Job Description

Job title University Unit Course Content Course Creator

Reports to MSA Sub-committee - University Unit Course Content
Direct reports Anne Evans

Key relationships
internal: MSA sub-committee
external: Professor Melanie Ooi, Walter Giardini

Role purpose
The University of Waikato has agreed to run a new Measurement Unit as part of their Year 4 Engineering programme. The purpose of this role is to create the course content for this unit.

Key responsibilities
The successful applicant will be required to create the course material for a Measurement & Instrument Unit. See Draft outline of course attached.

The role includes the preparation of 20-30 editable PowerPoint slides for each of 12 lectures - in most cases, a surplus will be required in order to cover all the material and give some flexibility in emphasis for the person who delivers the lecture, and to ensure that all the material is covered.

Instead of including lecturer's notes in the PowerPoint slides, a separate word document for each lecture shall give an explanation for each slide, plus examples, and exercises. In the future as other people use the slides, they will be able to add to these notes. Examples of measurements will be included in each lecture.

Some examples of Assignment questions, tutorial topics, Lab topics and Examination questions will also be created.

This course material will be relevant, current and contain meaningful examples.
It is aimed at all engineering under graduates as they will deal with instrumentation, sensors and measurements on a daily basis.
It will be helpful to people who are in the field of calibration and testing and it will teach engineers and scientists how to take measurements, understand measurement uncertainty and make sense of the international system of units.

All engineers and scientists will perform experiments and/or use measured data in their study and work. The knowledge obtained from the content created for this course will give students an understanding of the quality of the measurements being used and if their data is fit for purpose.

Deliverables/outcomes

The unit content is required for Semester One 2022. The course material must be completed prior to February 14th 2022.
Monthly updates of lecture PowerPoint slides and notes shall be submitted to the 'Course Content Sub-committee' for review.

Relationship management
• develop and maintain collaborative relationships with the sub-committee and the University
• establish and maintain active and constructive relationships with other interested parties

Qualifications and Experience

The successful candidate will be well versed in conveying best measurement practice.
The successful candidate:

- has taught / delivered Metrology training for a minimum of 10 years
- has been / is currently employed in the field of Metrology
- has authored papers associated with Metrology
- has experience with the workings of academia

Current membership of MSA is desirable.

Health and safety

The course creator will work as a contractor to MSA and shall ensure they are informed and trained in safe practices and procedures in their specific areas of work.

Applications

Applications close on 4th October 2021.
Applicants shall be remunerated for this work and shall submit an email quote and all relevant supporting documentation to the MSA sub-committee prior to 4th October 2021.
Please email applications to anne@teltherm.co.nz

Draft Measurement Course Content

	Measurement
	The Nature of Measurement
Lesson 1	What is a measurement? • Examples of measurements: temperature, voltage, shoe size, octane rating, chemical names, crystal structures, bus routes, species, colour, latitude and longitude, permeability, resistivity, transmittance and reflectance, surface roughness, particle counts, fugacity, humidity, gauge pressure, soil strength, … • These are all symbolic representations that help us to make decisions: Air conditioning should be off, the battery is flat, that's not my size, this is the correct fuel for my car, this is the right fertiliser for my lawn, … **Definition:** measurement is the symbolic representation of any object, state, attribute, or event, to aid in the making of a decision. What makes a good measurement? Consider the example of a fishing contest. Discuss and introduce the various problems that arise, leading to • Need to identify and control influence factors to avoid measurement error, note the possibility of poor decisions because of measurement error, and need for uncertainty assessment to manage the costs and risks associated with measurement error. • Need for agreement on measurement scales, leading to the concept of traceability, the need for calibration, and physical standards of measurement. • Need for agreement on definition of the measurand (what do we mean by the length of the fish and how should it be measured), hence consensus on procedures, and documentary standards. • Need for competence of measuring staff, training and accreditation. • Need for approved measuring systems, legal metrology. Course outline… what will be covered in the next 11 lectures. Examples: Long list of different measurements, as above Exercises: to be determined – but perhaps… • Identify 10 different measurements that you make in your daily life. • What decisions do the measurements influence? • What happens if the decision is incorrect? • Who else is involved in the measurement?
Lesson 2	Different types of measurements: Stevens' measurement scales – definitions based on permissible mathematical operations. • Nominal scales – a renaming or labelling, so that equivalence of attributes can be determined e.g., the elements, books, bus routes, species, DNA codons, amino acids, chemicals…

	• Ordinal scales – can establish order – hotel or restaurant ratings, metal hardness, octane ratings, historic temperature scales, Moh hardness, • Interval scales – differences are meaningful – time of day, date, year, Celsius temperature, longitude and latitude, altitude, position, gauge pressure… • Rational scales – ratios are meaningful – all the usual SI measurements, length, mass, voltage, current, pressure, momentum, energy, … Also… • Counting – the unit of measurement is self-evident, apples, oranges, cows, busses, children etc, wavelengths, • Dimensionless (independent of unit definitions) – ratios such as transmittance and reflectance, relative humidity, engineering correlations (Reynolds number, Nusselt number, etc) What mathematical operations can be carried out for each scale type? What are the consequences for statistical analysis? e.g., average may be {mode, median, mean, geometric mean} depending on scale type. How many definitions are required to define each type of scale? What are the consequences for the traceability of measurements? Exercise: Classify the 10 measurements you identified earlier, how are the measurement scales defined?
Lesson 3	Different types of measurement: Representational measurements • For representational measurements there exists a model with variables *representing* the various measured quantities and their inter-relationships, examples: $V = IR$, $F = ma$, $h = gt^2/2$ etc. • Measurands are defined by physical concept and a model, e.g., all SI quantities, length, mass, temperature, voltage, current, etc. • Cauchy's relation tests the measurements for linearity: does Meas(A) + Meas(B) = Meas (A+B)? Then Meas(*r*.A) – *r*.Meas(A) => this means rational measurement scales are possible: Meas(*r*.A) = *r*.Meas (A) and the measurements are *quantitative*. • Distinguish intensive and extensive quantities (note existence of Conjoint Measurement as corresponding test for intensive quantities). • There is a one-to-one correspondence between the states of the model and the states of the measured system – which enables us to make predictions about the behaviour and interactions of the system. • Measurements are often fitted values for parameters in the model – e.g., amplitude, frequency, and phase of a sinewave. • Take care to distinguish model vs reality – if the model is not correct – measurements may be biased or not meaningful – e.g., model with a fixed frequency may not be useful for describing a system where the frequency is changing. • True value is a useful concept, hence also measurement error is also meaningful. • Dimensional analysis, base units of the SI, checking units in equations.

	• Note existence of other types of representational measurements e/g/, Group theory – quantum measurements, nominal scales, chemical nomenclature. • Uncertainty analysis covered by standardised methods to be covered shortly. Exercises:
Lesson 4	Different types of measurement: Operational measurements. • Operational Measurements are those defined by procedures, many examples lead to ordinal or nominal scales (octane, Beaufort wind scale, BMI, historical temperature scales, …) • There is usually no model possible – system is too complicated to model, or sometimes there is a simple but unsatisfactory model, often, many different systems can give the same measurement results (many-to-one mapping) => predictions based on measurements may be unreliable or ambiguous. • Note the importance of consensus, documentary standards, importance of avoiding intelligent interferences. • Distinguishing features of operational and representational measurements. • Examples Material properties: octane (M and R), metal hardness (> dozen different definitions), soil strength, distillation range, viscosity. • Examples Figures of merit: BMI, bandwidth, distortion, colour, colour rendering index, percentage distortion. • Examples Resolution dependent: rms voltage and current, particle counts, surface roughness, rate of change of voltage, number of peaks or zeros. • Some measurements mix representational and operational characteristics, e.g., viscosity, thermal resistance, permeability, thermal conductance, rms voltage, current, ITS-90, and use SI units so may not be obviously operational. • Uncertainty is the reproducibility - no true value, no measurement error. Any measurement made in compliance with the procedure is legitimate. **Definition:** Reproducibility is the variation in measurement results obtained in replicate measurements on the same or similar objects with different conditions of measurement including different locations, different operators, different measuring systems, and different measurement conditions. **Definition:** Repeatability is the variation in measurement results obtained in replicate measurements on the same or similar objects with the same conditions of measurement including location, operator, measuring system, and measurement conditions
	Uncertainty
Lesson 5	Experiment/demonstration: Spreadsheet simulation of a measurement with a fixed dc value plus noise. • Demonstrate noise with repeated measurement, calculate standard deviation. • Demonstrate reduced variation with averaged measurements, measure the mean and standard deviation for both, • Demonstrate that variance of the mean falls as $1/N$.

	Definition: uncertainty is a parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand. (We use the standard deviation as the basis for all calculations of measurement uncertainty.) Experiment/demonstration: Measurement with both random and systematic errors • Demonstrate systematic error becomes evident only with averaging. • Different random errors occur on every repeat of a measurement, systematic errors are the same on each repeated measurement. **Definition:** Measurement error is the difference between the measured value and the true value. In most cases the true value and the error cannot be known exactly. **Definition:** Random error arises from unpredictable or stochastic temporal and spatial variations of influence quantities giving rise to variations in repeated observations of the measurand. **Definition:** Systematic error arises from an effect of an influence quantity on a measurement result that cannot be reduced by averaging, equal to the average error. Note, measurement error occurs in each measurement. Uncertainty characterises the dispersion of measurements caused by the errors. Exercises: • Calculate means and standard deviations of data.
Lesson 6	Type A uncertainties (experimental): based on repeated measurements and sampling, • Not specific to random or systematic errors • **Definition: Standard uncertainty** as measure of dispersion of results from the measurement system – descriptive statistic. Used as a parameter in statistical models to describe the measurement process. • **Definition: Expanded uncertainty** as measure of range of values attributable to the measurand – inferential statistic. Used to characterise the measured value. • Confidence intervals and their meaning, decision making – many types of decisions {describe parameter value, compliance with standard, tolerance bands, hypothesis testing} - all equivalent to determining a confidence interval.

	• Degrees of freedom, what are they, how many significant figures to report? • Spreadsheet tools Exercises:
Lesson 7	Type B uncertainties (theoretical): based on mathematical models, assumptions, data drawn from other experiments. • Not specific to systematic or random errors • Examples: examples of random errors assessed by theoretical means: Quantisation error, Johnson noise, shot noise • Examples: examples of systematic errors assessed using theory and other data: freezing points and air pressure, calibration bath non-uniformity, ambient temperature, … • Use of effective degrees of freedom to account for weak assessments. Examples: • Quantisation error (round off error) leading to uniform or rectangular distribution • Two identically distributed quantisation errors (e.g., in measurements of difference using the same rule) leads to triangular distribution • Squares of normal random errors leads to chi-square distribution. • Random samples of sinewave lead to arcsine distribution Exercises:
Lesson 8	Total uncertainty • Mathematical models, propagating and combining uncertainties, • Effective degrees of freedom, Welch-Satterthwaite formula, • Sums of random variables, convolution, moments of distributions and sums of central moments (n = 1, 2, 3) • Central limit theorem (sums of distributions tend to normal distribution) • Tools: numerical approaches, Monte Carlo, Spreadsheets, GUM-tree • Reporting, how many significant figures, improving measurements. Exercises: Numerous examples and worked exercises possible here.
Lesson 9	Least-squares fits, regression and interpolation • Used for determining calibration curves and determination of parameter values in models. • Interpolation and propagation of uncertainty for interpolation

	• Ordinary least squares fits (linear regression) • Weighted least-squares. • Generalised least squares (overview only) • Non-linear least squares (overview only), multiple solutions, need for starting conditions, different algorithms (iterative) • Degrees of freedom, chi-squared test, covariances • Least squares tools, including spreadsheets. Exercises/examples: • Least squares fit of a constant (leads to the mean of data) • Weighted least-squares of a constant leads to weighted mean • Linear interpolation and uncertainty propagation • Splines and uncertainty propagation • Quadratic interpolation and uncertainty • Quadratic fit and uncertainty • Uncertainty vs number of measurements • Uncertainty with extrapolation • Interpolation error
	Measurement Infrastructure
Lesson 10	If you are dealing with measurements in a professional capacity, you need to recognise, know the functions of, and how to interact with different elements of the measurement infrastructure: National quality infrastructure part 1 • Primary Physical Standards - International: Metre Convention, CGPM, CIPM, BIPM (place and organisation), The International System of Units, unit definitions, MRA, CMC database. • Primary Physical Standards - National: Measurement Standards Laboratory of New Zealand, National Measurement Institutes in other countries, URL, location, services, and expertise. • Documentary standards - International: ISO, IEC, …standardising organisations, covering procedures, instruments, materials, testing (for environment, health safety, trade) • Documentary Standards- National: Standards New Zealand, URL, location, services and expertise Exercises:
Lesson 11	National quality infrastructure part 2

	• Accreditation – International: ILAC, 3rd part audit of technical competence to ISO17025, • Accreditation – National: International Accreditation New Zealand (IANZ), URL, location, services and expertise, online directory of test and cal labs • Also mention certification and inspection – approval of objects (lifts, boilers, measuring instruments, electrical safety, health, medical testing, etc), including management tools (ISO 9000), JAS-ANZ. Certification applies to objects, accreditation applies to people. • Legal metrology – International: OIML (calibrate traders measures, shop scales, petrol pumps, etc,) calibration and pattern approval – approve measuring instruments for trade. • Legal metrology – National: Trading Standards, URL, location, services, and expertise, … Exercises:
Lesson 12	What makes a high-quality measurement? (Check the topic listed in lesson 1) Elements are covered by ISO 17025: *General requirements for the competence of testing and calibration laboratories*. • Staff: Appropriately trained and qualified staff. • Facilities and Environment: Laboratories with appropriate environmental controls, • Equipment: including appropriately calibrated instruments, reference standards, and reference materials required to validate all measurements. • Technical procedures: contract review, client requirements, method selection and validation, sample and equipment handling • Traceability: = ability to demonstrate accuracy of measurements with appropriate uncertainty. To SI for representational measurements, to SI and appropriate documentary standards for operational measurements. • Uncertainty evaluation: identify all significant influence factors, their effects, with appropriate analysis. • Validation of results and procedures • Proficiency testing: comparisons with other laboratories • Reporting: Unique ID for certificate, date, equipment under test, clients, testing lab, procedure, conditions, results, conclusions, uncertainty., authors. These are all covered by ISO17025 which also requires these points to be thoroughly documented. Further detail: • Importance of purpose – what decisions are being made? • Is the measurement fit for purpose? • Interpreting calibration reports • Identifying influence variables

	• Technical procedures and controlled documents: ideally include procedure, validation evidence, uncertainty analysis. • Where to go for help: texts, training courses, WWW, manufacturers specifications and application notes, experts. Exercises Assignment – concluding example, write a technical procedure including measurement model and uncertainty analysis