Education and training in coordinate metrology for industry
towards digital manufacturing

L Rocha¹, E Savio², M Marxer³, F Ferreira⁴

¹ CATIM Technological Centre for the Metal Working Industry, Porto, Portugal, luis.rocha@catim.pt
² Università di Padova, DII – Dipartimento di Ingegneria Industriale, Padova, Italy, enrico.savio@unipd.it
³ NTB Interstate University of Applied Science, Buchs, Switzerland, michael.marxer@ntb.ch
⁴ CATIM Technological Centre for the Metal Working Industry, Porto, Portugal, fernando.ferreira@catim.pt

Abstract. Today manufacturing industry is based on multiple suppliers located in different countries and continents, intensively using automation, data exchange and advanced manufacturing technologies embedded in the digital era, and a number of national and international initiatives (e.g. Industrie 4.0) are devoted to support this effort. New opportunities to advance manufacturing of high value products are based on innovating the measuring technologies and procedures for Geometrical Quality Control, in particular addressing the training needs since having well trained professionals is an important key of success for manufacturing companies in several sectors. The paper is summarising recent experience in the field, with quantification of learning success related to the implementation of remote workshops.

1. Introduction
Several European initiatives, like the well-known German initiative Industrie 4.0 [1,2], the Smart Industry in the Netherlands [3], Industrie du Futur in France [4] and the Portugal i4.0 Initiative [5], are supporting the Digitisation of Manufacturing. Due to the last evolutions and trends, across the industrialised countries, it’s imperative giving to the company’s workforce the digital skills they need to fill the actual and future jobs. Digital technologies became the central role in creating value in the economy and bring several innovations to all aspects of development, production and related services. Europe's reindustrialisation will be possible if digitisation of products, processes and business models is mainstreamed across all industrial sectors. The European Union manufacturing sector accounts for 2 million companies and 33 million jobs; it is the source of 15% of EU GDP and 80% of exports. Digital Manufacturing (i.e. Industry 4.0, Smart Industry, etc.) is the strategy at EU level to support innovation processes [6]. Coordinate Metrology (including 3D digital measuring technologies) is by far the most important tool for these specialised activities. As widely reported, operators with their decisions are frequently the most relevant error sources in Coordinate Metrology operations, especially when dealing with new measuring technologies supporting Digital Manufacturing [7].
2. Education and Training in Coordinate Metrology

Highly qualified labour force remains a key source of future growth, and a particular focus is needed on the automotive and aerospace sectors [8,9,10]. A key enabler for innovation is the competent use of advanced equipment for the 3D measurement and digitisation of parts, as needed for advanced product/process engineering and quality control in customer-supplier business-to-business (B2B) interactions. Coordinate Metrology (including 3D digital measuring technologies) is by far the most important tool for these specialised activities, in particular Coordinate Measuring Machines (CMMs). As widely reported, operators with their decisions are frequently the most relevant error sources in Coordinate Metrology operations, especially when dealing with new measuring technologies supporting the Digital Manufacturing. Capacitate the industry employees is urgent, especially those operating in SMEs that are newcomers on 3D measuring technologies. This target group benefits from getting access to advanced 3D measuring equipment and special training for support the new needs in digital manufacturing.

3. The CMTRAIN Education and Training Approach

After a project was carried out, supported by the European Union, the EUKOM project, based on the experience of several national training concepts for coordinate metrology [11], the project returned a European-wide harmonized concept for teaching metrological competence and machine-independent basic knowledge for coordinate metrology. The Association “CMTrain – Training for Coordinate Metrology e.V. (CMTrain) [12] was founded, for assure the sustainability of the project. Nowadays CMTrain manages training activities and the further development of new learning materials and contents.

The CMTrain training approach is based on the manufacturer-independent concept developed by the EUKOM project (Figure 1). The training program comprises at several hierarchical levels (levels 1 to 3); this includes hands-on training on real CMM’s blended learning concept [13]. Level 1 is basic training, level 2 advanced training and level 3 training for specialists. Each training level is followed by further training and hands-on experience using CMM manufacturer’s specific measuring devices.

Figure 1. CMTrain learning concept

Each level of training consists of a combination of several forms of learning (blended learning). Participants work on e-competence and also with some of the experts during the contact hours. This form of learning is also used for supervised intensive hands-on training in small groups (4-5 people per group). Participants use a learning platform to develop their area of expertise. At the end of each level of training there is a practical and theoretical exam. The theoretical part of the exam is performed in a written form using a combination of multiple choice questions as well as open questions to be answered by the participants. Together with the evaluation, by the tutors, of the practical skills during the
workshops, a pass or fail evaluation is being held. It’s necessary to reach a minimum score of 60%. If
the candidate does not reach the required number of points, the test can be repeated within a certain
period of time defined by the participant together with the tutor. This period is typically within four to
six weeks after attending the first one. If this second attempt is not successful, the participant has to
repeat the level to be able to attend the test once again [13].

In addition to hands-on training in small groups, practical e-training is also available. For this type
of practical training, that feature was dominated as Remote Learning (RL) participants have access to a
real CMM via the Internet (Figure 2). They have full access to the control and programming of the CMM
and are in touch with a competent tutor who is on site where the CMM is located. Communication with
this tutor also takes place via the Internet using information and communication technologies such as
video and audio transmission.

This training approach is used for advanced training in industry and education organisations up to
tertiary level [13]. For use in industrial enterprises, courses are offered as blended learning way in
various languages and include a standardized final exam, which is internationally recognized.

The feedback of first remote workshop courses was registered based on three actions. The
participants of each action have been divided into two groups. The participants in group 1 attended
conventional workshop in a presence-based way, the participants of group 2 attended the workshop on
a remote basis. The feedback of the pilot courses showed that the remote workshops were rated at least
as good as the conventional workshops. This result was surprising and it showed that the approach is
promising.

The comparison of the learning success in a written examination showed that the participants of the
remote workshop had better results than the participants of the conventional workshop in two out of
three actions (Figure 3).

Figure. 2. Remote hands-on workshops on real CMMs via the Internet

Figure. 3. Learning success comparison presence-based workshop to remote workshop (Marxer,
2012)
Following the promising results based on the first pilot tests comparing presence-based workshops and remote workshops (Figure 3), the remote workshop method was incorporated for further development within the ongoing EU project “European Training for Coordinate Metrology 4.0”, currently under development and in an early stage.

The learning concept of CMTrain is used in universities as well, some packages are integrated into conventional lectures and the e-learning component supports self-study. This process is articulated with the Bologna Process initiated by the European Union. Up to now, this concept has been used in Bachelor and Master Courses in Germany, Switzerland, Italy and Poland. The existing training contents are available in several languages: English, German, Romanian, Polish and Portuguese. New versions in French and Italian are currently being developed.

4. Added value for companies

We need to take in account several factors that brings added value to companies, and trainees, by getting CMTrain courses as a perspective of sustainability (Figure 4) [13, 14, 15, 16]. We can identify environmental aspect, this training model enables participants to reduce travels (energy consumption), paper consumption for course materials is significantly reduced as information is made, distributed and available electronically, contributing to pollution reduction. In the economic direction, the CMTrain concept implies lower travel costs, lower course fees and less time out of the working place, such comprehensive training was not possible in the past for small and medium-sized companies as it meant that employees were not at their place of work.

![Figure 4. Sustainability aspects](image)

Regarding the social issues, this training approach certification presented significantly increases equality of opportunity when it comes to accessing to knowledge, as for a company or learners, for example, giving the opportunity to small companies and emerging markets that do not have widespread modern infrastructure but that can now benefit from this training method [16].

5. Future developments

The distribution channels are evolving very fast due to the technology evolution (metrology and media distribution), opening new ways and opportunities to exploit these factors. Boundaries between technologies are becoming blurred, like normal smartphone is now a car navigation system, a health monitor or a training delivery device, at the same time, in any place. Consequently, we began several trials with complementary devices to receive the training contents, beyond the traditional desktop or laptop computer, such as tablets and smartphone, using the increasing presence of large internet bandwidth in and out of working places, to maximise the impact of training.

Other efforts are made for create new contents, to provide in a near future, through CMTrain courses, aligned with the paradigm of digital industry and digital manufacturing. Contents such as optical measuring systems for digitisation of surfaces, computed tomography for full digitisation of parts, point-
cloud metrology, reverse engineering for digital modelling of products, data protocols and analysis among others contents.

6. Conclusions
After several editions of CM courses, during the last years, with the blended learning approach, we obtained positive evaluation, showing that the concept is adequate at industrial and university learning environments. For this reason, it is very important to propagate the concept of CMTrain internationally to give a wider access to this model of training to fill the present and future needs of the industrial companies in several sectors.

7. Acknowledgments
The authors wish to acknowledge the support of the members of CMTrain association and gratefully appreciate the feedback of the manufacturing companies, and university students that have participated in the field tests, and training editions, for their important contributions.

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