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METHODOLOGICAL GUIDELINES TO CREATE LEARNING CONTENTS FROM 3D MODELS

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Version control

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01	2021-12-09	Draft version of the report
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Summary

Deliverable 3.2 (D3.2) presents guidelines on how to create 3D models and how to create learning contents based on them. The guidelines are meant to assist the model generation, storage and retrieval according to a "best practice" policy, that guarantees their potential value as a resource for learning contents. These guidelines are agreed upon by all partners involved in 3D modelling.

Note: A part of the creation of 3D models has been presented in D3.3 *Methodological guidelines for 3D printing with training purposes* and is further researched in T4.2 *Specifications of 3D model creation tools*. The outcomes of T4.2 (with due date M15) will be provided in D4.1: *Specifications*.

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1. Introduction

The goal of Work Package (WP) 3 is to define the pedagogical needs of the target users (medical students, residents and mentors) that will benefit from the proposed solutions in the MIREIA project. These include all factors that must be taken into account in the design and implementation phase to facilitate learning. Additionally, WP3 provides a set of methodological guidelines for content creators in the design of 3D models and learning contents and their 3D printing using the available tools within the solution.

All the outcomes of the consortium's work on WP3 are covered in three deliverables: D3.1: *Pedagogical needs*; D3.2: *Methodological guidelines to create learning contents from 3D models* (this deliverable); and D3.3: *Methodological guidelines for 3D printing with training purposes*. D3.1 focuses on methodology, results and conclusions extracted from the pedagogical needs' analysis. D3.2 presents the guidelines on how to create 3D models and how to create learning contents based on them. D3.3 provides good practice guidelines for designing and developing 3D model printing for MIS training purposes.

In the following sections, we provide guidelines on how to create 3D models and how to create learning contents based on them. The guidelines are meant to assist the model generation, storage and retrieval according to a "best practice" policy, that guarantees their potential value as a resource for learning contents. These guidelines are agreed upon by all partners involved in 3D modelling.

It is necessary to mention that a part of the creation of 3D models has already been presented in D3.3 and is further researched in T4.2: *Specifications of 3D model creation tools*. T4.2 deals with the specifications (architecture, user interface design, Application Programming Interfaces -APIs- …) of the tools that will be available to create personalised 3D models and upload them into the MIREIA content repository. Once these are known and decided upon, the guidelines on creating 3D virtual models can be provided. The outcomes of T4.2 (with due date M15) will be provided in D4.1: *Specifications*. The latter (deliverable D4.1) will present in detail the design and functional requirements of the solution addressed in this project, as well as the specifications for all the different tools provided by it.

2. Creating 3D models

As indicated in the Introduction, *Creating 3D models* section provides guidelines on 3D printed models only. More information on 3D virtual models and guidelines on how to create and store them in the MIREIA content repository will be provided in D4.1.

2.1 Guidelines on creating 3D printed models

The guidelines on creating 3D printed models are based on D3.3. In order to create a 3D printed model, one needs to identify the required anatomical structure for the model. Once the specific anatomical structure is identified, the following four steps need to be executed:

1. **Step 1**: Collect data by performing medical imaging (e.g. CT, MRI). This is done in order to record the details of the anatomy of the structure to be analysed for subsequent creation of the 3D model for training. Figure 1 presents the sub-steps needed for data collection. Anatomical structure to be replicated serves as *input*, and DICOM file is an *output* obtained in Step 1.

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a. *Configure the parameters of the medical imaging equipment*

Before conducting the medical imaging, it is necessary to establish the appropriate parameters of the imaging equipment to be used (e.g., CT, MRI). These parameters need to be established by a multidisciplinary team, including medical specialist, e.g., radiologists, imaging physics experts, 3D printing engineering experts), as they largely depend on the anatomical area of the patient and the characteristics of the specific anatomical structure to be analysed.

b. *Validate the medical images*

Obtained medical images need to be validated by multidisciplinary team (medical specialist, imaging physics experts, 3D printing engineering experts) in terms of resolution, anatomical area covered by the imaging study, number of slices and definition of the desired anatomical structure. If necessary, medical imaging needs to be repeated.

c. *Export the medical image study to DICOM format*

In order to further work with the medical images, they need to be exported to a standard medical image format such as DICOM.
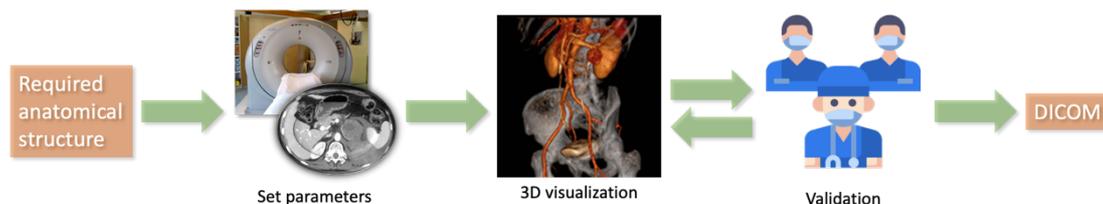
Figure 1: Flow diagram for the data collection phase.

2. **Step 2**: Perform segmentation and volume rendering of anatomical structure of interest. In this step, DICOM medical images format serves as *input*, and obtained *output* is STL or PLY format. Figure 2 presents the sub-steps of this segmentation and rendering phase.

a. *Import the DICOM medical images into the segmentation software*

Medical images (DICOM) need to be imported into a computer-aided design (CAD) software, in which the segmentation process is carried out (e.g., 3D Slicer).

b. *Segment the anatomical structures of interest*

Segmentation of the anatomical structure of interest can be done (among others) by means of segmentation techniques provided by the CAD, such as thresholding or region growing. The selection of these segmentation techniques, or their combination, depends on the characteristics of the tissue to be segmented (see D3.3 for more information on that).

Once the anatomical structure of interest has been segmented, a 3D volume rendering needs to be performed. Volume rendering represents a set of methods used to create 3D volume from a series of 2D images, such as slices from MRI or CT scans. Each CAD software usually has different options for performing this rendering process. For example, a series of 2D slice images to which a

segmentation process has been applied can be assembled to render the corresponding 3D volume.

c. *Validate the segmented 3D model*

Once the volumetric representation of the segmented anatomical structure is available, it needs to be validated with the medical professionals. This validation is needed in order to analyse whether the differences in geometry between the segmented 3D model and the DICOM dataset are adequate. This validation can be carried out by simply presenting the result obtained from the segmentation process to the medical professional for approval or feedback.

d. *Export the segmented 3D model to STL or PLY format*

Once the 3D model has been validated, it needs to be exported to a file format commonly used for 3D printing and CAD, such as STL or PLY.
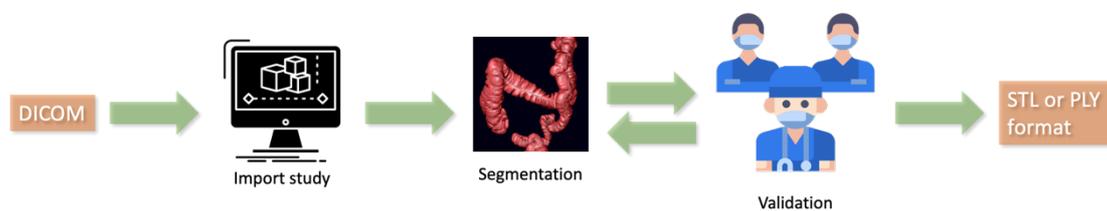
Figure 2: Flow diagram for the segmentation and volume rendering phase.

3. **Step 3**: Manually optimise the model and, if required, design the mould. The main objective of this step is to optimise the design of the 3D model extracted in the previous steps and, if necessary, to design the mould for the fabrication of the training model. Figure 3 presents the sub-steps of manual optimisation of the model and mould design.

a. *Import the segmented 3D model into a CAD software*

Load the 3D model of the segmented anatomical structure of interest into the CAD software. This needs to be done in order to allow post-processing tasks on the 3D model.

b. *Optimise the 3D model*

Apply smoothing methods (local smoothing, Poisson filter, etc.) and/or re-design the parts of the 3D model that might cause design errors or do not have enough anatomical details. D3.3 provides technical recommendations for the post-processing of the 3D models obtained from the import. Software such as Meshmixer and Materialise 3-Matic, among others, can be used for these post-processing tasks.

c. *(Optional) Generate mould*

In case when a 3D printed model is going to serve as a mould for creating anatomical models, the negative mould of that model needs to be obtained. For that, Boolean subtraction methods to generate negative mould can be used.

d. *Validate design with medical professionals*

Before proceeding to print the 3D model, it is recommended to validate the design with medical professionals. In some cases, it might be necessary to repeat step 3.b to adjust the design (if recommended by medical professionals).

e. *Export the surface meshes*

Once the 3D model is optimised and edited, the surface meshes of the model need to be exported to a standard 3D printing format (e.g., STL or PLY).

STL or PLY format → Import study into CAD SW → Smoothing & editing → Negative mold (optional) → Validation → STL or PLY format
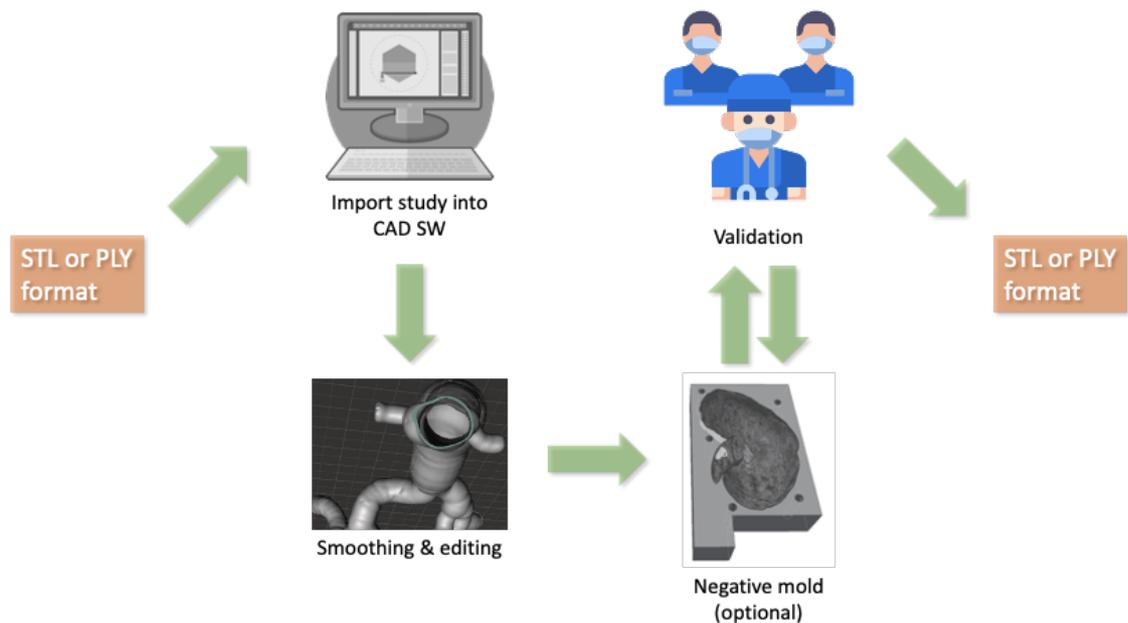
Figure 3: Flow diagram for the manual model optimisation and mould design phase.

4. **Step 4**: Selection of the 3D printing material. Before proceeding to print the 3D model it is necessary to choose the type of material depending on the fidelity of the model to be developed and the functionalities to be included. In general, 3D printed models for MIS training can belong to two fields: models for anatomical learning (anatomical models) and models for practical training (hands-on models).

a. *Anatomical models*

In general, anatomical models seek the visual representation of the elements, organs or anatomical systems (Figure 4).

In the case of anatomical models obtained from a mould (Figure 4, top half), 3D printing becomes an auxiliary procedure with which to produce the most precise details. The type of material for the manufacture of the mould, removable parts (if required), and the tissue of the anatomical structure should be taken into account. We recommend reviewing D3.3 for more details regarding the type of material to choose for each of these parts.

In the case of anatomical models manufactured entirely by 3D printing (Figure 4, bottom half), these models can include only visual information or also sensory information of the type of tissue (skin, muscle, bone, etc.). For the latter, the

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printing material of each tissue will depend on its properties (elastic, rigid, spongy tissue, etc.).
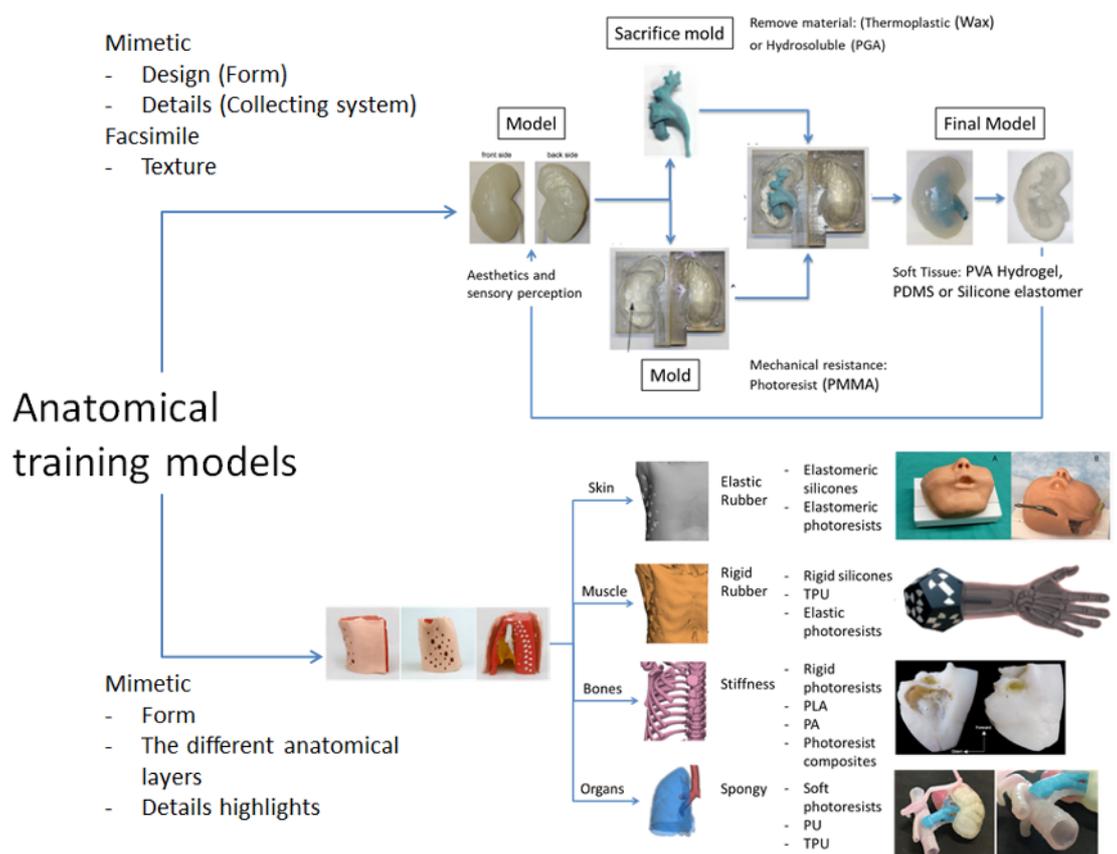
Figure 4: Workflow for the development of 3D printed models for anatomical training according to the expected reliability and functionality characteristics.

b. Hands-on models

From the point of view of models for MIS practice, it is challenging to determine a specific list of materials. The choice of materials will depend on the functionalities of the model (Figure 5). In this sense, we may need a model that provides parts with mobility or that simulates certain mechanical conditions. For example, for training a needle insertion in the liver, the mechanical properties of the liver (which is inhomogeneous) should feel realistic when inserting the needle. When during this training of needle insertion also ultrasound is used to guide the interventionalist/trainee, then also materials should be used that both reflect the mechanical properties as well as the imaging properties. Hence, for different training purposes different 3D printed materials will be needed. For mechanical properties this can be e.g., soft tissue, blood vessels walls, bone (Figure 5, top half). On the other hand, we may look for models that require a certain degree of realism and customization with respect to the patient anatomy or a pathology (Figure 5, middle). Finally, we may require the development of models that are as accurate as possible in their realism from a design point of view (Figure 5, bottom half). For each of these models, the set of materials to be used will be adapted to their functional needs (see D3.3).

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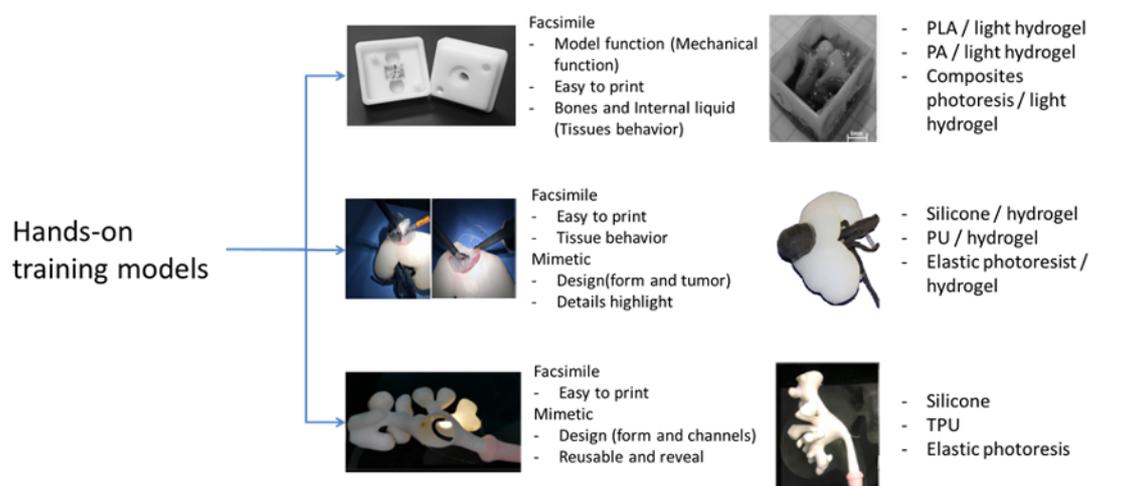
Figure 5: Workflow for the development of 3D printed models for hands-on training according to the expected functionality.

5. **Step 5**: 3D printing & model creation. Once the final 3D model to be printed and the materials to be used are defined, the last step is to configure the 3D printer to be used and proceed to print the model (Figure 6).

a. *Configure the 3D printing machine*

The parameters of the 3D printer need to be adjusted depending on, among other, the characteristics of the printer, the model to be printed, the type of material to be used, the expected level of detail, the printing time required. Technical recommendations for 3D printing have been compiled in Table 4 of D3.3.

b. *Print 3D models or moulds*

Depending on the type of model to be printed, there are additional actions that need to be undertaken:

   i. 3D models: if necessary, the support material used for the printer during the printing process should be removed.

   ii. Moulds: if they are used to cast soft-tissue models in various materials, they should be filled with the corresponding material (depending on the main training application) and the necessary parts (e.g. casting) need to be removed.

c. *Validate printed 3D model*

Once the model is printed, it is required to:

   i. Validate the differences in geometry between the printed model with the designed 3D model (segmented model) and the initial DICOM medical images.

   ii. If required, validate the mechanical properties of the printed model with respect to the real anatomy.

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iii.   Validate whether the printed model is suitable for medical professionals in terms of mechanical properties, aesthetics and interaction.

Technical recommendations to conduct these validations can be found in Table 5 in D3.3.
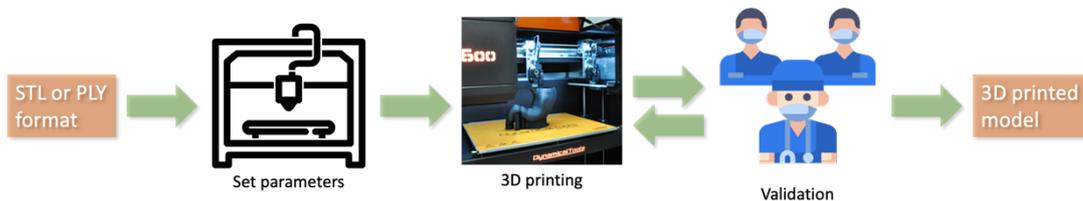
Figure 6: Flow diagram for the 3D printing and model fabrication phase.

3. Creating learning contents based on 3D models

The guidelines on creating learning contents based on 3D models are derived based on the EASIER pedagogical model[1]. This is done in order to create these contents from a pedagogical point of view. (See Appendix I for a short information on EASIER pedagogical model.)

A sort description of the terminology used in the guidelines on creating learning contents:

- **Skill** → skill is a particular ability to do something. The EASIER Consortium proposed 6 main categories for skills, including: cognitive, technical, interpersonal, decision making, stress management and leadership skills.
- **Learning outcome** → learning outcome identifies what the learner will know and be able to do by the end of a training activity. Learning outcome is defined from the point of view of the student, and should be defined such that it can be quantified. Learning outcome can be broken down into smaller learning objectives, which are used in rubric.
- **Action** → an action is the minimal training unit that students need to carry out to enable learning, directed towards a more specific learning goal.
- **Context** → context provides further information on the conditions under which the action takes place, allowing a better understanding of that action.
- **Pedagogical approach** → Pedagogical approach provides further information on how teachers/ educational content designers envision learning taking place through the action.
- **Rubric** → rubric defines what is expected of the student to get a particular grade. It is an attempt to communicate expectations of quality around a task. In many cases, scoring rubrics are used to delineate consistent criteria for grading.

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[1] EASIER: European Knowledge Alliance for Innovative education of Surgical and Interventional Skills; 588404-EPP-1-2017-1-ES-EPPKA2-KA

3.1 Guidelines on creating learning contents

In order to apply the EASIER pedagogical model and create learning contents based on the 3D models, one needs to define skill, learning outcome, context, action, pedagogical approach, and rubric. Table 1 provides mapping examples on skills, learning outcome, context, action, and pedagogical approach, while Table 2 provides example of a rubric for the examples provided in Table 1. This is done by executing the following nine steps:

1. **Step 1:** Identify the skill to be trained and its type (cognitive, technical, interpersonal, decision making, stress management, leadership). The skill needs to be "measurable" and well defined (e.g., "Knowing something…" is too generic and cannot be related to a measurable, observable result).

2. **Step 2:** Define the associated learning outcome that is measurable and specific. (Words like "recognize", "insert", or "describe" describe measurable outcomes, while, e.g., "understand" cannot really be measured.)

3. **Step 3:** Decide which action(s) are most suitable for reaching the learning outcome within that context. Note: Table 1 focuses on skills; therefore, there can be various actions listed for one skill.

4. **Step 4:** Describe the context of the action.

5. **Step 5:** Briefly describe the pedagogical approach and map the action(s) to the model accordingly. In other words:
   - First, reflect about how learning is going to be facilitated within the action (are students going to learn from each other? Will they be watching an expert performing a procedure? Will they need to reflect upon a reading?)
   - Second, assign a number to each axis accordingly.
     i. IS: Individual (1) – Social (11) [2]
     ii. NR: Non-reflective (1) – Reflective (11)
     iii. EI: Experience (1) – Information (11)

Please, note that "6" means "neutral", that is, dependent on the learners' involvement or choices.

Make a rubric that is based on the learning outcomes. Rubric is essential for the validation of both skill to be trained and learning content and method. Please note, that depending on whether rubric is used when applying 3D virtual models or 3D printed models, there might be a difference in the way the rubric is applied and how assessment is being made - automatically or by an expert/teacher.

6. **Step 6:** Write down the learning outcomes in the rubric.

7. **Step 7:** Break down each learning outcome into smaller, observable, measurable, specific learning objectives.

8. **Step 8:** Define the criteria for the different levels of achievement of each learning objective. (e.g., define what is: "outstanding performance", "good understanding", "basic understanding", "weak grasp on the topic", "poor performance" → the number

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[2] See Appendix I for more information

of criteria as well as the criteria themselves need to be defined by the training activity/educational content designers.)

9. **Step 9:** Assign a numeric grade for each level.

Table 1. Mapping example

Skill	Learning outcome	Action	Context	Pedagogical approach*
Recognize surgical anatomy of the upper abdomen (cognitive)	Recognize anatomy of the upper abdomen, including pathology and healthy tissues	Practicing on VR simulators (3D virtual models)	Simulation centre	Active learning / reflective learning IS: 2 NR: 8 EI: 3
		Practicing on phantoms (3D printed models)		Active learning / reflective learning IS: 2 NR: 6 EI: 2

* IS: Individual (1) – Social (11) ; NR: Non-reflective (1) – Reflective (11); EI: Experience (1) – Information (11)

Table 2: Example of rubric for Learning Outcome presented in Table 1

Learning objective	Critical	Criteria (achievement)					Weight in outcome score
		Poor	Inadequate	Adequate	Good	Outstanding	
Recognize anatomy of the upper abdomen, including pathology and healthy tissues.	Yes	Does not recognise pathology from healthy tissues, and is not able to point out and/or name organs, main blood vessels, and muscles.	Is able to point out and name the organs, main blood vessels, and muscles, but does not recognise pathology from healthy tissue.	Is able to point out and name the organs, main blood vessels, and muscles, and recognises healthy tissue, but does not recognise pathology.	Is able to point out and name the organs, blood vessels, and muscles, and recognises common pathologies.	Is able to point out and name the organs, blood vessels, and muscles, and recognises both common and uncommon pathologies.	20%

Appendix I

The EASIER model is based on the 3D pedagogy framework developed by Conole et al.[3] that allows for flexible aligning of learning theories with specific instructional approaches from different educational institutions, training providers, course designers and teachers, facilitating a standardized formal training practice. This framework provides a systematic mapping of tools and resources to expected learning outcomes and pedagogical theories of preference. The mapping gives an answer to the designer's question: 'Is this course/tool/resource adequate for what and how I want my students to learn?' This is suitable for Technology Enhanced Learning (TEL), where not only there is a wide array of tools and resources, but there is a great variability in the way they can be used. For example, an online discussion board can be used to submit and receive feedback from assignments, or as a communication tool for collaborative tasks.

The 3D framework sets up the basis for mapping training technology and learning outcomes without being linked to the specifics of a particular field of knowledge. Mapping is described in terms of the Activity Theory as revised by Kuutti[4], transforming higher-level activities into outcomes by means of **actions**. One activity may be performed using different actions, depending on the situation; e.g., the activity of learning the steps of a surgical procedure will require a different action depending on prior knowledge (does the learner need to learn everything from scratch, or does he/she already have some knowledge on the topic?), resources available (text, videos, conversations with tutors), and so forth.

To determine whether a particular learning action / resource is adequate within a given course design, the model matches the pedagogical profile of that action / resource with its suitability to reach one or more of the course's learning goals. The three axes of the 3D pedagogy framework allow mapping actions / resources to learning goals, ensuring that the resources available actually support the desired learning outcomes[5], according to the following dimensions (Figure 7):

- **Individual – Social** (IS): learning is considered a mainly individual experience, or achieved through interaction with others.
- **Non reflection – Reflection** (NR): learning comes through drill and practice, or from conscious elaboration.
- **Experience – Information** (EI): learning is achieved through direct experience and activity, or depends on using the available sources of information.

[3] Conole G, Dyke M, Oliver M, Seale J (2004) Mapping pedagogy and tools for effective learning design. *Computers & Education*, 43(1), 17-33

[4] Kuutti K (1995) Activity Theory as a potential framework for human-computer interaction research. In B. Nardi (Ed.), Context and Consciousness: Activity Theory and Human Computer Interaction (pp. 17–44). Cambridge: MIT Press. Gordon (1989)

[5] Oropesa I, Gutiérrez D, Chmarra MK, Sánchez-Peralta LF, Våpenstad C, Sánchez-González P, Pagador JB, González-Segura A, Langø T, Sánchez-Margallo FM, Dankelman J, Gómez EJ (2020). Can effective pedagogy be ensured in minimally invasive surgery e-learning?. *Minimally Invasive Therapy & Allied Technologies*, 16, 1-11.
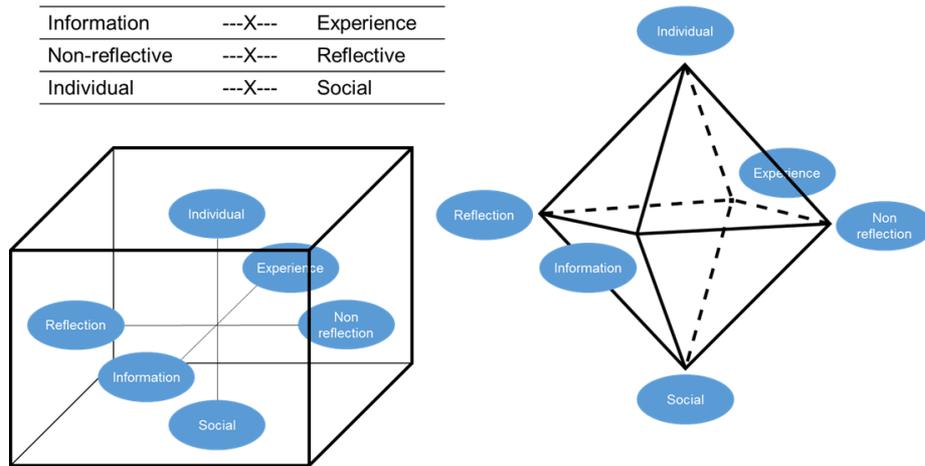
Figure 7: Graphical representation of mapping actions to 2D axis.

The 3D pedagogy framework was first adapted to its use in minimally invasive surgery (MIS) for the MISTELA project[6]. The MISTELA model was originally focused on how to set/assess cognitive skills in e-learning contexts. The model was expanded to technical and other nontechnical skills for the EASIER project.

The EASIER model provides a scaffold in which to build and structure didactic contents supported by TEL assets. The model proposed 9 steps to build a MIS learning activity. First, one must define what the learning outcomes of a course (or **activity**) are in order to acquire the necessary skills. Then, the learning context in which learning takes place must be described, so that one can define and map the possible actions against the 3D model (printed or virtual). In order to validate the model and measure the achievement of learning outcomes, a **rubric** must be defined. The rubric breaks down learning outcomes into smaller learning objectives that can be graded in terms of level of achievement.

In its current form, the model provides guidelines on how to set/assess learning outcomes of technical and nontechnical (e.g., cognitive) skills. It also allows for individual and collaborative learning activities so that the trainees can choose an approach that is the most suitable for them.

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[6] MISTELA: 528125-LLP-1-2012-1-UK-LEONARDO-LMP