



# Measurement Uncertainty Training Workshop

## Survey of training courses on MU evaluation



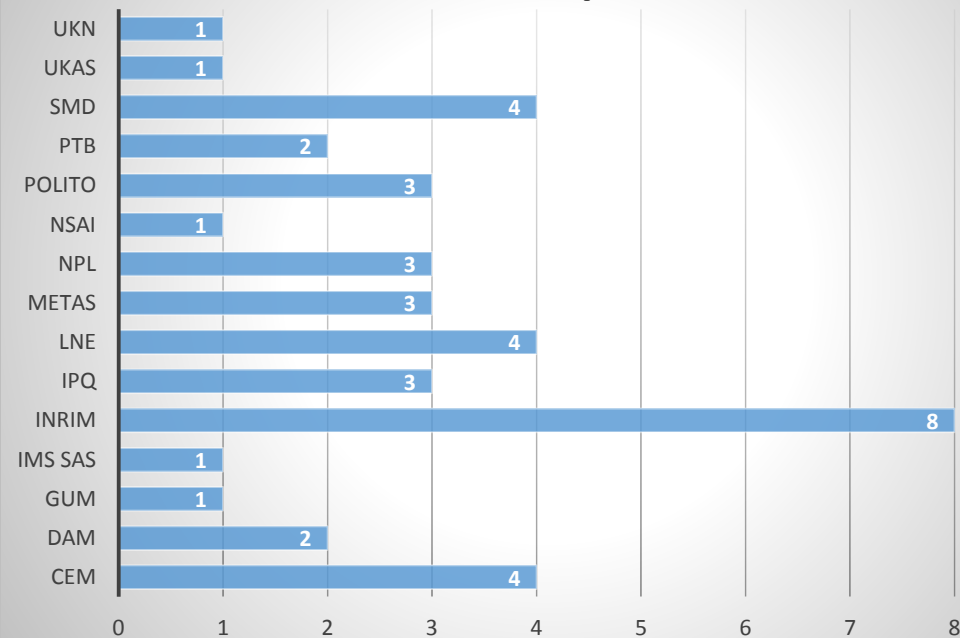
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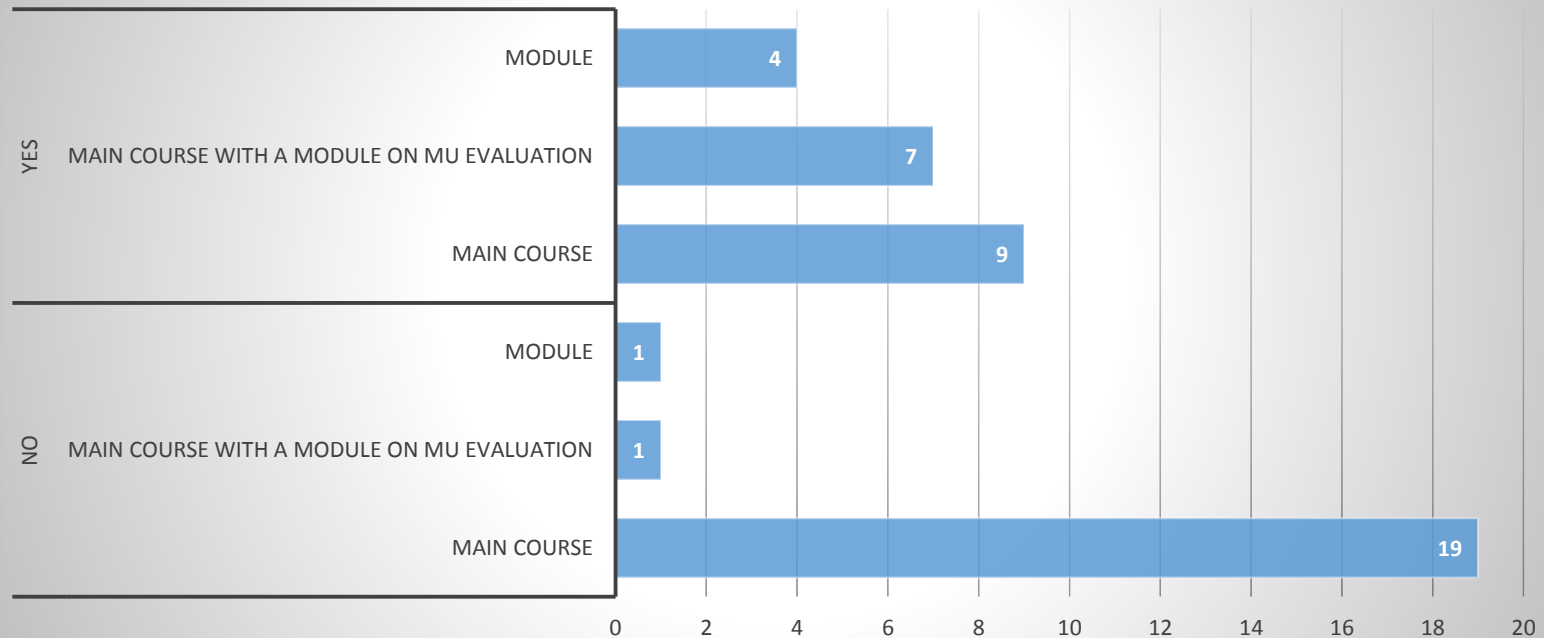
## Collected courses (Framework & Kind)

- **Survey**: 41 courses on MU evaluation, from 14 Partners and 1 Stakeholder (about 3 courses/institution).  
More than 880 hours of teaching activity, overall.
- **Integrated into a training framework/project**: about 50 %
- **Main course or module**: Main courses (28), main courses with a module on MU evaluation (8), modules on MU (5)
- **Note**: The highest INRIM number (8) is probably biased (half were main courses with a module on MU)

Courses providers



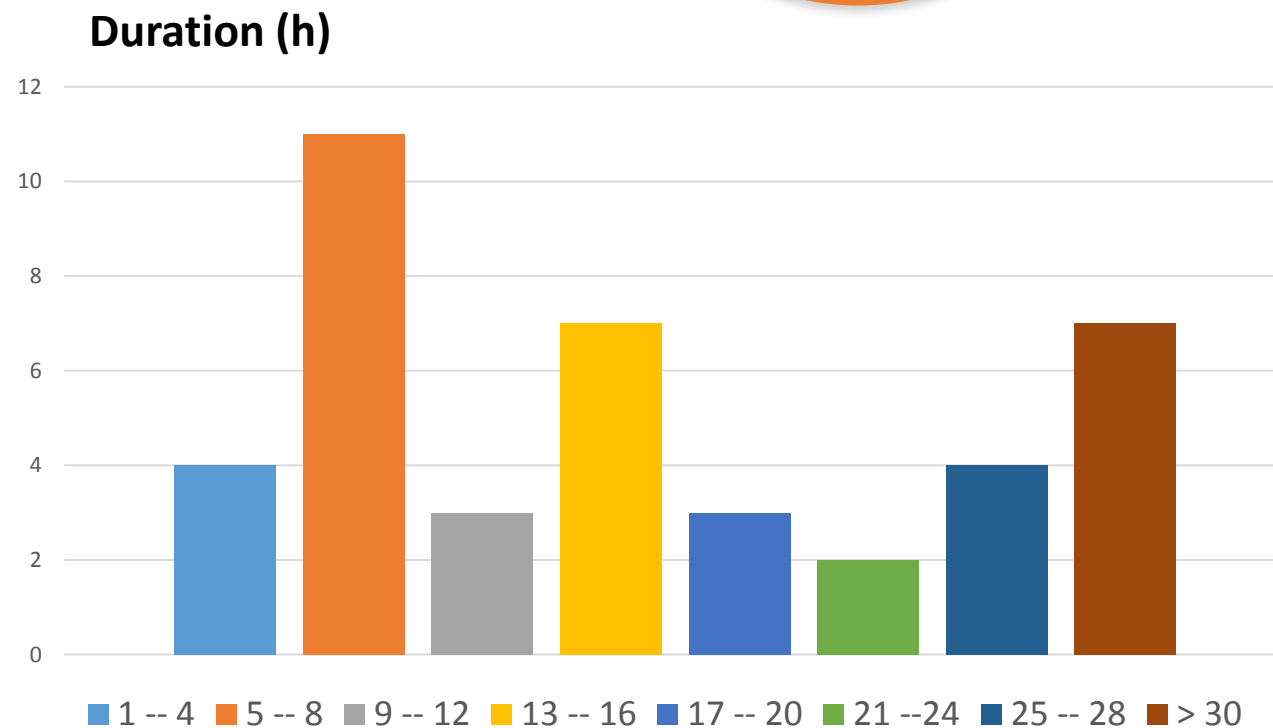
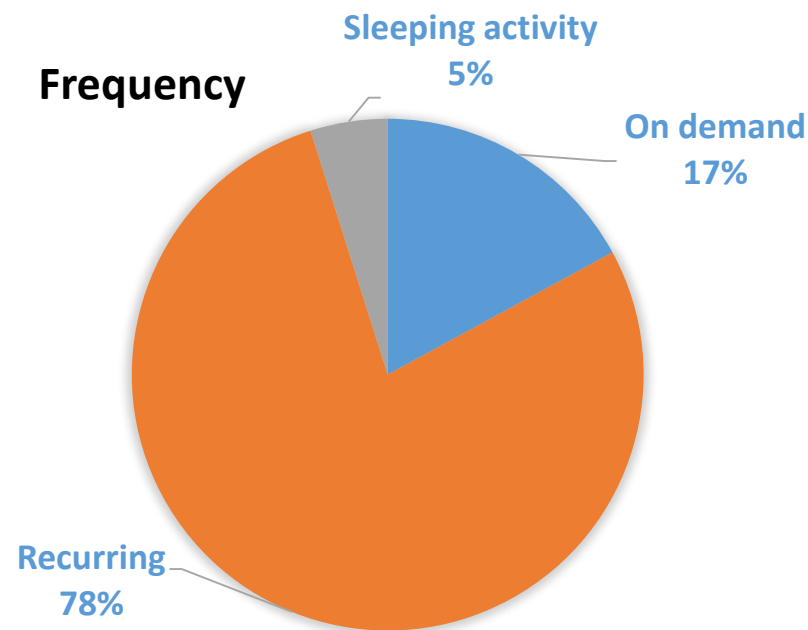
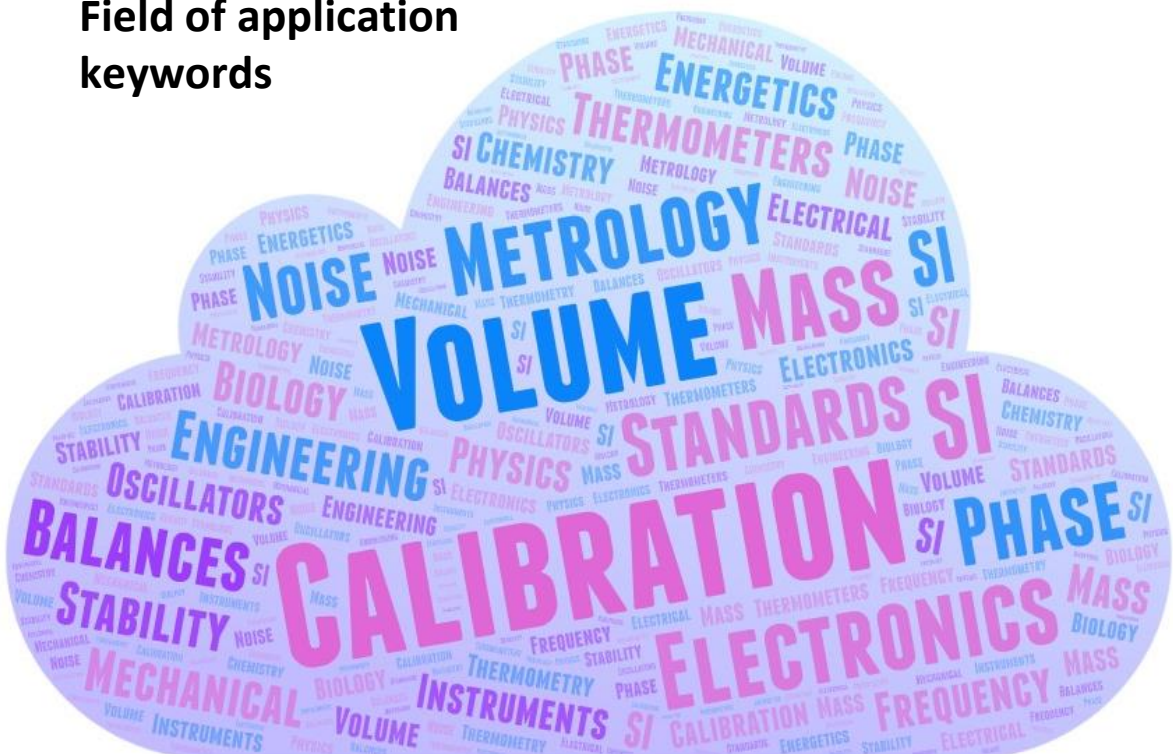
Framework by kind of courses



## Specific field of application, Duration & Frequency

- **Specific field of application:** 56 % reported with no specific field of application  
→ general courses on MU suitable for every application
- **Duration:** 21.5 h on average; 5 of the 7 longest courses are from Academia
- **Frequency:** recurring courses from once/any 2 years up to 8 times/year.

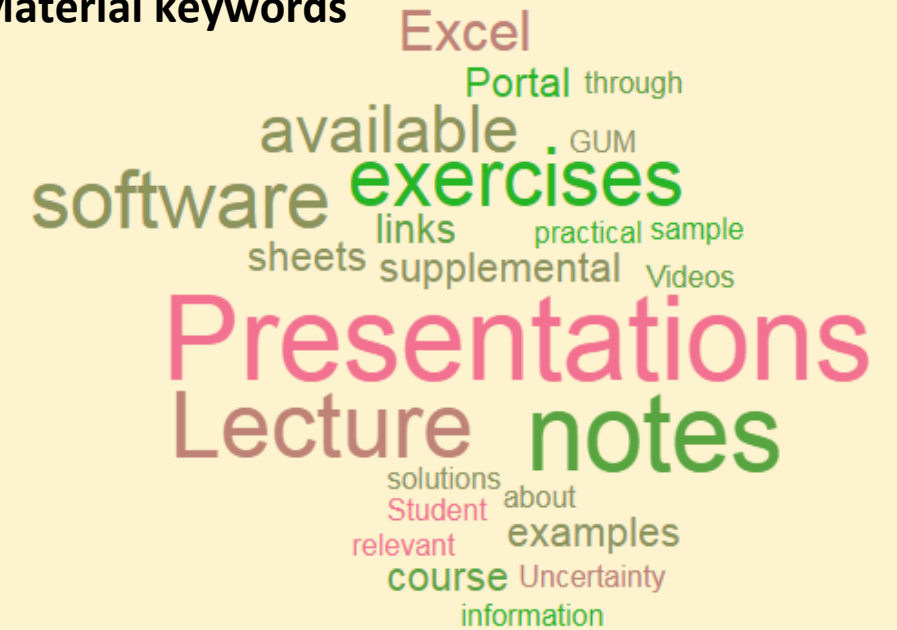
## Field of application keywords



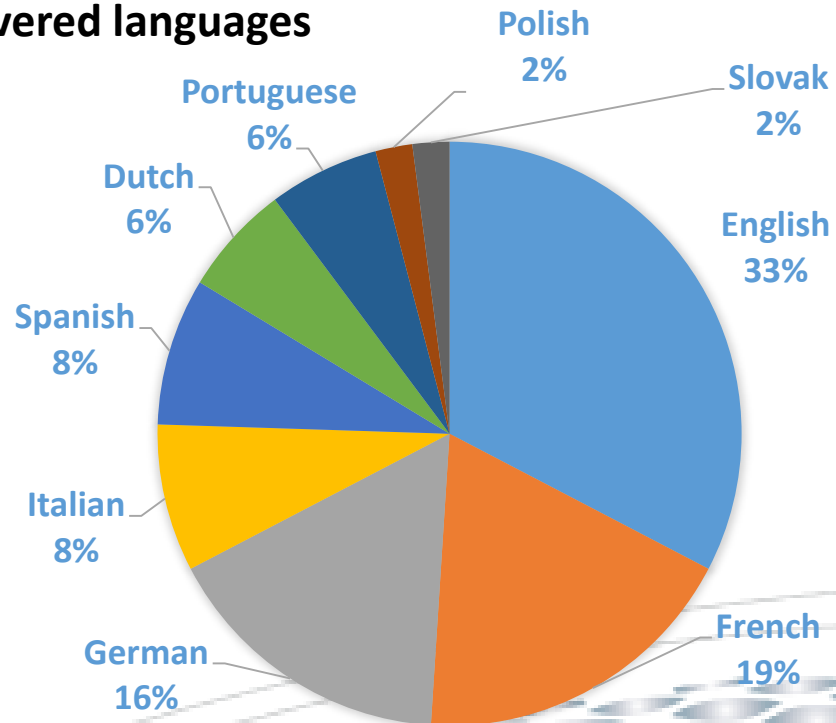
# Language, Location & Material

- **Language**: 15 % 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

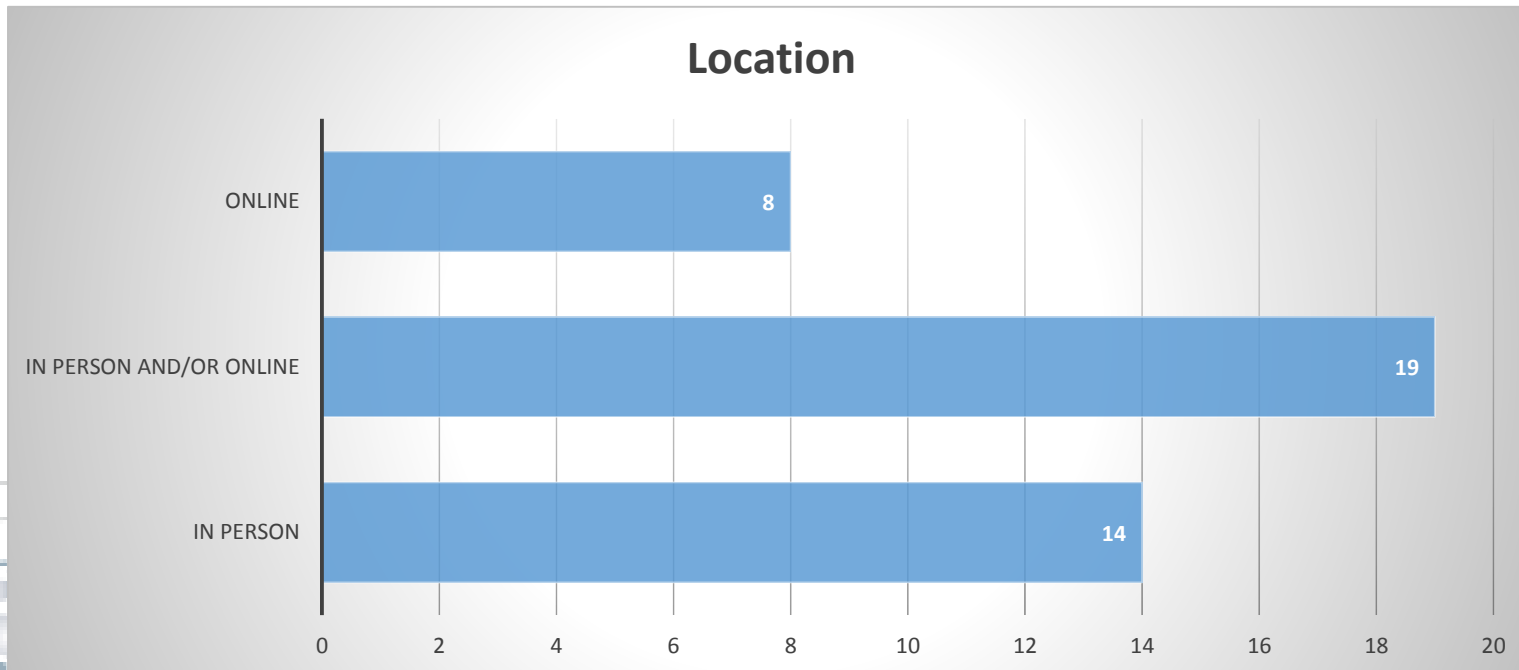
## Material keywords



## Covered languages

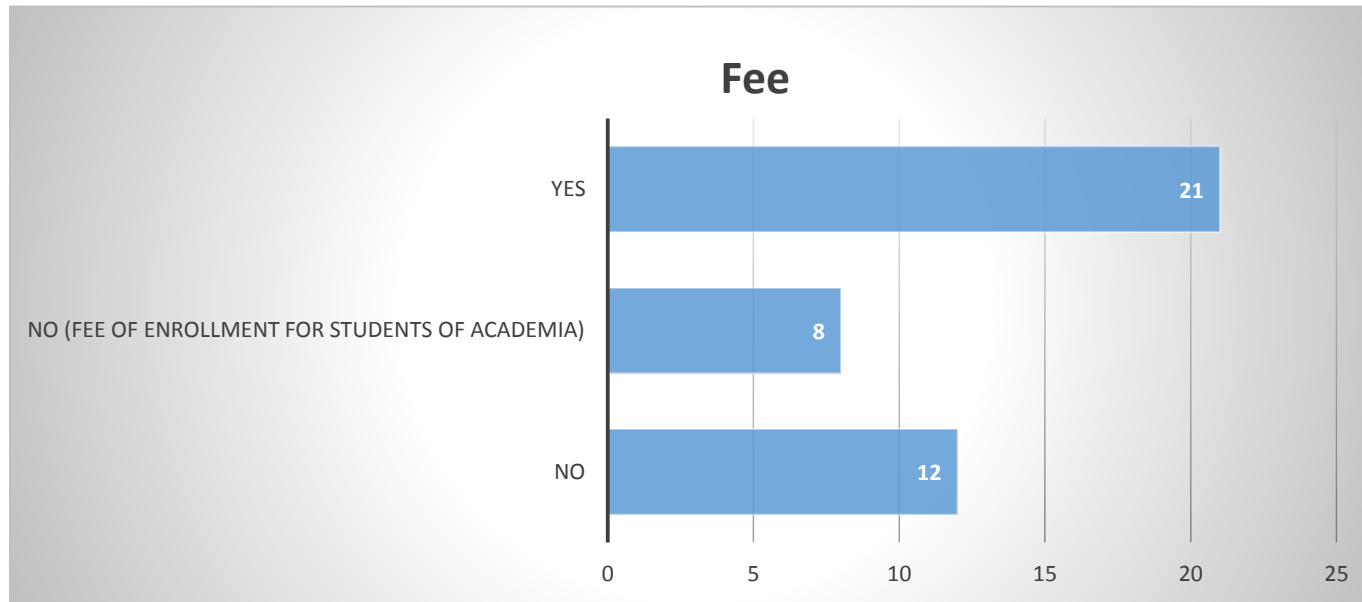


## Location



# Examination, Certificate & Fee

- **Examination**: 50 % courses with final examination
- **Certificate**: Most of courses without final examination provide a Certificate of attendance; 60 % of courses with a final examination provide a final grade or a more specific Certificate, the remaining 40 % a Certificate of attendance
- **Fee**: 50 % courses with fee. In case of participation of a not-academic student to the university courses, no fee is foreseen

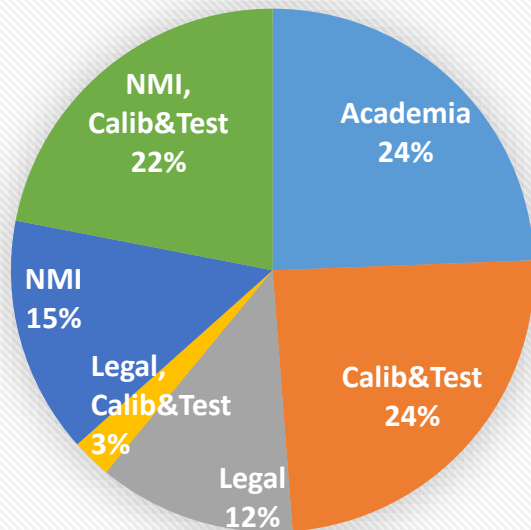




# Audience

- **Target audience**: 15 % courses for legal metrology; 37 % for NMI; 46 % for calibration and testing labs, 24 % for Academia
- **Specific constraints/prerequisites**: Basic knowledge on maths and statistics is to some extent required to any audience, especially Academia, NMI and Calib&Test; Basic knowledge of the GUM is required to Calib&Test and NMI\*; Academia is the audience for which more constraints are specified; When good mathematical and metrology knowledge is required, this happens to Academia and NMI; Legal audience has a very few constraints
- **Average number of attendees**: 25 is the mean number of attendees per course (18 the median)

Target audience



Constraints/prerequisites	Academia	Calib&Test	Legal	Legal, Calib&Test	NMI	NMI, Calib&Test	Total
Basic knowledge of the GUM		5				2	7
Basic knowledge on maths and statistics	3	1	1	1	1	5	12
General background in science and engineering	2						2
Good mathematical and metrology knowledge	3				1		4
None	2	4	4		4	2	16
<b>Total</b>	<b>10</b>	<b>10</b>	<b>5</b>	<b>1</b>	<b>6</b>	<b>9</b>	<b>41</b>

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

# Technical contents

Review of mathematical tools	
Answer	Counts
No	27
Pre-requisite, with an *	2
Yes	10
Yes (basic)	2
<b>Totale complessivo</b>	<b>41</b>

Review of probability concepts	
Answer	Counts
No	6
Yes	33
Yes (basic)	2
<b>Totale complessivo</b>	<b>41</b>

Basic metrological concepts	
Answer	Counts
No	2
Yes	37
Yes (basic)	2
<b>Total</b>	<b>41</b>

Input standard uncertainties and covariances	
Answer	Counts
No	1
Yes	36
Yes (no covariances)	4
<b>Total</b>	<b>41</b>

66 % do not provide a review: basic knowledge on maths is generally assumed

\* Pre-requisite, with an online self-learning module offered beforehand

85 % provide a review of probabilistic topics

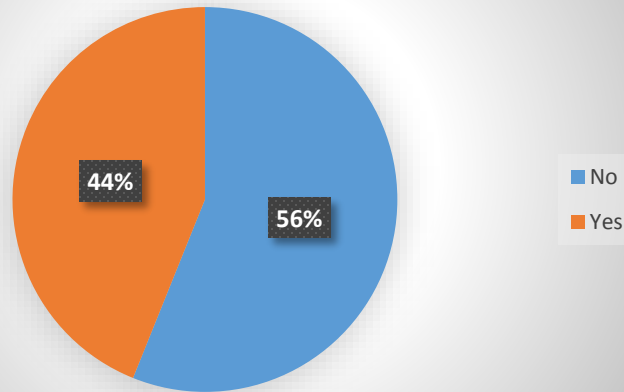
95 % provide a review of metrological topics

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

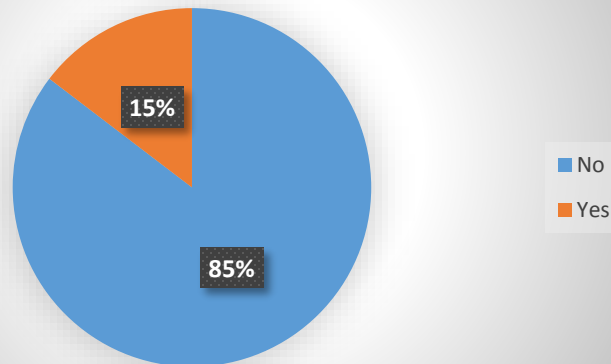
# Technical contents

- **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)**: 80 % do not treat LPU for multivariate models (8 courses do)

MCM (JCGM 101 univariate models)



MCM (JCGM 102 multivariate models)



**MCM: JCGM 101 vs. JCGM 102**

Counts			
JCGM 101	JCGM 102		Total
	No	Yes	
No	23		23
Yes	12	6	18
<b>Total</b>	<b>35</b>	<b>6</b>	<b>41</b>

6 of the 18 courses (33 %) dealing with JCGM 101, deal also with JCGM 102

**LPU (JCGM 102) vs. MCM (JCGM 102)**

Counts			
LPU (JCGM 102)	MCM (JCGM 102)		Total
	No	Yes	
No	33		33
Yes		6	6
Yes (basic)	2		2
<b>Total</b>	<b>35</b>	<b>6</b>	<b>41</b>

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

**MCM (JCGM 101) vs. validation with GUM**

Counts			
MCM (JCGM 101)	validation with GUM		Total
	No	Yes	
No	23		23
Yes	4	14	18
<b>Total</b>	<b>27</b>	<b>14</b>	<b>41</b>

14 out of 18 (78 %) courses dealing with MCM (JCGM 101) deal also with its validation with the GUM



# Technical contents by Audience

Audience vs. LPU (JCGM 102)				
Counts Audience	LPU (JCGM 102)			Total
	No	Yes	Yes (basic)	
Academia	6	2	2	10
Calib&Test	9	1		10
Legal	5			5
Legal, Calib&Test	1			1
NMI	4	2		6
NMI, Calib&Test	8	1		9
<b>Total</b>	<b>33</b>	<b>6</b>	<b>2</b>	<b>41</b>

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

Audience vs. MCM (JCGM 101)			
Counts Audience	MCM (JCGM 101)		Total
	No	Yes	
Academia	3	7	10
Calib&Test	7	3	10
Legal	5		5
Legal, Calib&Test		1	1
NMI	2	4	6
NMI, Calib&Test	6	3	9
<b>Total</b>	<b>23</b>	<b>18</b>	<b>41</b>

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

## References:

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

## Software: 32 % 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

Under consideration in the  
Software review (A1.1.3)

## ANY QUESTIONS OR COMMENTS?

# DISCUSSION

## Comments on specific aspects of the courses

The reported “Main course with a module on MU” have an audience from a specific field of measurements (e.g., electronic, temperature, mass&volume, time&frequency measurements). Also a certain number of “Main courses” and “Modules” are not actually focused only on MU evaluation, but on some application or, more generally, on Metrology. Overall, **a good fraction of courses (44 %) is reported to be designed for some specific application.** → Should we pay attention on the different characteristics that courses completely focused on MU from a general perspective should have with respect to those application-driven?

Pros.&Cons. of **pre-recorded courses**: self-paced courses allow trainees to manage their training time as they prefer, but they allow no immediate exchange between trainers and trainees. → Would it be useful to design some live discussion moment with the teacher, after the trainee has attended the pre-recorded course? On the other hand, for a live course, would it be useful to design a pre-recorded video on some general/introductory MU topics that a trainee should attend, as a basis, ahead of the live course? Is either of the solutions already applied by any of the Partners?

85 % courses provide a **review of probabilistic topics**, 95 % a **review of metrological topics.** → Large consensus on the importance of such bases. 40 courses address input standard uncertainties, 4 of them without treating input covariances. → This would need some improvement. What is the feeling about that? Which are the reasons why input covariances are not treated in those courses?

80 % courses **do not treat LPU for multivariate models** (only 8 courses do). → GAP! This implies no calculation of covariances among measurands estimated at the same time/in the same process, which is in contrast with the fact that the main target audience (46 %) are calibration and testing labs (in calibration procedures, multivariate models involving the same input quantities often arise, implying correlations between the measurands estimates even when the input quantities are uncorrelated). Matrix calculus should not frighten, thanks to the help of appropriate SW, as far as the concept of covariance is well acquired.

**Only a few (6) courses address MCM according to JCGM 102**: they are 6 of the 18 courses (33 %) dealing with JCGM 101 (a pre-requisite for JCGM 102). → GAP! It would be meaningful to increase this percentage (at a relatively low cost, the generalization of 101 is worthy of being taught). 6 of the 8 courses (75 %) in which LPU for multivariate models is addressed, deal also with the corresponding MCM. → This is quite fine.