



Survey of training courses

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Collected courses

- MATHMET
- <u>Survey</u>: 43 courses on MU evaluation, from 14 Partners and 3 Stakeholders (about 2.5 courses/institution).
- More than 915 hours of
 - teaching activity, overall.



> Raw data available: on the "For Trainees - Measurement Uncertainty Training" webpage

(https://www.euramet.org/european-metrology-networks/mathmet/activities/measurement-uncertainty-training-

activity/for-trainees-measurement-uncertainty-training)

<mark>Owner</mark>	Title of the course
	Management uppertainty and statistics ("Massuppide what upd Statistic")
DAIVI	Measurement uncertainty and statistics (Messunsicherneit und Statistik)
	(reliving the sector)
	Thermal measurements and controls
	In evaluation of uncertainty in measurement
	Uncertainty of measurements
	JCGM 101:2008 e JCGM 102:2011 - Valutazione deil incertezza di misura con il metodo Monte Carlo e per casi multivariati
	La taratura di masse, bilance e misuratori di volume
INRIM	La taratura di misuratori di temperatura
INRIM	Time and frequency, Instrumentation, and Metrology
UKAS	Measurement uncertainty for practitioners
PIB	Einfuhrung in die Berechnung der Messunsicherheit nach dem GUM (Introduction to evaluating measurement uncertainty according to the GUM)
РТВ	"Einführung in die Berechnung der Messunsicherheit nach dem GUM" (Introduction to evaluating measurement uncertainty according to the GUM)
GUM	Practice of measurement uncertainty evaluation
NSAI	Evaluating Measurement Uncertainty - CT002
POLITO	Electronic Measurement
POLITO	Testing and Certification
POLITO	Sistemi di Misura e Sensori (Measurement Sistems and Sensors)
CEM	Curso virtual de metrología. Módulo básico
CEM	Curso virtual de metrología. Módulo intermedio
CEM	Curso virtual de metrología. Módulo avanzado
CEM	Curso de calibración por comparación de termómetros de contacto
METAS	Grundlagen der Messunsicherheit - Principes de base en incertitude de mesure (Basic principles in MU)
METAS	Messunsicherheit und Konformitätsbewertung (MU and evaluation of conformity)
METAS	Messunsicherheit in der analytischen Chemie und Biologie (MU in analytical chemistry and biology)
SMD	Incertitudes de mesure
SMD	Uncertainties for SPRT calibrations in fixed points
SMD	Introduction to the Guide of Uncertainty in Measurement (GUM) - Comparison GUM LPU/MC
SMD	Measurement uncertainty evaluation - An overview of different techniques and methods
IMS SAS	Theoretical aspects of measurement
IPQ	Curso de Experimentadores Metrologistas (Training for Metrologist Experimenters)
IPQ	Good practices for the use and maintenance of standard test measures within the scope of gas pumps verification
IPQ	Oficina à medida (workshop with measure)
NPL	Understanding Uncertainty Budgets
NPL	Introduction to Measurement Uncertainty
NPL	Understanding and Evaluating Measurement Uncertainty
UKN	Introduction to working with measurement data ("Einführung in das Arbeiten mit Messdaten")
LNE	Introduction to measurement uncertainty
LNE	Evaluation and control of MU
LNE	Evaluation and control of MU
LNE	Evaluation of MU by MMC
JRC	Estimation of uncertainties and the use of reference materials
NURE	Measurement uncertainty evaluation at calibration of measurement instrument



Collected courses cont.

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- Integrated into a training framework/project: about 50 %
- <u>Main course or module</u>: Main courses (29), main courses with a module on MU evaluation (8), modules on MU (6)





Specific field of application, Duration & Frequency

- **<u>Frequency</u>**: recurring courses from once/any 2 years up to 8 times/year.
- Duration: 21 h on average; 5 of the 7 longest courses are from Academia
- Specific field of application: 53 % reported with no specific field of

application \rightarrow general courses on MU suitable for every application



> 30





Language, Location & Material

- MATHMET
- Language: 16 % courses offered in more than one language
- Location: Some online courses are supposed to be activated during the Covid19 pandemic
- Material: Lecture notes/presentations always provided







Examination, Certificate & Fee

- **Examination**: 50 % courses with final examination
- <u>Certificate</u>: Most of courses without final examination provide a Certificate of attendance; 58 % of courses with a final examination provide a final grade or a more specific Certificate, the remaining 42 % a Certificate of attendance
- **Fee**: About 50 % courses with fee. In case of participation of a not-academic student to the university courses, no fee is foreseen





Audience

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- **Target audience:** 12 % courses for Legal metrology; 33 % for NMI; 55 % for Calib&Test labs, 28 % for Academia

Specific constraints/prerequisites: Basic knowledge on maths and stats is required (up to 1/3 of courses) to any audience; Basic knowledge of the GUM is required to Calib&Test and NMI; When good mathematical and metrology knowledge is required, this happens to Academia and NMI*; Legal audience has a very few constraints

Target audience



Constraints/prerequisites	Acad.	Calib&Test	Legal	Legal, Calib&Test	NMI	NMI, Calib&Test	Calib&Test, Academia	Tot.
Basic knowledge of the GUM		5				2		7
Basic knowledge on maths and statistics	3	2		1	1	5	1	13
General background in science and engineering	2							2
Good mathematical and metrology knowledge	3				1			4
None	2	5	4		3	2	1	17
Total	10	12	4	1	5	9	2	43

*Corresponding courses are on more advanced methods (like MCM) and require the trainees to be already familiar with basics of uncertainty evaluation

	Review of		
	mathematical tools		
	Answer	•	Counts
	No		28
	Pre-requisite, with a	an	* 2
	Yes		10
тимет	Yes (basic)		3
	Totale complessivo		43
	Review of		
	probability concept	ts	
	Answer	•	Counts
	No		6
	Yes		35
	Yes (basic)		2
	Totale complessivo		43
	Basic metrological		
	Answor	_	Counts
	No	•	Counts
	NO		20
	Ves (basic)		35
	Total		43
	Input standard		
	uncertainties and		
	covariances		
	Answer	•	Counts
	No		1
	Yes		38
	Yes (no covariances)	4
	Total		4 3

Technical contents

65 % do not provide a review: basic knowledge on maths is generally assumed * Pre-requisite, with an online self-learning module offered beforehand

86 % provide a review of probabilistic topics

96 % provide a review of metrological topics

The only "No" corresponds to a course fully devoted to MCM



Technical contents cont.

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LPU (GUM 1st or also higher orders Taylor expansion, expanded uncertainty): Only 3 courses do not

treat LPU (two are focused on MCM and one on phase noise and frequency stability in oscillators)

- LPU (JCGM 102 multivariate models): 81 % do not treat LPU for multivariate models



MCM (JCGM 102 multivariate models)



MCM: JCGM 101 vs. JCGM 102					
JCGM 102					
JCGM 101	No	Yes	Total		
No	24		24		
Yes	13	6	19		
Total	37	6	43		

LPU (JCGM 102) vs.					
MCM (JCGM 102)					
LPU (JCGM 102)	No	Yes	Total		
No	35		35		
Yes		6	6		
Yes (basic)	2		2		
Total 37 6 43					

6 of the 19 courses (32%) dealing with JCGM 101, deal also with JCGM 102

6 of the 8 courses (75 %) dealing with LPU for multivariate models deal also with corresponding MCM

15 out of 19 (79 %) courses dealing with MCM (JCGM 101) deal also with its validation with the GUM



Audience vs. LPU (JCGM 102)

LPU (JCGM 102)

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Audience	No	Yes	Yes (basic)	Total
Academia	6	2	2	10
Calib&Test	11	1		12
Legal	4			4
Legal, Calib&Test	1			1
NMI	3	2		5
NMI, Calib&Test	8	1		9
Calib&Test, Acad.	2			2
Total	35	6	2	43

Audience vs. MCM (JCGM 101)

Counts

Counts

MCM (JCGM 101)

Audience	Νο	Yes	Total
Academia	3	7	10
Calib&Test	9	3	12
Legal	4		4
Legal, Calib&Test		1	1
NMI	1	4	5
NMI, Calib&Test	6	3	9
Calib&Test, Acad.	1	1	2
Total	24	19	43

Technical contents by Audience

The 8 courses dealing with LPU for multivariate models address Academia, NMI and Calib&Test; no one addresses Legal audience

MCM taught in almost no legal course, a third of the Calib&Test, half of the NMI and most of the Academia courses



Further topics, references, software

Further treated topics:

Linear regression, quality control, acceptance sampling Bayesian inference, comparison with frequentist view of probability Conformity assessment, conformance probability, risks, decision rules, specifications and tolerances Statistical foundations to measurement uncertainty evaluation Spectral Analysis, Allan Deviation, Phase and Frequency noise Uncertainty related to fit model Writing units, symbols and measurement results Use of uncertainty budgets Analytical approaches to measurement uncertainty evaluation Practical examples Linear regression with frequency and set of the set of the

References:

GUM (JCGM 100), JCGM 101, 102, 104, 106, 200, GUM-6 Origin SI Brochure EURAMET Guides, OIML standards, ISO Standards, ILAC Guides, COOMET Recommendations EMUE compendium of examples Documents by EA, EURAMET, UKAS, DIN, EURACHEM/CITAC

Software: 33 % courses do not mention use of SW Excel worksheet, VBA NIST uncertainty machine R GUM workbench pro 2.4 Matlab, Octave LabVIEW Stable32 WolframOne Origin



Comments

MATHMET

- ➤ Main differences among courses depend on the target audience (MU from a general perspective or application-driven): e.g., the courses dealing with LPU for multivariate models address Academia, NMI and Calib&Test, but none the legal audience; MCM is taught in almost no legal course, a third of the Calib&Test, half of the NMI and most of the Academia courses.
- Pre-recorded courses allow trainees to manage their training time as they prefer, but they allow no immediate exchange between trainers and trainees.
- > Majority of courses provide a review of probabilistic topics and a review of metrological topics \rightarrow Large consensus on the importance of such bases.
- > A few courses on LPU for multivariate models \rightarrow GAP!
- > A few courses address MCM according to JCGM 102 \rightarrow GAP!
- More than 80 % courses do not treat multivariate models! However, those doing that, generally treat both LPU and MCM.
- ➢ 67 % of the courses mention the use of some SW or programming language (Excel, Matlab, R, LabVIEW, Origin, NIST uncertainty machine and the GUM Workbench).





Thank you for the attention! Any question?

