Surg*. 2020. doi:10.1016/j.ijsu.2020.08.036
64. Govsa F, Ozer MA, Sirinturk S, Eraslan C, Alagoz AK. Creating vascular models by postprocessing computed tomography angiography images: a guide for anatomical education. *Surg Radiol Anat*. 2017. doi:10.1007/s00276-017-1822-2
65. Govsa F, Yagdi T, Ozer MA, Eraslan C, Alagoz AK. Building 3D anatomical model of coiling of the internal carotid artery derived from CT angiographic data. *Eur Arch Oto-Rhino-Laryngology*. 2017. doi:10.1007/s00405-016-4355-0
66. Hendricks BK, Hartman J, Cohen-Gadol AA. Cerebrovascular Operative Anatomy: An Immersive 3D and Virtual Reality Description. *Oper Neurosurg (Hagerstown, Md)*. 2018;15(6):613-623. doi:10.1093/ons/opy283
67. Javan R, Davidson D, Javan A. Nerves of Steel: a Low-Cost Method for 3D Printing the Cranial Nerves. *J Digit Imaging*. 2017;30(5):576-583. doi:10.1007/s10278-017-9951-z
68. Javan R, Zeman MN. A Prototype Educational Model for Hepatobiliary Interventions: Unveiling the Role of Graphic Designers in Medical 3D Printing. *J Digit Imaging*. 2018. doi:10.1007/s10278-017-0012-4
69. LewandrowskI K-U, Muraleedharan N, Eddy SA, et al. Feasibility of Deep Learning Algorithms for Reporting in Routine Spine Magnetic Resonance Imaging. *Int J spine Surg*. 2020;14(s3):S86-S97. doi:10.14444/7131
70. Garcia-Garcia S, Kakaizada S, Oleaga L, Benet A, Rincon-Toroella J, González-Sánchez JJ. Presurgical simulation for neuroendoscopic procedures: Virtual study of the integrity of neurological pathways using diffusion tensor imaging tractography. *Neurol India*. 2019. doi:10.4103/0028-3886.263199
71. Bati AH, Guler E, Ozer MA, et al. Surgical planning with patient-specific three-dimensional printed pancreaticobiliary disease models - Cross-sectional study. *Int J Surg*. 2020;80:175-183. doi:10.1016/j.ijsu.2020.06.017
72. Laverdiere C, Harvey E, Schupbach J, Boily M, Burman M, Martineau PA. Effect of Teaching Session on Resident Ability to Identify Anatomic Landmarks and Anterior Cruciate Ligament Footprint: A Study Using 3-Dimensional Modeling. *Orthop J Sport Med*. 2020. doi:10.1177/2325967120905795
73. Avasarala J, Pietila T. The first 3D printed multiple sclerosis brain: Towards a 3D era in medicine [version 4; peer review: 1 approved with reservations, 3 not approved]. *F1000Research*. 2018. doi:10.12688/f1000research.12336.1
74. Grillo FW, Souza VH, Matsuda RH, et al. Patient-specific neurosurgical phantom: assessment of visual quality, accuracy, and scaling effects. *3D Print Med*. 2018. doi:10.1186/s41205-018-0025-8
75. Kasten Y, Doktofsky D, Kovler I. End-To-End Convolutional Neural Network for 3D Reconstruction of Knee Bones from Bi-planar X-Ray Images. In: *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and*

Lecture Notes in Bioinformatics). ; 2020. doi:10.1007/978-3-030-61598-7_12

76. Zeng G, Wang Q, Lerch T, et al. Latent3DU-net: Multi-level latent shape space constrained 3D U-net for automatic segmentation of the proximal femur from radial MRI of the hip. In: *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. ; 2018. doi:10.1007/978-3-030-00919-9_22
77. Lim PK, Stephenson GS, Keown TW, et al. Use of 3D Printed Models in Resident Education for the Classification of Acetabulum Fractures. *J Surg Educ*. 2018;75(6):1679-1684. doi:10.1016/j.jsurg.2018.04.019
78. Muraru D, Veronesi F, Maddalozzo A, et al. 3D printing of normal and pathologic tricuspid valves from transthoracic 3D echocardiography data sets. *Eur Heart J Cardiovasc Imaging*. 2017;18(7):802-808. doi:10.1093/ehjci/jew215
79. Sieber D, Erfurt P, John S, et al. Data descriptor: The openEar library of 3D models of the human temporal bone based on computed tomography and micro-slicing. *Sci Data*. 2019. doi:10.1038/sdata.2018.297
80. Zilverschoon M, Vincken KL, Bleys RLAW. The virtual dissecting room: Creating highly detailed anatomy models for educational purposes. *J Biomed Inform*. 2017;65:58-75. doi:10.1016/j.jbi.2016.11.005
81. Yaremenko AI, Lysenko A V., Ivanova EA, Galibin O V. Augmented reality technology for auricular reconstruction in the treatment of microtia. *Cell Ther Transplant*. 2020. doi:10.18620/ctt-1866-8836-2020-9-2-78-82
82. Jacquesson T, Simon E, Dauleac C, Margueron L, Robinson P, Mertens P. Stereoscopic three-dimensional visualization: interest for neuroanatomy teaching in medical school. *Surg Radiol Anat*. 2020;42(6):719-727. doi:10.1007/s00276-020-02442-6
83. Lorenz C, Krahnstover N. 3D statistical shape models for medical image segmentation. In: *Proceedings - 2nd International Conference on 3-D Digital Imaging and Modeling, 3DIM 1999*. ; 1999. doi:10.1109/IM.1999.805372
84. Zheng B, Wang X, Zheng Y, Feng J. 3D-printed model improves clinical assessment of surgeons on anatomy. *J Robot Surg*. 2019;13(1):61-67. doi:10.1007/s11701-018-0809-2
85. Low CM, Morris JM, Matsumoto JS, Stokken JK, O'Brien EK, Choby G. Use of 3D-Printed and 2D-Illustrated International Frontal Sinus Anatomy Classification Anatomic Models for Resident Education. *Otolaryngol neck Surg Off J Am Acad Otolaryngol Neck Surg*. 2019;161(4):705-713. doi:10.1177/0194599819860832
86. Javan R, Zeman MN. A Prototype Educational Model for Hepatobiliary Interventions: Unveiling the Role of Graphic Designers in Medical 3D Printing. *J Digit Imaging*. 2018;31(1):133-143. doi:10.1007/s10278-017-0012-4
87. Li A, Tang R, Rong Z, et al. The Use of Three-Dimensional Printing Model in the Training of Choledochoscopy Techniques. *World J Surg*. 2018. doi:10.1007/s00268-018-4731-6
88. Garcia-Garcia S, Kakaizada S, Oleaga L, Benet A, Rincon-Toroella J, González-Sánchez JJ. Presurgical simulation for neuroendoscopic procedures: Virtual study of the integrity of neurological pathways using diffusion tensor imaging tractography. *Neurol India*. 2019;67(3):763-769. doi:10.4103/0028-3886.263199
89. Lee D, Yi JW, Hong J, Chai YJ, Kim HC, Kong H-J. Augmented Reality to Localize Individual Organ in Surgical Procedure. *Healthc Inform Res*. 2018;24(4):394-401. doi:10.4258/hir.2018.24.4.394
90. Ugidos Lozano MT, Blaya Haro F, Juanes Mendez JA. FAST SCANNING

TECHNOLOGY AND 3D PROTOTYPE OF BONES FOR TEACHING PURPOSE. In: *INTED2017 Proceedings*. ; 2017. doi:10.21125/inted.2017.0507

91. Higgins GC, Thomson SE, Roditi G, Riehle MO, Murnaghan C, Hart AM. Anatomically accurate 3D modelling and printing in a case of obstetric brachial plexus injury. *JPRAS Open*. 2020. doi:10.1016/j.jpra.2020.02.003

92. Javan R, Davidson D, Javan A. Nerves of Steel: a Low-Cost Method for 3D Printing the Cranial Nerves. *J Digit Imaging*. 2017. doi:10.1007/s10278-017-9951-z

93. Grillo FW, Souza VH, Matsuda RH, et al. Patient-specific neurosurgical phantom: assessment of visual quality, accuracy, and scaling effects. *3D Print Med*. 2018;4(1):3. doi:10.1186/s41205-018-0025-8

94. Zilverschoon M, Vincken KL, Bleys RLAW. The virtual dissecting room: Creating highly detailed anatomy models for educational purposes. *J Biomed Inform*. 2017. doi:10.1016/j.jbi.2016.11.005

95. Gillis CJ, Bishop N, Walsh G, Harvey D. Evaluation of a Novel 3D-Printed Urinary Catheterization Simulation Model in Undergraduate Medical Teaching. *Cureus*. 2020. doi:10.7759/cureus.8377

96. J. M, M.S. H, A. H, eds. Studies in Health Technology and Informatics. 2015;213. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85056369380&partnerID=40&md5=f08af263b203ecd354224edca992ea8b.

- Appendix A. Invitation to participants to the workshops

Dear participants,

The main objective of MIREIA project is to provide an innovative methodology to support medical and surgical education through learning content and customized training environments based on immersive extended reality visualization technologies and 3D printing technologies. We are interested in your ideas, wishes and conceptions regarding the incorporation of 3D models into medical and surgical training. Please, reflect on the following questions and your concerns will be discussed on the "MIREIA Workshop" on July-August, 2021. All opinions are valuable to us, both positive and negative. All information will be treated confidentially. In case a concept or question is not completely clear to you, please indicate it and it will be discussed during the workshop.

1. In your experience, for what skills can the use of 3D models be beneficial for training? (e.g., technical, cognitive, interpersonal, stress management, decision-making, leadership...)

2. How do you envision the integration of 3D models (virtual & printed) into learning programmes?

3. What are the main barriers to the incorporation of 3D models (virtual & printed) into medical training?

4. In your opinion, what is the most suitable way to interact with a (virtual & printed) 3D model?

- Appendix B. Questionnaire

Thank you for agreeing to partake on this questionnaire. The goal of MIREIA project is to develop a methodology and tools to provide interactive pedagogical content for customized training, based on 3D models, such as anatomical models (with and without pathologies) built from real-patient cases (e.g. medical imaging studies) or virtual scenarios for basic training in minimally invasive surgery (MIS). We aim to do this by combining the use of cutting-edge technology in immersive virtual technology and 3D printing with personalized learning content to promote the student-centered learning process of medical students and residents.

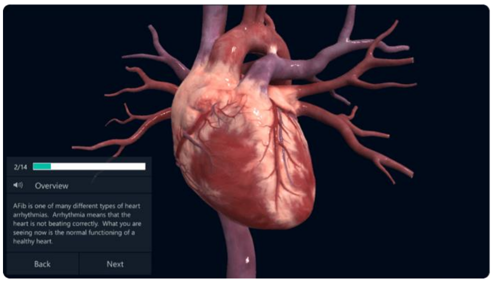
Your feedback is very important to us in the process of capturing the needs of medical trainers and trainees, defining what aspects of 3D models, computer generated objects that can be used for 3D printing and virtual / physical simulators, are up to the required standard and what aspects can be improved.

Completion of the questionnaire should not take more than 10 minutes. We ask you to please read each question carefully before providing a final answer.

Again, thank you for your most valuable contribution.

3D VIRTUAL MODELS

The following questions are related to 3D virtual models, which are virtual representations of organs or tissues.



1. In a scale from 1 to 5 (being 1 not beneficial at all and 5 very beneficial), rate how beneficial the use of 3D virtual models is when training:

- Technical skills
- Decision making
- Stress management
- Cognitive skills: anatomy
- Cognitive skills: pathology
- Cognitive skills: procedure
- Teamwork
- Leadership
- Interpersonal skills

2. Regarding the integration of 3D virtual models into learning programs, rate from 1 to 5 how much do you agree with the following statements (1 being not at all and 5 completely)

- Virtual models should be used as an initial step of the learning program
- Virtual models should be used as a complement to current learning programs
- Virtual models should be used as an aid to learn anatomical and procedural competencies

3. Rate from 1 to 5 the importance of 3D virtual models' features to be incorporated within medical training (1 being not important at all and 5 being very important)

- Personalization (i.e., dependent on the patient)
- Realism
- Ability to model organs in motion
- Ability to interact with models in real time
- Ability to incorporate models within mixed reality applications
- Possibility to including different levels of complexity and layers of information
- Ability to share and easily download models

4. Is there any other feature you would like to mention?

5. Rate from 1 to 5 the relevance of 3D virtual models' barriers for their incorporation within medical training (1 being not relevant at all and 5 being very relevant)

- Lack of pedagogical background
- Financial issues
- Technical issues (e.g., lack of familiarization with technology, lack of resources, etc.)
- Logistic issues (e.g., low accessibility, limited personnel to create/print models, limited coordination between models creators and hospitals, etc.)
- Difficulty in the adaptation of the current learning program of your training center/hospital
- Great differences with respect to patients' anatomy
- Long time required to create the model
- Unrealistic texture and tissue consistency

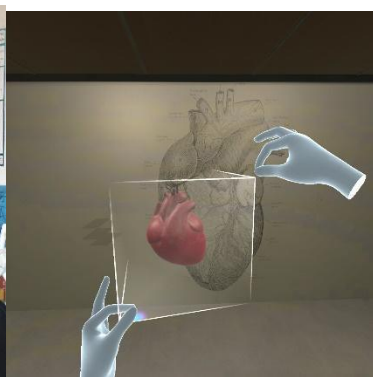
6. Is there any other barrier you would like to mention?

7. Would any of these barriers deter you from using these models?

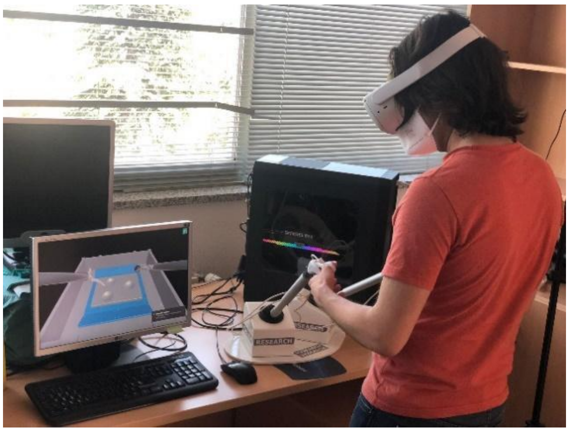
8. If you answered positively to the previous question, which one?

9. Rate the suitability from 1 to 5 of the following ways to interact with 3D virtual models (1 being not suitable at all and 5 being very suitable)

- Interaction with virtual model using hand tracking:

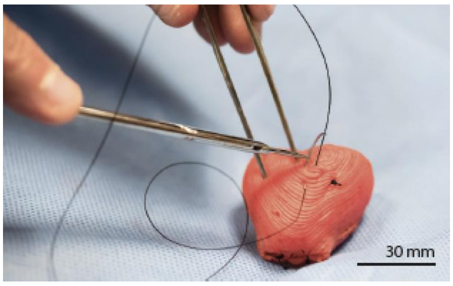
- Interaction with virtual model using haptic devices:



- Interaction with virtual model using VR headset:

3D PRINTED MODELS

The following questions are related to 3D printed models, which are physical representations of organs or tissues obtained using 3D printers.



1. In a scale from 1 to 5 (being 1 not beneficial at all and 5 very beneficial), rate how beneficial the use of 3D printed models is when training:

- Technical skills
- Decision making
- Stress management
- Cognitive skills: anatomy
- Cognitive skills: pathology
- Cognitive skills: procedure
- Teamwork
- Leadership
- Interpersonal skills

2. Regarding the integration of 3D printed models into learning programs, rate from 1 to 5 how much do you agree with the following statements (1 being not at all and 5 completely)

- Printed models should be used as a replacement of animal models
- Printed models should be used as a complement to current hands-on programs
- Printed models should be used as an aid to learn anatomical and procedural competencies

3. Rate from 1 to 5 the importance of 3D printed models' features to be incorporated within medical training (1 being not important at all and 5 being very important)

- Personalization (i.e., dependent on the patient)
- Realism of the tissues to facilitate interaction with them
- Ability to interact with models in real time
- Ability to incorporate models within mixed reality applications
- Possibility to including different levels of complexity and layers of information

4. Is there any other feature you would like to mention?

5. Rate from 1 to 5 the relevance of 3D printed models' barriers for their incorporation within medical training (1 being not relevant at all and 5 being very relevant)

- Lack of pedagogical background

- Financial issues
- Technical issues (e.g., lack of familiarization with technology, lack of resources, etc.)
- Logistic issues (e.g., low accessibility, limited personnel to create/print models, limited coordination between models creators and hospitals, etc.)
- Difficulty in the adaptation of the current learning program of your training center/hospital
- Great differences with respect to patients' anatomy
- Long time required to create the model
- Unrealistic texture and tissue consistency

6. Is there any other barrier you would like to mention?

7. Would any of these barriers deter you from using these models?

8. If you answered positively to the previous question, which one?