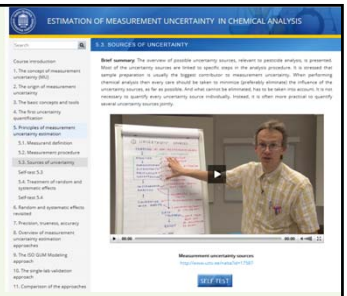


Education
Activities in Metrology in Chemistry

Ivo Leito

ivo.leito@ut.ee

20.10.2016
CroLab 2016
Vinkovci

Contents

- Jobs/careers in analytical chemistry
- Study programmes
  - **Applied Measurement Science**
  - **Excellence in Analytical Chemistry (EACH)**
- MOOCs
  - Estimation of **Measurement uncertainty** in chemical analysis
  - **Validation** of LC/MS methods
- Tutorial papers

Importance of analytical chemistry?

- Critical decisions (economical, social, medical) are based on results chemical analysis
- It has been estimated that measurements and chemical analyses make up ca **4-6% of the GDP** in developed countries
- **25% of the EU directives** involve chemical analysis

This importance is constantly increasing!

The Assessment of the Economic Role of Measurements and Testing in Modern Society. Survey directed by Geoffrey Williams, Pembroke College, Oxford, **2002**

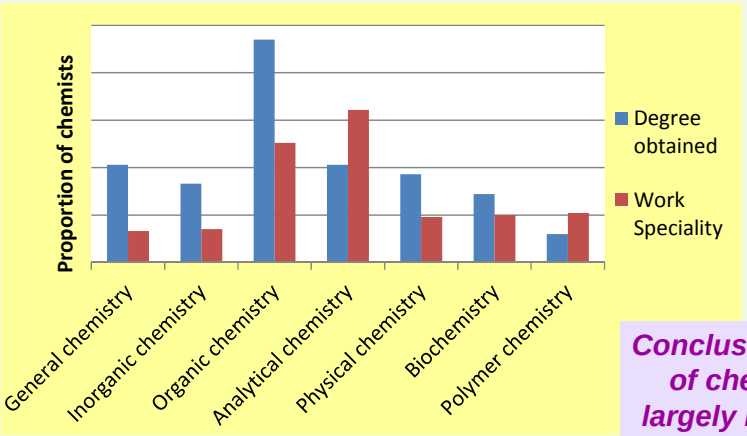
Jobs/career worldwide

*… This reveals a **larger demand** from the job market for analytical chemists **than the supply** by higher education institutions.*

R. Salzer *Anal. Bioanal. Chem.* **2015**, *407*, 639-643

R. Salzer *Chem. Eur. J.* **2015**, *21*, 9921-9935

Jobs/career worldwide



Conclusion: the jobs of chemists are largely in analytical chemistry

D. J. Hanson *Chem. Eng. News*. **2011**, *89*, 33.
ACS Employment and Salary Survey 2011

5

Applied Measurement Science

Master's Programme

www.ut.ee/ams

Programme structure

Obligatory Module (45 ECTS)

***Courses**: Measuring and Instrumentation, Measurement Data Processing, Lab of Physical Measurements, Practical Chemical Analysis Methods, Lab of Chemical Analysis Methods, Fundamentals of Metrology, Metrology in Chemistry, Seminar in Measurement Science, Quality management*

Elective Module (30 ECTS, courses can be chosen from the list)

***Courses**: Atomic Spectroscopy, Materials Characterization and Testing, Measurements in Biochemistry, Measurements and the Law, Economic Aspects of Measurements, Signal Processing, Chemometrics, Environment and Measurement, Electrochemical Measurement and Analysis Methods, Nanometrology, Quality Systems etc*

Optional Subjects
*(**6 ECTS**, any courses can be chosen university-wide)*

Practical speciality training
*(**9 ECTS**, internship placement in industry or analysis or calibration laboratories)*

Master's thesis
*(**30 ECTS**, reasearch project with a topic related to measurement science)*

www.ut.ee/ams

7

AMS Outline

- **Interdisciplinary** 3+2 master's degree programme
- **Cross-sectorial**
  - Physical measurements
  - Chemical measurements (chemical analyses)
  - Metrology
  - Quality systems
  - Economic and legal aspects of measurements
- Tuition in english

The education that students will get is of very broad applicability

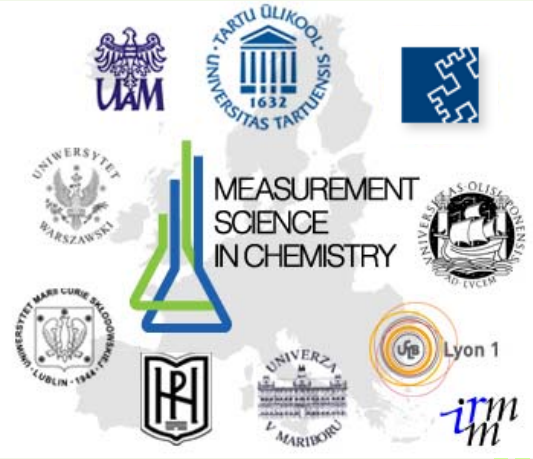
20/10/2016

www.ut.ee/ams

8

Measurement Science in Chemistry

- International consortium
- 9 countries
  - Estonia, Slovenia, Bulgaria, France, Portugal, Poland, Finland, Belgium Ireland
- 11 universities
- 9 Summer schools during 2008-2016



20/10/2016 **www.msc-euromaster.eu** 9

Excellence in Analytical Chemistry *Erasmus Mundus*

Co-funded by the Erasmus+ Programme of the European Union

Lyon 1

Åbo Akademi University

UPPSALA UNIVERSITET

Co-funded by the Erasmus+ Programme of the European Union

Excellence in Analytical Chemistry

- **Four European universities excelling in different fields:**

Fundamentals of analytical chemistry, metrology in chemistry, quality assurance, socio-economic aspects

UPPSALA UNIVERSITET

Organic and bioorganic analysis, advanced separation methods, mass spectrometry

Åbo Akademi University

Advanced analytical devices, sensors, miniaturization, electrochemistry

Lyon 1

Industrial analysis, process control and monitoring

Co-funded by the Erasmus+ Programme of the European Union

Excellence in Analytical Chemistry

- **Full-fledged contemporary analytical master degree programme** (120 ECTS)
- Tuned to the job market needs
  - Metrology topics
  - Socio-economic aspects
  - Practical placement

EACH Programme structure:

University of Tartu
Fundamentals of analytical chemistry, metrology in chemistry, quality assurance, socio-economic aspects

Year 1: Fundamentals + Placement — *60 ECTS*

Uppsala University
Organic and bioorganic analysis, advanced separation methods, mass spectrometry

University of Lyon
Industrial analysis, process control and monitoring

Åbo Akademi
Advanced analytical devices, sensors, miniaturization, electrochemistry

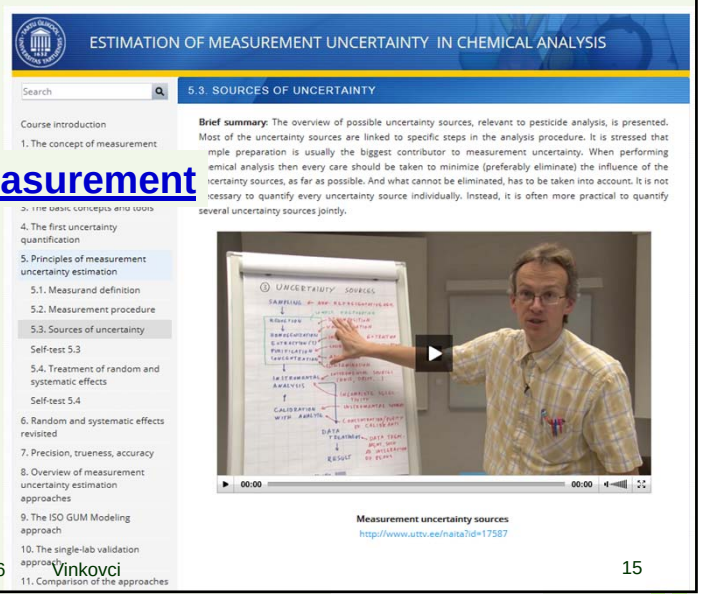
Year 2: Specialisation + Master's thesis — *60 ECTS*

Congo, Jordan, Ukraine, Croatia, Serbia, Ukraine, Estonia, Serbia, Montenegro, China, China, Nepal, Nepal, Macedonia, USA, Nigeria, China, India, Estonia (Tutor)

On this photo you can see all EACH Students who started studies in 2015

On-line course: Estimation of measurement uncertainty in chemical analysis

sisu.ut.ee/measurement



Measurement uncertainty in Chemistry

- **„Notoriously difficult“** ← **In practice: often underestimated uncertainties**
- Needs:
  - In-depth understanding of the particular chemical analysis procedure: physical-chemical pronciples, influencing factors
  - Knowledge and skills in mathematics (random quantities, distribution functions, …)
- Chemical analysis usually cannot be modeled well

Teaching measurement uncertainty

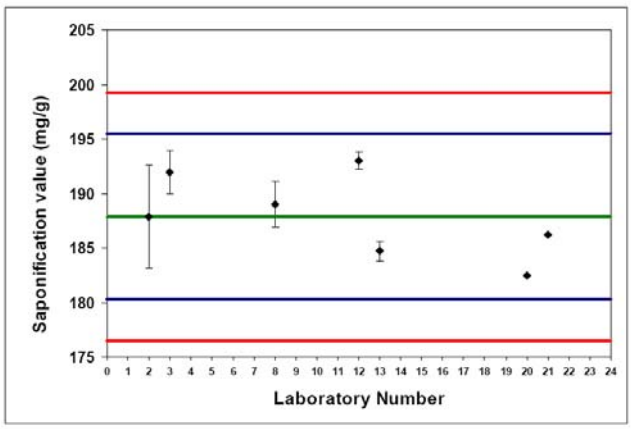
- **Very difficult**

It is usually taught at the level of basics but difficulties emerge first of all with practical applications

- Usually taught in connection with analytical chemistry
- Many guideline materials and courses
- **Most of them stop exactly at the moment when it starts getting interesting and useful**

Consequences?

Figure 6. Results of Participants with Self-declared Uncertainties and z-Score Boundaries.[a] SAPV Measurement.



[a] The consensus value found as average is denoted by the solid green line. The dotted green line denotes the median consensus value. The 2*s* boundaries are denoted by blue lines. The 3*s* boundaries are denoted by red lines.

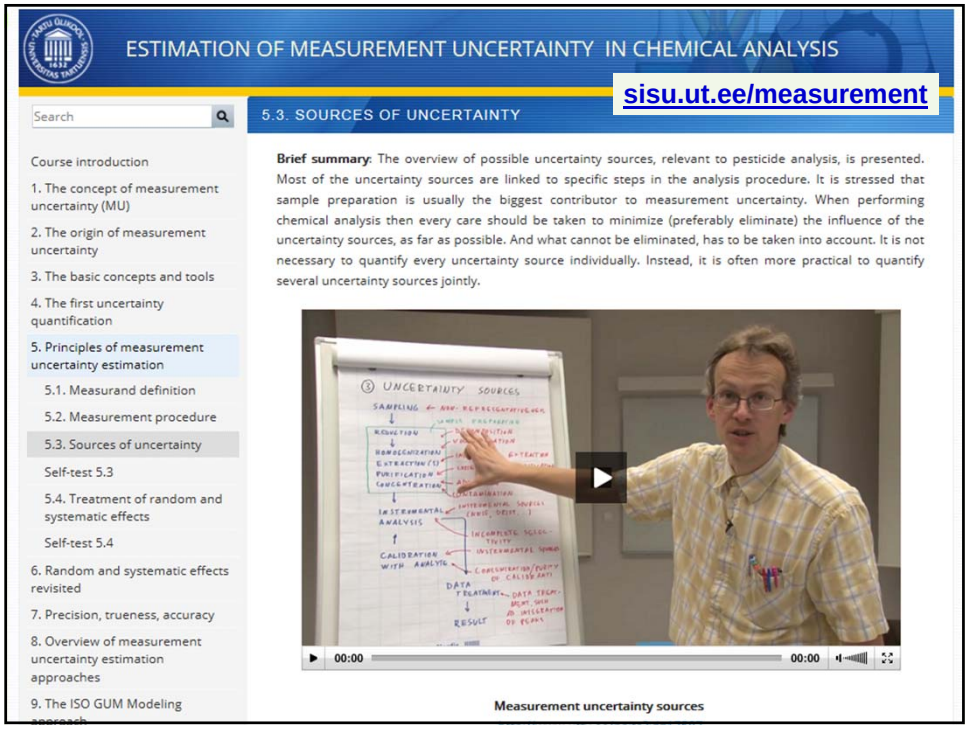
***EstOil-5 Final report*, 2009**
http://www.ut.ee/katsekoda/ILC/

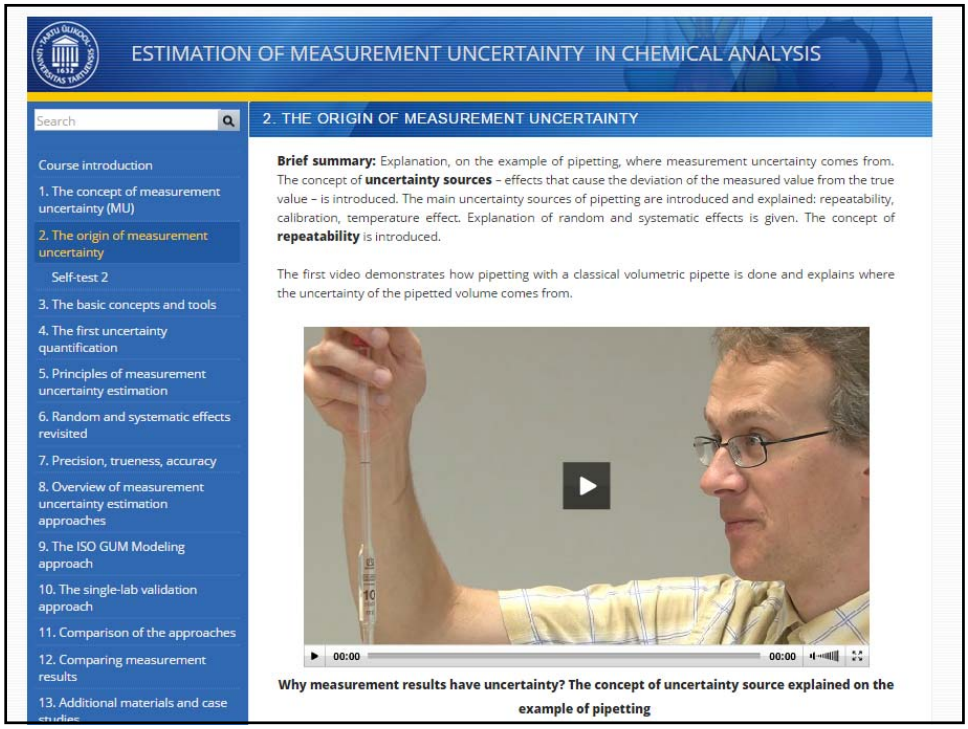
Our goal

- Web-based teaching material for
  - **Independent** learning to estimate measurement uncertainty **in real-life situations**
  - On-line **reference point** of explanations of concepts and approaches
  - **Support for auditorial teaching** of metrology in chemistry at UT, summer schools, etc
  - Offering as **MOOC**
- Required previous knowledge
  - General analytical chemistry knowledge

Course contents

- **Theoretical** basis as well as **practical** skills
- **Detailed** and **example**-based treatment
  - Modeling (ISO GUM)
  - Within-lab validation (Nordtest)
- Close to **50** short **video lectures**
  - Supplemented by textual explanations and downloadable slides and calculation files
- Numerous **tests** and **calculation exercises**
  - Understanding of main concepts
  - Calculation exercises from **real life** situations
  - **Feedback** is given

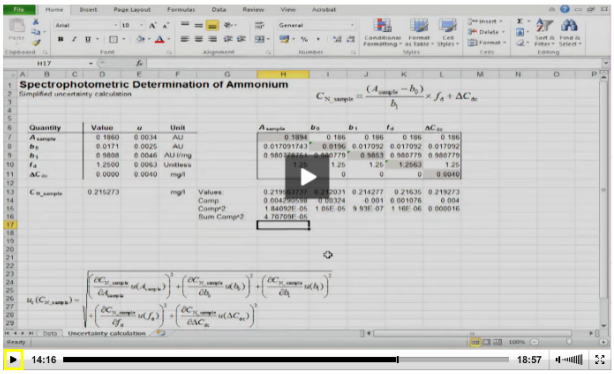

ESTIMATION OF MEASUREMENT UNCERTAINTY IN CHEMICAL ANALYSIS
sisu.ut.ee/measurement
Search
5.3. SOURCES OF UNCERTAINTY
Course introduction
1. The concept of measurement uncertainty (MU)
2. The origin of measurement uncertainty
3. The basic concepts and tools
4. The first uncertainty quantification
5. Principles of measurement uncertainty estimation
5.1. Measurand definition
5.2. Measurement procedure
5.3. Sources of uncertainty
Self-test 5.3
5.4. Treatment of random and systematic effects
Self-test 5.4
6. Random and systematic effects revisited
7. Precision, trueness, accuracy
8. Overview of measurement uncertainty estimation approaches
9. The ISO GUM Modeling approach
Brief summary: The overview of possible uncertainty sources, relevant to pesticide analysis, is presented. Most of the uncertainty sources are linked to specific steps in the analysis procedure. It is stressed that sample preparation is usually the biggest contributor to measurement uncertainty. When performing chemical analysis then every care should be taken to minimize (preferably eliminate) the influence of the uncertainty sources, as far as possible. And what cannot be eliminated, has to be taken into account. It is not necessary to quantify every uncertainty source individually. Instead, it is often more practical to quantify several uncertainty sources jointly.
00:00
00:00
Measurement uncertainty sources


ESTIMATION OF MEASUREMENT UNCERTAINTY IN CHEMICAL ANALYSIS
Search
2. THE ORIGIN OF MEASUREMENT UNCERTAINTY
Course introduction
1. The concept of measurement uncertainty (MU)
2. The origin of measurement uncertainty
Self-test 2
3. The basic concepts and tools
4. The first uncertainty quantification
5. Principles of measurement uncertainty estimation
6. Random and systematic effects revisited
7. Precision, trueness, accuracy
8. Overview of measurement uncertainty estimation approaches
9. The ISO GUM Modeling approach
10. The single-lab validation approach
11. Comparison of the approaches
12. Comparing measurement results
13. Additional materials and case studies
Brief summary: Explanation, on the example of pipetting, where measurement uncertainty comes from. The concept of uncertainty sources – effects that cause the deviation of the measured value from the true value – is introduced. The main uncertainty sources of pipetting are introduced and explained: repeatability, calibration, temperature effect. Explanation of random and systematic effects is given. The concept of repeatability is introduced.
The first video demonstrates how pipetting with a classical volumetric pipette is done and explains where the uncertainty of the pipetted volume comes from.
00:00
00:00
Why measurement results have uncertainty? The concept of uncertainty source explained on the example of pipetting

9. The ISO GUM Modeling approach
9.1. Step 1– Measurand definition
9.2. Step 2 – Model equation
9.3. Step 3 – Uncertainty sources
9.4. Step 4 – Values of the input quantities
9.5. Step 5 – Standard uncertainties of the input quantities
Self-test 9.5
9.6. Step 6 – Value of the output quantity
9.7. Step 7 – Combined standard uncertainty
9.8. Step 8 – Expanded uncertainty
9.9. Step 9 – Looking at the obtained uncertainty
Self-test 9 A
Self-test 9 B
10. The single-lab validation approach
11. Comparison of the approaches
12. Comparing measurement results

Calculating the combined standard uncertainty

http://www.uttv.ee/naita?id=17643



Numerical calculation of the uncertainty components: the Kragten method

http://www.uttv.ee/naita?id=17721

The initial XLS file (i.e. containing only the data but not the calculations) used in this example and the XLS file containing the also the combined standard uncertainty (and expanded uncertainty) calculation according to the Kragten's approach can be downloaded from here:

uncertainty_of_photometric_nh4_determination_kragten_initial.xls	49 KB
uncertainty_of_photometric_nh4_determination_kragten_solved.xls	52 KB

ESTIMATION OF MEASUREMENT UNCERTAINTY IN CHEMICAL ANALYSIS

Search
Course introduction
1. The concept of measurement uncertainty (MU)
2. The origin of measurement uncertainty
3. The basic concepts and tools
4. The first uncertainty quantification
5. Principles of measurement uncertainty estimation
6. Random and systematic effects revisited
7. Precision, trueness, accuracy
8. Overview of measurement uncertainty estimation approaches
9. The ISO GUM Modeling approach
10. The single-lab validation approach
11. Comparison of the approaches
12. Comparing measurement results
13. Additional materials and case studies
14. Tests and Exercises

14. TESTS AND EXERCISES

This section contains a compilation of all the tests and exercises of this course.

- The concept of measurement uncertainty (MU) - Self-test 1
- The origin of measurement uncertainty - Self-test 2
- The Normal distribution - Self-test 3.1
- Mean, standard deviation and standard uncertainty - Self-test 3.2
- Standard deviation of the mean - Self-test 3.4
- Rectangular and triangular distribution - Self-test 3.5
- The Student distribution - Self-test 3.6
- Quantifying uncertainty components - Self-test 4.1
- Calculating the combined standard uncertainty - Self-test 4.2
- Looking at the obtained uncertainty - Self-test 4.3
- Expanded uncertainty - Self-test 4.4
- Presenting measurement results - Self-test 4.5
- Sources of uncertainty - Self-test 5.3
- Treatment of random and systematic effects - Self-test 5.4
- Random and systematic effects revisited - Self-test 6
- Precision, trueness, accuracy - Self-test 7
- Overview of measurement uncertainty estimation approaches - Self-test 8
- Standard uncertainties of the input quantities - Self-test 9.5
- The ISO GUM Modeling approach - Self-test 9 A and Self-test 9 B
- Uncertainty component accounting for random effects - Self-test 10.2
- Uncertainty component accounting for systematic effects - Self-test 10.3
- Determination of acrylamide in snacks by LC-MS - Self-test 10.5 A and Self-test 10.5 B
- Comparison of the approaches - Self-test 11

sisu.ut.ee/measurement

1. The concept of measurement uncertainty (MU)
2. The origin of measurement uncertainty
3. The basic concepts and tools
4. The first uncertainty quantification
5. Principles of measurement uncertainty estimation
6. Random and systematic effects revisited
7. Precision, trueness, accuracy
8. Overview of measurement uncertainty estimation approaches
9. The ISO GUM Modeling approach
10. The single-lab validation approach
10.1. Principles
10.2. Uncertainty component accounting for random effects
Self-test 10.2
10.3. Uncertainty component accounting for systematic effects
Self-test 10.3
10.4. Roadmap
10.5. Determination of

A laboratory wants to estimate the measurement uncertainty of protein content determination in different foods. For this protein content in a control sample of smoked sausage was determined repeatedly during a time period of almost one year. Every day when this smoked sausage was analysed only one parallel measurement was made. The following results were obtained:

Week	Result
	g/100g
3	18.1
5	20.5
11	18.3
14	19.1
15	19.3
27	20.2
34	19.7
41	19.5
42	18.6
48	20.1

In addition the laboratory analysed two certified reference materials: Ham with protein content (19.6 ± 0.6) g/100g (k=2, norm) and cheese with protein content (26.3 ± 0.7) g/100g (k=2, norm). The laboratory has carried out four bias determinations with the following results (each found value is found as a mean from a number of parallel measurements):

Reference value (g/100g)	Found value (g/100g)
26.3	26.9
26.3	27.2
19.6	20.1
19.6	20.4

Please calculate the combined standard uncertainty of the protein determination procedure (please give 1 or 2 decimals). Absolute uncertainties can be used in this case.

definition
9.2. Step 2 – Model equation
9.3. Step 3 – Uncertainty sources
9.4. Step 4 – Values of the input quantities
9.5. Step 5 – Standard uncertainties of the input quantities
Self-test 9.5
9.6. Step 6 – Value of the output quantity
9.7. Step 7 – Combined standard uncertainty
9.8. Step 8 – Expanded uncertainty
9.9. Step 9 – Looking at the obtained uncertainty
Self-test 9 A
Self-test 9 B
10. The single-lab validation approach
11. Comparison of the approaches
12. Comparing measurement results
13. Additional materials and case studies
14. Tests and Exercises
Please comment!

Response:

This standard uncertainty takes into account the repeatability of the pipetting and titration steps of the procedure.

Feedback:

Since sample preparation was performed only once it is not included in the repeatability. The remaining steps are included.

If the indicator is suboptimal and a systematic over-titration occurs as a result then this standard deviation does not take it into account.

Feedback:

Such overtitration is a systematic effect (both within day and in the long term) and it cannot be accounted for by repeatability (which takes into account only effects that are random within day).

If the organic bases that cause basicity are sensitive compounds and partially decompose during sample preparation, preparation of solution or during titration then this standard uncertainty takes this decomposition into account.

Feedback:

Decomposition always involves a systematic effect. This effect cannot be taken into account by repeatability standard deviation. Decomposition can (and usually does) in addition also have a random component – for different replicate titrations the amount of decomposed analyte is different. This effect is taken into account by repeatability. So, if the compounds are unstable then one usually sees that repeatability standard deviation gets higher. However, the true effect is still bigger. So if one expects that the standard deviation fully includes the uncertainty due to analyte instability then the uncertainty will be underestimated.

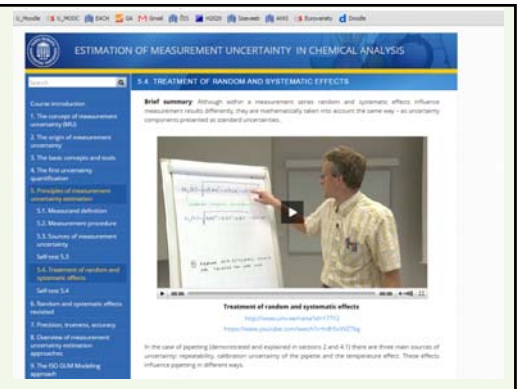
This standard uncertainty takes into account the overall repeatability of all steps of the procedure (sample preparation, pipetting, titration).

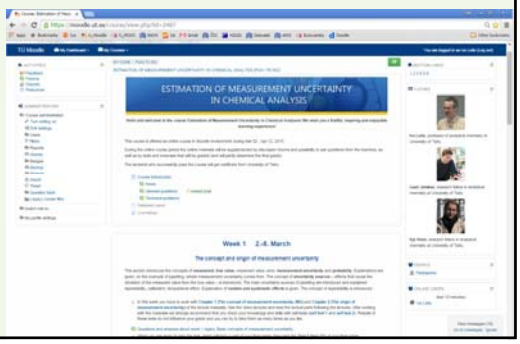
Feedback:

Since sample preparation was performed only once it is not included in the repeatability. The remaining steps are included.

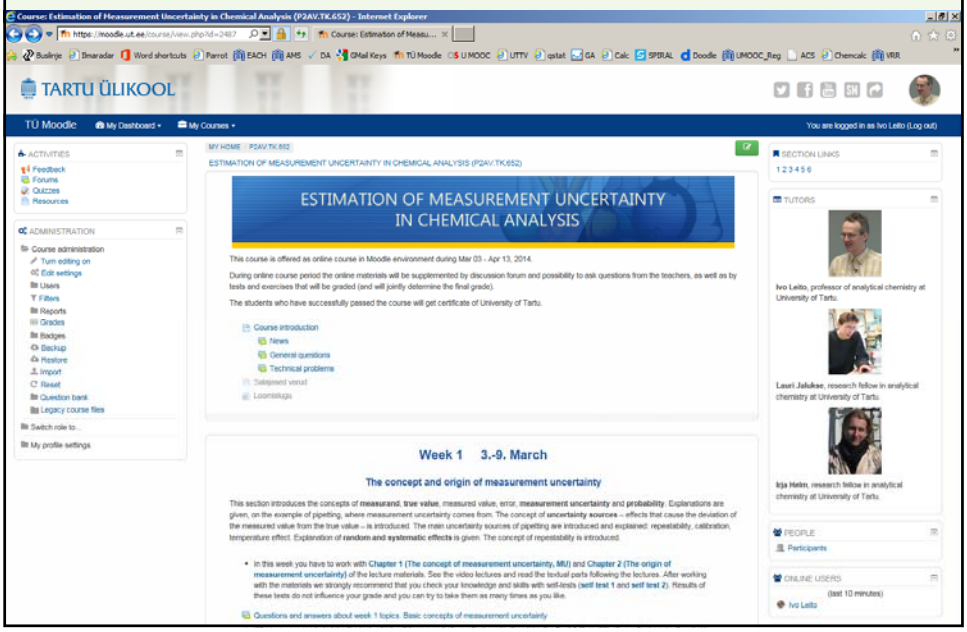
Platforms

- Course contents: sisu.ut.ee
- Admin, forums, knowledge evaluation (graded tests): moodle.ut.ee





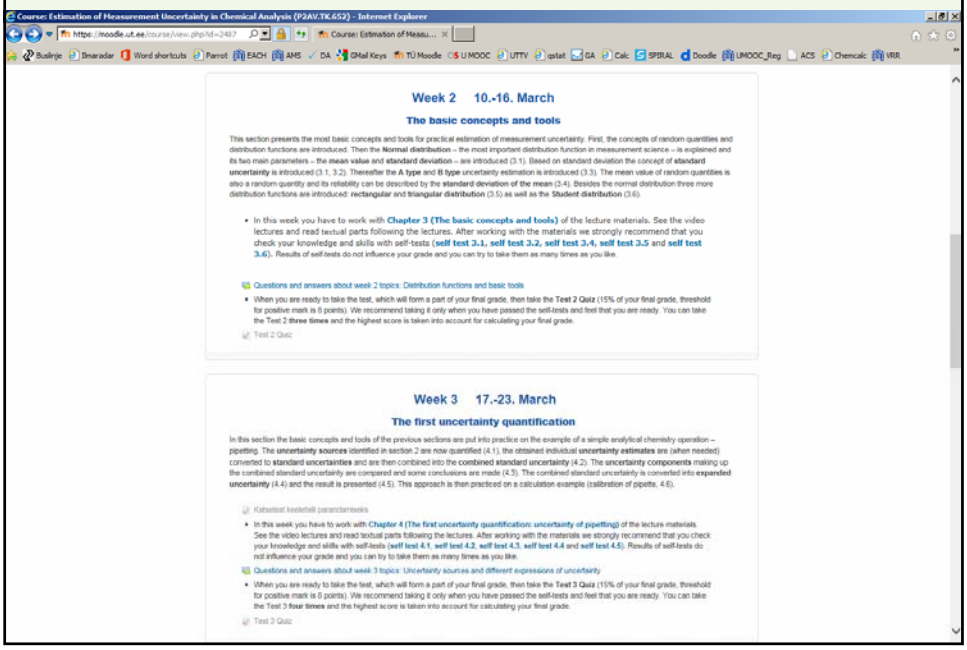
MOOC: UT Moodle Environment



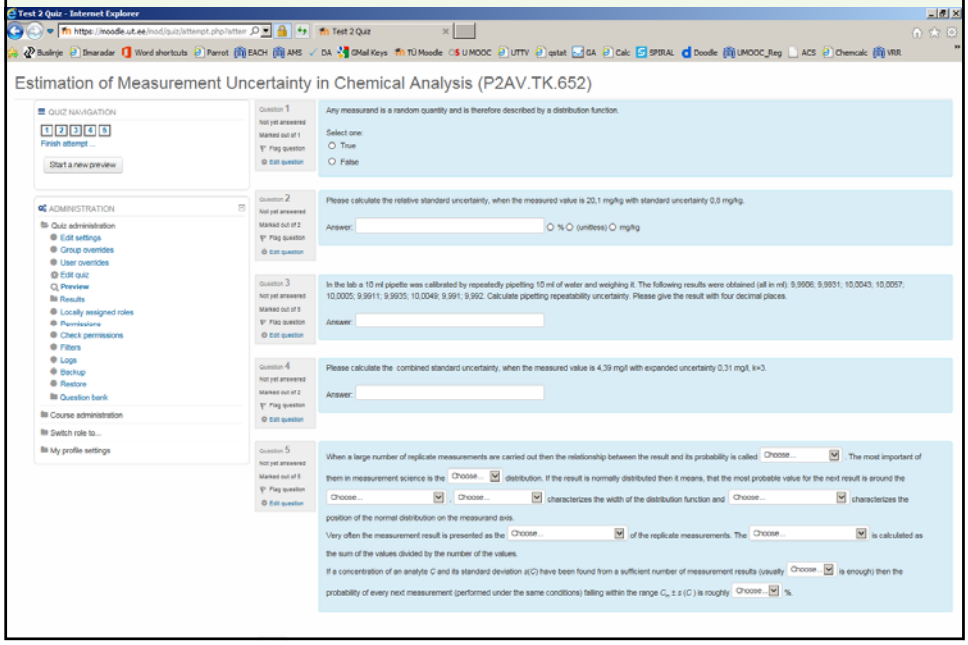
Divided into 6 weeks

1. The **concept** and **origin** of measurement uncertainty
2. The basic **concepts** and **tools**
3. The **first uncertainty quantification**
   - On the example of pipetting
4. The **principles** of measurement uncertainty estimation (random and systematic effects and definitions for precision, trueness, accuracy)
5. Overview of the measurement uncertainty estimation **approaches**. The ISO GUM **modeling approach**
   - On the example of photometric determination of NH_4^+
6. The single lab **validation approach**. Comparison of different approaches. Comparing measurement results.
   - On the example of LC-MS determination of acrylamide

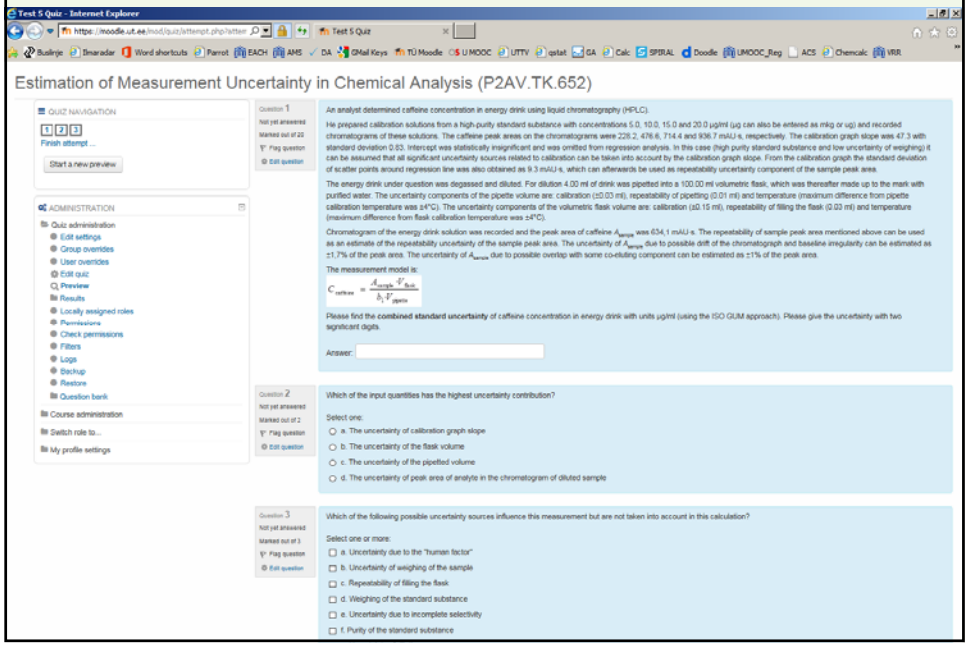
Weeks in Moodle



„Easy“ Test

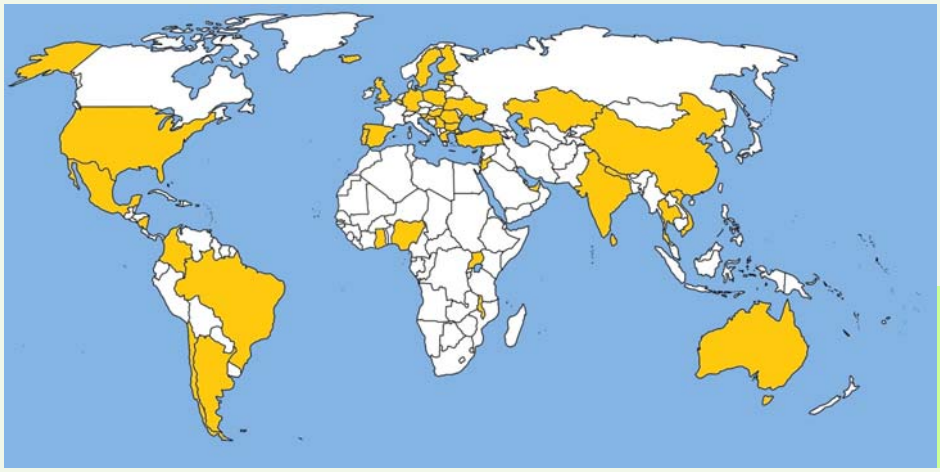


„Difficult“ Test



MOOC: Spring 2014 edition

270 registered participants from 40 countries!

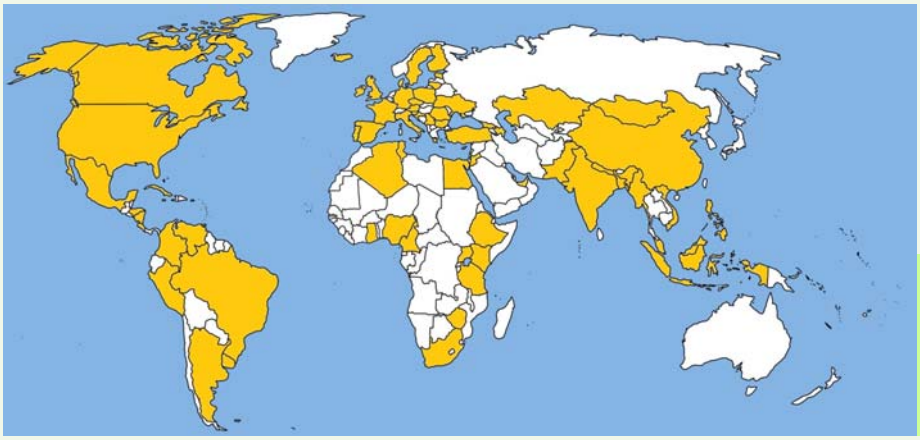


Overall completion rate: 52%

Completion rate of those who started: 67%

MOOC: Spring 2015 edition

489 registered participants from 70 countries

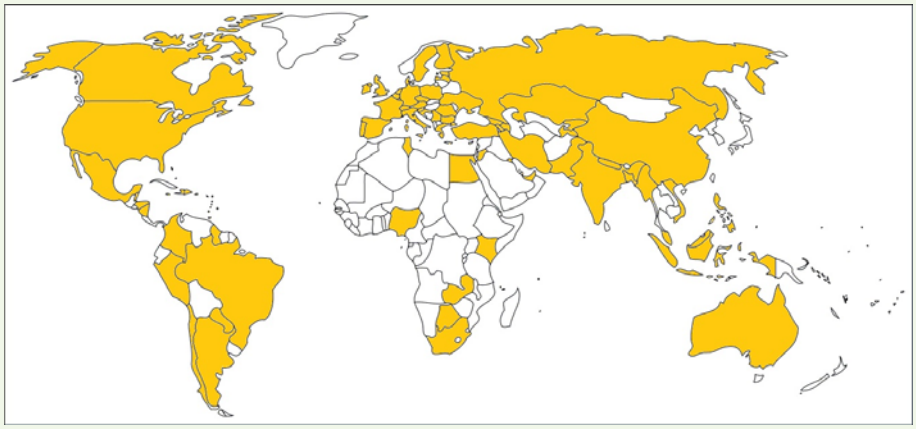


Overall completion rate: 34%

Completion rate of those who started: 60%

MOOC: Spring 2016 edition

757 registered participants from 85 countries
Around 600 forum posts



Overall completion rate: 40%
Completion rate of those who started: 67%

MOOCs vs „traditional“ teaching

I. Leito, I. Helm, L. Jalukse
Anal Bioanal Chem, **2015**, *407*,1277–1281

Aspect	Conventional university course	Practitioner training (short) course	MOOC
Interaction between students and teachers	Direct	Direct	Remote
Possibility to deliver the course simultaneously to many participants	Low	Low	High
Level of self-discipline needed from participants	Average	Average	High
Time constraints, time to “digest” the knowledge	Not a problem	Serious time constraints	Not a problem
Possibility of independent homework	Possible	Usually impossible	Possible
Possibility of hands-on problem-solving	Possible	Possible (within the time constraints)	Possible
Possibility of teamwork	Possible	Possible (within the time constraints)	Not easy
Possibility of experimental work	Easy	Possible, but not easy	Not possible
Possibility of working with participants of uneven level or preparation	Difficult but doable	Difficult	Possible
Possibilities of meaningful assessment of obtained knowledge	Wide possibilities	Difficult	Possible
Danger of cheating during knowledge assessment	Can be made low	Can be made low	Can be high
Costs of setting up the course[a]	Medium	Medium	Medium
Costs of running the course[a]	High	High	Low
Travel and accommodation costs	Can be high	Can be high	None

„Usage modes“

Estimation of Measurement Uncertainty in Chemical analysis
sisu.ut.ee/measurement

On-line course for independent learning
available any time anywhere

On-line reference point
of terminology, explanations and self-testing possibilities

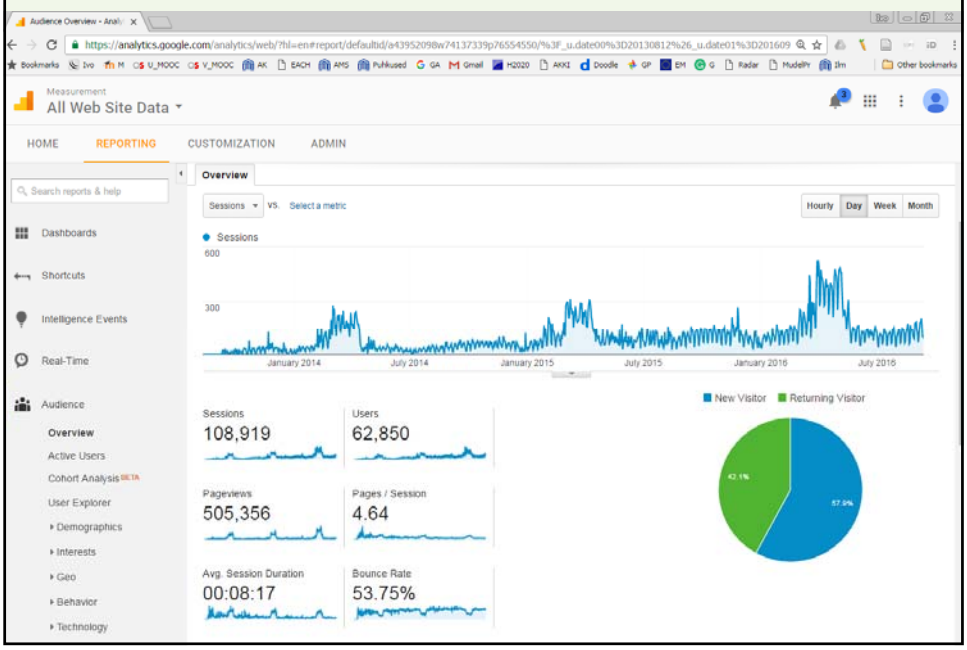
Running as MOOC
with registered participation, on-line counseling, graded tests and certificate

Course material
for running training courses e.g. by labs

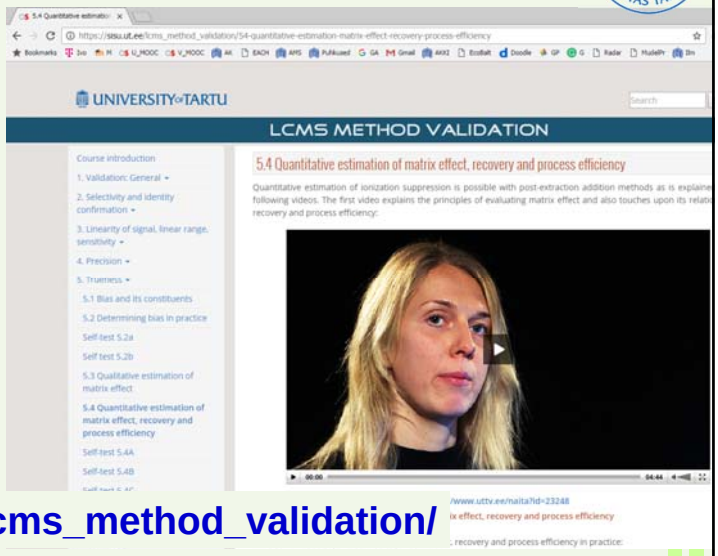
Support to university teaching
Students can be directed here e.g. for self-testing

I. Leito, I. Helm, L. Jalukse.
Anal Bioanal Chem, **2015**, *407*, 1277–1281

Visiting statistics



On-line course: LC/MS Method Validation



sisu.ut.ee/lcms_method_validation/

LC/MS Validation course

- Validation: General
- Selectivity, Identity
  - Incl specifics of LC/MS
- Linearity, linear range, sensitivity
- Precision, Trueness, Accuracy
  - Including matrix effects
- Stability
- LoD, LoQ
  - Including specifics of LC/MS
- Ruggedness, Robustness

Course contents

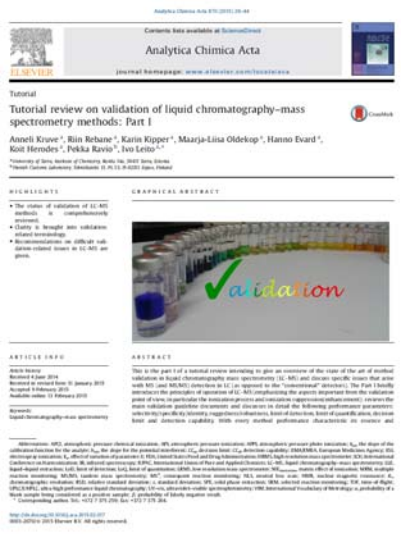
- **Theoretical** basis as well as **practical** skills
- **Detailed** and **example**-based treatment
- More than **50** short **video lectures** by **6 teachers**
  - Excel videos demonstrating calculations
- Numerous **tests** and **calculation exercises**
  - Understanding of main concepts
  - Calculation exercises from **real life** situations
  - **Feedback** is given
- **Discussion dialogues**

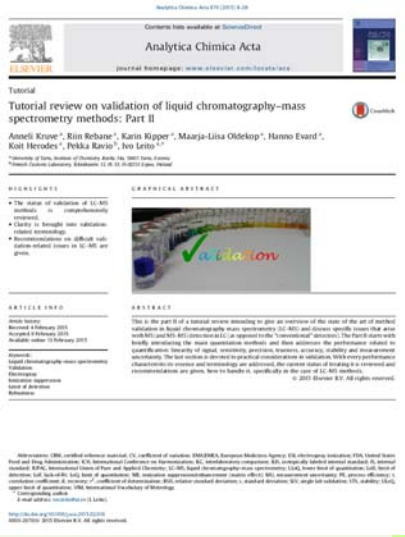
The first edition will launch soon!

LC/MS Validation MOOC – Firste dition: Winter 2016-2017
Registration will open in the beginning of Nov 2016

sisu.ut.ee/lcms_method_validation/

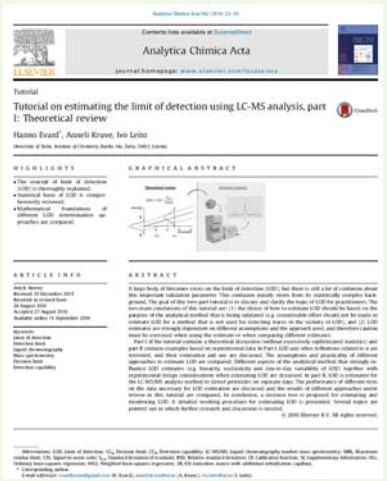
Tutorial review on LC/MS validation

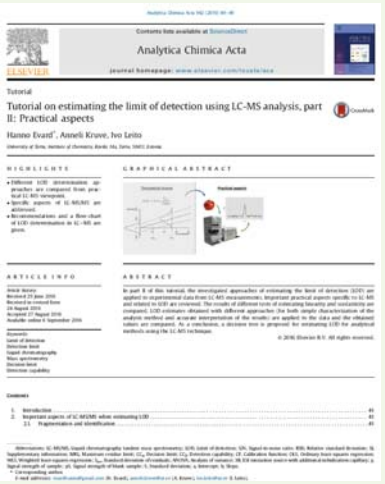




http://tera.chem.ut.ee/~ivo/Temp/CROLAB_2016/

Tutorial review on estimatingLoD (on the example of LC/MS)





http://tera.chem.ut.ee/~ivo/Temp/CROLAB_2016/

Many thanks to the team!

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Thank you for your attention!

Uncertainty MOOC – Fourth edition: Spring 2017
Registration will open in the beginning of 2017

sisu.ut.ee/measurement

LC/MS Validation MOOC – Firste dition: Winter 2016-2017
Registration will open in the beginning of Nov 2016

sisu.ut.ee/lcms_method_validation/

Tutorial papers:

http://tera.chem.ut.ee/~ivo/Temp/CROLAB_2016/