# Report on a training scheme for all target groups and different working areas

## Introduction

The changes that are observed from few years in the field of manufacturing and production engineering popularly known as "Fourth Industry Revolution" utilizes the achievements in the different areas of computer sciences, introducing new solutions at almost every stage of the production process, just to mention such concepts as: mass customization, cloud computing, knowledge based engineering, virtual reality, rapid prototyping or virtual models of measuring systems. To effectively speed up the production process and make it more flexible, it is necessary to tighten the bonds connecting individual stages of the production process and to raise the awareness and knowledge of employees of individual sectors about the nature and specificity of work in other stages. As an example of such diversity the training of industrial design students in field of coordinate metrology can be indicated, which allows them to design the product more consciously taking into consideration also the requirements of quality control departments. Such relations exist between all production stages. In addition to quality control demands, staff of design departments must be also aware of manufacturing-related aspects of production. Afterwards, staff of manufacturing departments should understand information given to them as technical drawings, 3d models and other relevant information given using possibilities of sophisticated engineering software by designers and also should have knowledge from the metrology field such as geometrical dimensioning and tolerancing (GD&T) framework or measurement and measuring equipment errors that are important during stating the conformity of products with their specifications. Quality control workers must know the technical documentation and rules that are used for preparing it in order to be able to prepare correct measurement routines for different inspection equipment and they also should know the basics of manufacturing using various methods (including additive manufacturing) as this will help them in deciding which specifications of the measured workpiece are crucial from the functionality point of view and in proper alignment of the workpiece in measuring volume of the inspection machine.

Due to that, finding and developing appropriate education methods adapted to the specifics of individual stages of the production process becomes extremely important issue which can be crucial to properly exploit the potential of the fourth industrial revolution.

**Training scheme development: tools and assumptions**

In order to make the training recipient-targeted, the needs evaluation of the target groups was performed as a basis for development of the training scheme.

The target groups that were addressed in performed users need analysis survey included:

- Target group A: Apprenticeship students (design, manufacturing, quality assurance)

- Target group B: Bachelor degree students (design, manufacturing, quality assurance)

- Target group C: Master degree students (design, manufacturing, quality assurance)

- Target group D: Teachers and tutors

- Target group E: Developers of learning material

Following aspects were investigated in the context of "training for dimensional metrology in digital manufacturing":

- organisational aspects,

- technical aspects in the areas of:

     - design (e.g. model based definition, product manufacturing information),

     - manufacturing (e.g. additive manufacturing processes),

     - quality assurance (e.g. mobile measuring devices such as articulated measuring arms),

- didactical aspects.

The results of users need analysis survey were presented in separate report. Basing on them and on the previous experiences of the project team the structure for consistent curricula development for design, manufacturing and verification parts of the training was developed and presented at the end of this report.

During training structure development it was decided that the general structure for three different levels of learning, which are apprenticeship studies, bachelor degree studies and master degree studies, will be similar while the content at each level will differ in:

- stage of advancement of theoretical information,

- the complexity of the presented examples, practical exercises and comprehension questions,

- other specific requirements of different levels of study in relation to topics that will be dealt in the scope of individual learning modules.

To implement it in practice, for each learning module the learning content will be developed. It will contain whole necessary theoretical knowledge from the beginner to expert level and examples, practical exercises and comprehension questions of different complexity and level of details. The examination questions for all of the levels will also be included.

The structure of the Learning Module was also developed. It is presented below:

**TITLE OF LEARNING MODULE**

**LEARNING AIM**
Sentence defining the learning aim.

**INTRODUCTION**
A short introduction to the content, with no sub-sections.

**EXPLANATION**
The core of the module, both theory and practice. Sub-sections available. Direct links to related examples and exercises sections.

**EXAMPLES**
Practical applications of the explanation content.

**EXERCISES**
Practical activities, to be made in group if possible. Material not already seen in the explanation.

**COMPREHENSION QUESTIONS**
Auto-comprehension questions. Based on the explanation content

**WORKSHOP** (hidden from the students)
Suggestions for the tutors for practical/shared activities (both during frontal lectures and e-learning phase).

**EXAMINATION** (hidden from the students)
Question for final exam related to the explanation content.

At the following pages the developed structure for consistent curricula development for design, manufacturing and verification parts of the training is presented.

**Structure for consistent curricula development for design, manufacturing and verification:**

| | Global Masterplan | | |
|---|---|---|---|
| **Sign** | **Title of Step/Learning Module** | **Expected Study Time** | **Learning Outcome** |
| GM-S1-01 | Introduction to Digital Manufacturing | 0.5 h | You can recall the distictive elements of digital manufacturing. |
| GM-S1-02 | Design, manufacturing and verification workflow in the digital era | 0.5 h | You can recall the workflow of design, manufacturing and verification activities in the digital era. |
| GM-S1-03 | Metrological aspects in design and manufacturing | 0.5 h | You can explain the relevance of metrology throughout the design and manufacturing processes. |

| Design | | | |
|---|---|---|---|
| **Sign** | **Title of Step/Learning Module** | **Expected Study Time** | **Learning Outcome** |
| **D-S1** | **Definition of the product concept and functions** | | |
| D-S1-01 | The design process | 0,5 h | You can recall the design process in the digital era. |
| D-S1-02 | Design for X guidelines | 1 h | You can recall the main "design for manufacturability" guidelines. |
| D-S1-03 | Design for Additive Manufacturing | 1 h | You can recall the benefits of AM tecnologies and understand how to design AM parts. |
| **D-S2** | **Definition of the product specifications** | | |
| D-S2-01 | The need for Geometrical Product Specifications | 0,25 h | You can understand the need for Geometrical Product Specifications. |
| D-S2-02 | GPS concept | 0,25 h | You can recall the Geometrical Product Specification (GPS) framework. |
| D-S2-03 | Nine categories in the GPS matrix | 0,25 h | You can differentiate between the nine geometrical |

| | | | property categories indicated in the GPS matrix. |
|---|---|---|---|
| D-S2-04 | Introduction to geometrical tolerancing | 1 h | You understand what is a geometrical feature and of the relationships between geometrical features. |
| D-S2-05 | Introduction to geometrical tolerancing p. 2 | | You can recognize symbols of geometrical tolerances and of the rules of indication. |
| D-S2-06 | Profile tolerancing | 0,5 h | You will be able to differentiate between the tolerance of any line and the tolerance of any surface. |
| D-S2-07 | Profile tolerancing p. 2 | | You will be able to apply the default rules and the rules using additional specification elements. |
| D-S2-08 | Specification of AM parts | 0,25 h | You will be able to provide specifications to suppliers of AM parts. |
| **D-S3** | **Preparation of the digital model of the product** | | |
| D-S3-01 | Digital model of the product | 0,5 h | You can recall the 3D digital model main aspects. |
| D-S3-02 | Methods for documenting digital models and specifications | 0,5 h | You can illustrate how to document a 3D digital model including geometrical product specifications. |
| D-S3-03 | Formats for product data exchange | 0,5 h | You can recall the main formats for the exchange of product data. |

| | Manufacturing | | |
|---|---|---|---|
| **Sign** | **Title of Step/Learning Module** | **Expected Study Time** | **Learning Outcome** |
| **M-S1** | **Identification of manufacturing requirements** | | |
| M-S1-01 | Definition of additive manufacturing | 0,5 h | You can point out key features and advantages of additive manufacturing. |
| M-S1-02 | Characterisation of typical materials used in AM | 0,5 h | You know types of materials and feedstock solutions used in additive manufacturing. |
| M-S1-03 | Process capabilities of additive manufacturing | 0,5 h | You can describe the opportunities and limits of additive manufacturing regarding complexity, surface quality and tolerances. |
| **M-S2** | **Manufacturing equipment selection** | | |
| M-S2-01 | Definition of main additive manufacturing processes | 1 h | You know the functional principle and pros and cons of four additive manufacturing processes. |
| M-S2-02 | Description of typical 3d printers construction | 0,5 h | You know four different 3d printers architectures. |

| M-S3 | Materials and manufacturing process preparation | | |
|---|---|---|---|
| M-S3-01 | Digital definition of the process | 0,5 h | You understand principles of additive manufacturing process planning and execution. |
| M-S3-02 | Preparation of 3d printer | 0,5 h | You know why it is important to properly set up the 3d printing eqquipment. |
| M-S4 | Manufacturing process execution | | |
| M-S4-01 | Extrusion based additive manufacturing process execution | 1 h | You know what are the main functions of 3d printers' modules in relation to material changes that happen during FDM processes execution. |
| M-S4-02 | Power bed fusion based additive manufacturing process execution | 0,5 h | You know what are the main functions of 3d printers' modules in relation to material changes that happen during SLS processes execution. |
| M-S4-03 | Automation and supervision of additive manufacturing | 0,5 h | You know the systems used for automation and diagnostics of AM. |
| M-S5 | Manufacturing post processing | | |
| M-S5-01 | Finishing of the printouts - methods and requirements | 0,5 h | You can select proper finishing method to each AM process. |

| M-S6 | Management of manufacturing environment | | |
|------|------|------|------|
| M-S6-01 | Management of additive manufacturing machines | 0,5 h | You know how to supervise the AM machines and how to assure their constant operability. |
| M-S6-02 | Testing of AM machines (at higher level) | 0,5 h | You can recall the methods for testing of AM machines. |
| M-S6-03 | Economical and ecological aspects of additive manufacturing | 0,5 h | You can optimize the additive manufacturing process regarding costs, time and quality. |

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| Verification | | | |
|---|---|---|---|
| Sign | Title of Step/Learning Module | Expected Study Time | Learning Outcome |
| **V-S1** | **Identification of measurement requirements** | | |
| V-S1-01 | Identification of measurement requirements | 2 h | You can use informations about: features to be checked, general tolerances, tolerancing principle, material, reference to cad model. |
| V-S1-02 | Identification of measurement requirements p. 2 | | You can identify distances as an ambiguous specification. |
| V-S1-03 | Identification of measurement requirements p. 3 | | You can implement datum, common datum and datum system into a measuring strategy. |
| V-S1-04 | Identification of measurement requirements p. 4 | | You can implement position specification into a measuring strategy. |
| V-S1-05 | Identification of measurement requirements p. 5 | | You can implement line- and surface profile specification into a measuring strategy. |
| V-S1-06 | Identification of measurement requirements p. 6 | | You can implement size specification into a measuring strategy. |

| V-S2 | Measurement equipment selection | | |
|------|---------------------------------|---|---|
| V-S2-01 | Architecture of Articulated Arm CMM | 0,5 h | You can identify the components of an Articulated Arm CMM. |
| V-S2-02 | Measurement equipment selection | 1 h | You can distinguish two sensors available for Articulated Arm CMM. |
| V-S2-03 | Measurement equipment selection p. 2 | | You can explain the principle function of a tactile probing system on an Articulated Arm CMM. |
| V-S2-04 | Measurement equipment selection p. 3 | | You can explain the principle of functioning of a laserline sensor. |
| V-S2-05 | Measurement equipment selection p. 4 | | You can describe the opportunities and limits of Articulated Arm CMM regarding features and tolerances. |
| V-S2-06 | Measurement equipment selection p. 5 | | You can state typical artefacts for qualification used for Articulated Arm CMM. |
| V-S2-07 | Measurement equipment selection p. 6 | | You can interpret basic performance indicators for Articulated arm CMM. |
| V-S3 | Workpiece and measuring system preparation | | |

| | | | |
|---|---|---|---|
| V-S3-01 | Workpiece preparation process | | You can recall the the workpiece preparation process. |
| V-S3-02 | Cleaning of workpieces | | You can apply different cleaning procedures. |
| V-S3-03 | Fixturing of workpieces | | You can recall single and modular tools for fixturing. |
| V-S3-04 | Workpiece and measuring system preparation p. 2 | | You can prepare an Articulated Arm CMM ready for measurement. |
| V-S3-05 | Workpiece and measuring system preparation p. 3 | 1,5 h | You can apply the qualification procedure of a tactile probing system on an Articulated Arm CMM. |
| V-S3-06 | Workpiece and measuring system preparation p. 4 | | You can apply the qualification procedure of a laser line system on an Articulated Arm CMM. |
| V-S3-07 | Workpiece and measuring system preparation p. 5 | | You can perform a suitable interim check with an ready to use Articulated Arm CMM. |
| **V-S4** | **Measurement process execution** | | |
| V-S4-01 | Number and distribution of measuring points | 0,5 h | You can recall criteria for choosing number and distribution of measuring points. |
| V-S4-02 | Measurement process execution | 0,5 h | You can apply the acquisition procedure for Articulated Arm CMM. |

| V-S5 | Result evaluation process | | |
|---|---|---|---|
| V-S5-01 | Result evaluation process | | You can implement the measurement strategy for position specification. |
| V-S5-02 | Result evaluation process p. 2 | | You can implement the measurement strategy for line- and surface profile specification. |
| V-S5-03 | Result evaluation process p. 3 | 1,5 h | You can implement the measurement strategy for size specification. |
| V-S5-04 | Measurement Influences | | You can recall the five groups of error sources. |
| V-S5-05 | Documentation Overview | | You can recall the need of appropriate documentation of measurements. |
| V-S5-06 | Result evaluation process p. 4 | | You can prepare a measurement report. |
| V-S6 | Management of measurement environment | | |
| V-S6-01 | Measurement standards | 0,5 h | You can apply good practice of handling measurement standards. |
| V-S6-02 | Performance verification of measuring systems | | You can explain the terms acceptance test, reverification test and interim testing. |