KNOWLEDGE AND SKILL REQUIREMENTS IN REGULATORY TOXICOLOGY IN THE UK AND GAPS IN EDUCATION PROVISION

Phase 1 Education and skills gap project

Report to advisory group 2022

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SUMMARY

This report provides

- A consensus on the knowledge and skills required in regulatory toxicology, applicable to human health, across UK government agencies, contract research organisations, and pharmaceutical, agrochemical, consumer product, and chemical companies. This consensus can be used by education and training providers to develop industry relevant curricula.

- Identification of the knowledge and skill requirements that are met and not met by the learning objectives (LOs) of undergraduate (UG) and postgraduate (PG) degrees, and recurrent continuing professional development (CPD) courses applicable to regulatory toxicology.

- Recommendations to facilitate the provision of education and training to fulfil the knowledge and skill requirements that are not currently met (which will be used in Phases 2/3 of the project).

Key findings

1. Regulatory toxicology requires an exceptional number of knowledge and skill attributes at intermediate and expert level. Expert representatives from across the sectors agreed 17 knowledge and skill attributes were important/ necessary at entry level (graduate), but an additional 93 knowledge and skills attributes were important/ necessary at intermediate level (5 years' experience) and a further 54 at expert level (degree plus 10 years' experience). This places an enormous training burden on the employer.

2. Whilst higher education degree programmes are quality assured, there are a limited number of toxicology courses in the UK. There are currently no UK UG degree courses in toxicology, although bioscience degrees such as pharmacology UG degrees often include a toxicology component. There are 6 toxicology master's degree courses, and one PhD course with a taught toxicology component. There are 3 recurrent CPD toxicology courses recognised by the Federation of European Toxicologists and European Societies of Toxicology (EUROTOX).

3. Learning objectives on taught degree courses meet the majority of the 17 attributes required for regulatory toxicology at entry level, and are beneficial for a research career in toxicology.

    - Most of the mechanistic and mode of action toxicology knowledge requirements
    - Basic pharmacokinetic / toxicokinetic knowledge requirements
    - Most of the scientific method, statistical analysis, and basic laboratory skill requirements
    - Graduate transferable skill requirements including presentation, writing, project management skills

4. Learning objectives on taught degree courses do not generally meet

- Most of the regulatory and policy knowledge requirements
- Most of the hazard identification knowledge requirements (i*n vivo, in vitro, in silico*, human, analytical)
- Most of the hazard data interpretation knowledge requirements (*in vivo, in vitro, in silico*, human, analytical)
- Most of the exposure assessment knowledge requirements
- Most of the dose response assessment knowledge requirements
- Most of the integrated approaches to risk assessment knowledge requirements
- Most of the uncertainty analysis knowledge requirements
- Most of the risk characterisation knowledge requirements
- Most of the Good Laboratory Practice knowledge requirements

5. One international CPD course fully meets some of the knowledge requirements not met by taught degrees but not all.

6. Most of the fundamental knowledge and skill requirements needed to conduct regulatory toxicology at intermediate and expert level are not being met by taught UK courses. This is quite unlike gaps in newly emerging skills, such as digital skills, reported in other sectors. Consequently the majority of education and training is currently through in-house training.

7. Many toxicologists from all sectors already contribute to different degrees and CPD courses. Therefore, the willingness to share knowledge and expertise is evident and bodes well for future education provision.

1. INTRODUCTION

Regulatory toxicology

Chemical safety assessment and regulation is vital to protect human and animal health, and the environment. Without it our pharmaceutical, agrochemical, consumer product and chemical industries would be unable to produce safe products, so it also plays a critical role in our economy too [1].

The process of chemical safety assessment and regulation is also known as regulatory toxicology, a distinct speciality within the field of toxicology

> **"the generation, evaluation and interpretation of toxicological data, together with other data, to inform regulatory-decisions"**

Regulatory toxicology, applicable to human health, not only requires testing chemicals for adverse effects (hazard identification) but many more essential steps; determining the relationship between the adverse effects and exposure levels e.g. dose (dose response assessment), interpreting the test data and its relevance to humans, determining the likelihood of exposure for different populations (exposure assessment), and finally integrating all the relevant data together, whilst considering the uncertainty within the data, in order to make a decision on the risk to human health (risk characterisation). All these steps need to be conducted following the guidelines and policies of national and international regulators.

For new products which are regulated, for example therapeutic drugs, hazard identification and dose assessment data can be generated by the production companies or by contract research organisations, which undertake the study on their behalf (Figure 1). Regulatory consultants are often contracted to compile safety dossiers using the study reports and other relevant data. Dossiers are submitted to the appropriate regulating government agency for approval.

However, government agencies also conduct safety assessments on other sources of chemicals in order to protect human health, for example air pollution, chemicals in food. In these cases, scientists use the hazard and exposure data that is available to them, which frequently has limitations, in order to make a decision.

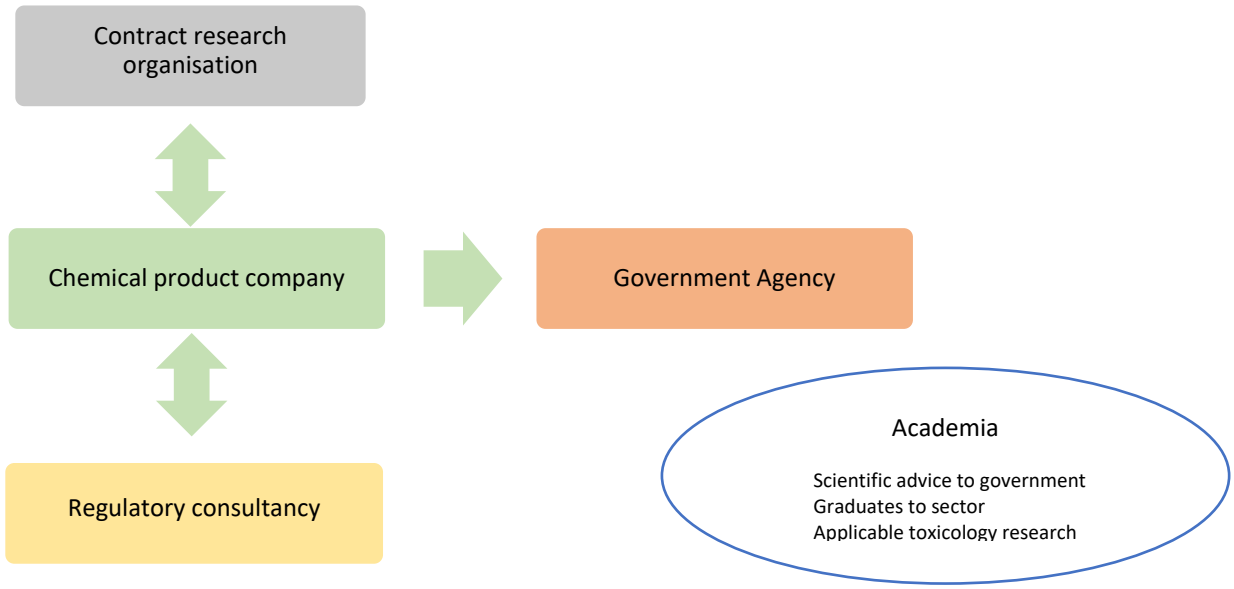

Figure 1. Organisations involved in regulatory toxicology

Scientists involved in regulatory toxicology

Regulatory toxicology is conducted by very highly educated and skilled scientists, many requiring a very comprehensive understanding of toxicology across a wide breadth, extensive data interpretation skills, knowledge of risk assessment factors and also regulatory knowledge.

Entry to the field typically requires an undergraduate (UG) / postgraduate (PG) degree(s) (Table 1) in a relevant subject. A degree(s) plus 5 years' experience in the sector would generally be considered intermediate level and degree(s) plus 10 years' experience would be considered expert level (Figure 2).

Level	Examples of Qualifications at this level
1	GCSE - grades 3, 2, 1
2	GCSE - grades 9, 8, 7, 6, 5, 4
3	A levels, Level 3 national vocational qualification
4	Level 4 national vocational qualification, level 4 diploma
5	Foundation degree, Higher national diploma
6	UG Bachelor of science (BSc) hons
7	PG Master's degree
8	PG PhD

Table 1. Qualification levels in England, Ireland and Wales

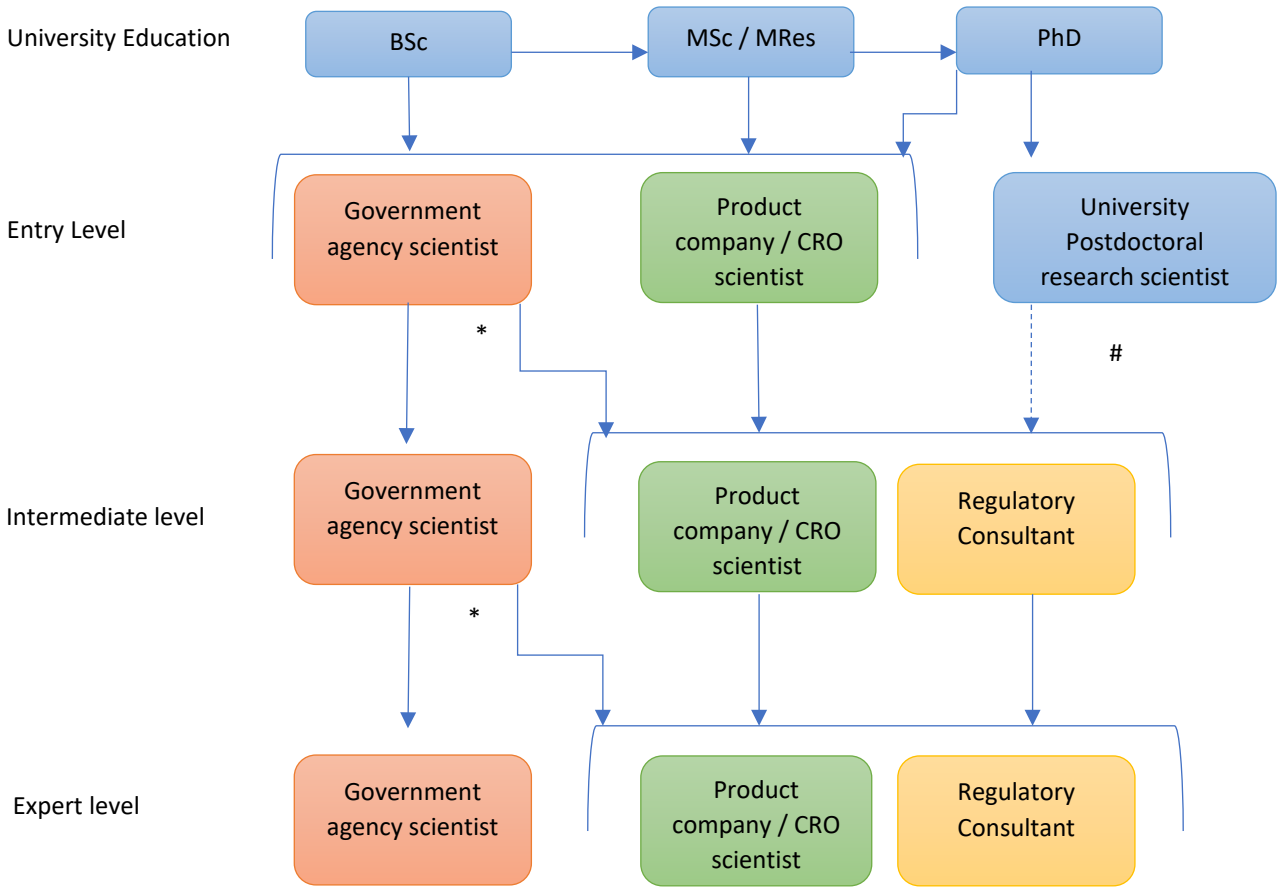

Figure 2. Examples of career pathways in regulatory toxicology. * Attrition from government agencies to private companies # extra education and training needed. CRO Contract Research Organisation

It is common for regulatory toxicologists employed in one type of organisation to move to another organisation type after gaining experience (Figure 2). It is suggested that this is typically away from government agencies rather than towards. The salary of a regulatory toxicologist in a government agency with a degree(s) and extensive experience of undertaking human-health hazard and risk assessment of chemicals is £39,334 - £45,865 (www.civilservicejobs.service.gov.uk, July 2022). For comparison, a university postdoctoral research scientist with a PhD and 5 years' experience would typically be earning £37,000 - £40,000. A university postdoctoral research scientist entering the regulatory toxicology profession should have extensive experience in data interpretation but is likely to require additional training in hazard and risk assessment.

The role of the British Toxicology Society and the Skills Gap

In the UK many scientists working in chemical safety assessment are members of the British Toxicology Society (BTS). BTS members have reported for some time, a decrease in the number of skilled applicants for toxicology roles, and this appears to be particularly acute in regulatory toxicology applicable to human health. Furthermore, the demand for government agency regulatory toxicology scientists has increased substantially in recent years following the exit from EU.

In response to this need, the BTS created the Education and Training Advisory Group, with members from industry, government agency and academia. Dr Phil Botham (Syngenta; BTS vice president 2022) was appointed chair and the other members include Dr Emma Barnes (Syngenta), Drs David Gott and Cath Mulholland (Food Standards Agency), and Professor Shirley Price (University of Surrey; BTS president 2020-2022).

The BTS Education and Training Advisory Group launched a multiphase project in January 2022 to facilitate education and training provision, so the knowledge and skills required in regulatory toxicology are met.

2. DEFINING EDUCATION AND TRAINING

Definition

- **Education** is about gaining theoretical knowledge, usually in the classroom or an institution.
- **Training** refers to an act of inculcating specific skills in an individual.
- **Training** is a way to develop specific skills in an individual applicable to their working environment, whereas **education** is a typical system of learning the principles which then are applied**.**

Quality of Courses

Courses offered by the Higher Education Institutions in the UK have their own quality assurance processes which are consistent through the Quality Assurance Agency for Higher Education (QAA). This is an independent body that checks on standards and quality in UK higher education, including adequate course assessments to determine learning objectives have been met by the students. It conducts quality assessment reviews, develops reference points and guidance for providers, and conducts or commissions research on relevant issue that can endorse quality courses/programmes in education and training.

Courses accredited by Professional Bodies for Continual Professional Development (CPD) such as the Royal College of Pathologists and Learned Societies such as the Royal Societies of Chemistry and Biology also have credibility. The accreditation process undertaken checks the courses against specified criteria and by agreeing to accrediting the course quality is assured, meeting the criteria and standards set out.

Types of Courses

Higher Education Institutions provide quality UG and PG programmes as defined by the QAA. There has been some criticism of the Higher Education programmes in general that they do not meet the ongoing needs of the industries they serve and do not meet skills gaps.

Degree and Higher Degree apprenticeships are a relatively new type of programme developed to focus primarily on developing skills competing with the traditional education of students. These programmes are developed by employers, universities, and professional bodies working in partnership. Degree apprentices are employed throughout the programme and spend the majority of their time with their employer and study part of their time at university to achieve a full bachelor's or master's degree. The disadvantage currently is that they are limited to places available and lack of flexibility on how those employed can take advantage of the education provided as most degree courses are full time over 3-4 year (UG) 1-2 years (PG).

There is a move to offer degree and higher degree apprenticeships to those already in employment which is attractive. However the opportunities for this in the area of Regulatory Toxicology is very limited. On searching the web one programme available was offered is in Forensic Toxicology in the Laboratory of the Government Chemist.

Commercial CPD courses can offer education and/or training and upskilling. They can be provided as in person course , from a one-day workshop through to a one week residential, but there are a growing number offered on-line. There can be a very wide-range in provision; some set clear learning objectives and determine if the learning objectives have been met by the participants, whereas others do not. CPD courses are often provided by companies that have a track record and are sometimes accredited through Learned Societies and Professional Bodies.

Some Higher Education Institutions may also be able to provide training and upskilling through the same routes as Commercial Operations. These are quality courses being validated through the QAA and can also be accredited by Learned and Professional Bodies for Continual Professional Development. The advantage of courses provided by Higher Education Establishments are that they are cheaper to produce. The disadvantage is that they are often required to be offered separately *en bloc* to meet the industry needs rather than spread through a semester or the academic year as offered to a student.

3. PHASE 1 PROJECT OBJECTIVES AND SCOPE

The Advisory Group appointed Dr Sarah Judge (Newcastle University) as Phase 1 project co-ordinator.

The objectives and scope of Phase 1 (January – June 2022) of the project were decided by the Advisory Group.

The objectives were to

- define gaps in training and education provision offered to safety scientists, particularly in regulatory toxicology
- make recommendations for future phases to facilitate education and training provision

The scope of Phase 1 was to:

- Focus on regulatory toxicology applicable to human health. Whilst regulatory toxicology is also applicable to animals and the environment, the gap in human health area was felt to be particularly acute. The project may be expanded to these other areas in the future.

- Include entry, intermediate and expert level, when identifying the knowledge and skills required in regulatory toxicology and training and education needed.

- Include knowledge and skills required now and up to the next 5 years. Toxicology is in a transition between the generation and use of traditional toxicological data i.e. *in vivo* data and the generation and use of data using new approach methodologies (NAMs) and so the skills and knowledge required by people working in regulatory toxicology is likely to change and / or grow.

- Focus on knowledge and skills required in UK based regulatory toxicology. This will include global organisations.

- Focus on recurrent taught courses which have clearly defined Learning Objectives (LOs) and processes in place to assess the LOs have been met. This is to ensure the course is accessible to future participants and there are quality controls in place.

- Focus on courses that are accessible by people in the UK.

4. PHASE 1 APPROACHES TO ADDRESS OBJECTIVES

Approach to identify knowledge and skills requirements in regulatory toxicology

To define the gaps in education and training provision, we decided to map the knowledge and skills required in regulatory toxicology against the LOs of current taught causes. Mapping course LO's against industry-relevant professional standards or core curricula defined by professional societies, is often used to assess courses, for example Royal Society of Biology accreditation.

However, there is currently no defined list of entry, intermediate and expert knowledge and skill requirements for regulatory toxicology

Indeed the webpage for the International Diploma in Toxicology [2] states

> "Sometimes it is difficult to define what is meant by a toxicologist, certainly within the context of safety evaluation and regulatory affairs"

To create a list we used a modified version of the Delphi method. This is a consensus method which was initially used in healthcare to reach a consensus on guidelines but has more recently been used to develop curricula [3, 4], including the British Pharmacology Society core undergraduate curriculum [5].

For the Delphi method experts in the field are recruited and invited to rate the importance of attributes e.g. knowledge and skills. Through a series of rounds the collective opinion of the group is captured and a consensus on the attributes is reached. A panel of 15 – 30 experts is considered large enough to collect good quality data whilst being small enough to be manageable and allow time for encouragement and follow up and prevent drop out [4, 6].

Regulatory toxicology experts from 26 different pharmaceutical, agrochemical, consumer product and chemical companies, government agencies, CRO's and regulatory consultancies in the UK were invited to participate in the project. One expert asked to participate.

In round one, as there was no current list of knowledge and skills requirements for experts to rate, the experts were given the freedom to list knowledge and skill requirements in their regulatory toxicology sector. To help frame their list they were provided with a form with 32 knowledge/skill categories covering core theoretical knowledge, core experimental techniques, core skills, hazard identification and characterisation, and risk assessment (Appendix 1). Experts were advised they were free to add as many skill/knowledge details as they thought were required and could add additional categories.

Round one lists were collated by the project co-ordinator. By repeatedly going through the collated list, knowledge and skill attributes were identified and attributes that could be clearly grouped together under a common knowledge or skill attribute were. Specific details included in the description of the original attribute were included in the description of the new common attribute. Attributes that could not be easily grouped under a common attribute remained as single attributes. No details were excluded. Experts were asked to review the newly consolidated list of knowledge and skill attributes to ensure all attributes they had provided had been interpreted correctly.

In round two, experts were asked to rate the importance of each knowledge and skill attribute in the consolidated list for entry level, intermediate level and expert level. Experts were asked to rate each attribute either 1 unnecessary, 2 unimportant, 3 important, or 4 necessary, and were invited to also leave free text comments.

For each knowledge and skill attribute, average importance scores were calculated for entry, intermediate and expert level. The percentage of experts that agreed an attribute was important or necessary at entry, intermediate and expert level was also calculated. Consensus was defined as more than 70% of experts agreeing that an attribute was important or necessary.

Approach to map knowledge and skill requirements to Learning Objectives of taught courses

Taught degree and recurrent CPD courses in toxicology, or containing a module of toxicology, were identified through a subject search on the Universities and Colleges Admissions Service (UCAS) webpage [7], searches on the BTS Education and events webpage [8], the UK register of toxicologists [9], and general internet searches for "toxicology training UK", "toxicology module UK" and "toxicology education UK".

Course leaders on a sample of UG courses containing toxicology, all PG masters in toxicology degree courses in the UK, the Medical Research Council (MRC) Integrative Toxicology Training Partnership (ITTP) PhD programme, and all recurrent EUROTOX recognised CPD courses were contacted and invited to participate.

All degree course leaders who agreed to participate were sent a list of 108 knowledge and skill requirements that had been agreed to be important or necessary at entry level by experts in different sectors. All CPD course leaders who agreed to participate were sent the full list of 164 knowledge and skill requirements that had been agreed to be important or necessary at expert level by the experts. Course leaders were asked to indicate if the LOs of their courses fully met or partially met the knowledge and skill attributes listed.

As QAA set and assess the quality assurance processes universities have in place, degree course leaders were not asked further questions about quality assurance processes.

CPD course leaders were asked the following questions

- Do you determine if the knowledge and skills objectives for the course have been met by the participants? If so how?
- Do participants evaluate the quality of the course? Are processes in place to act on feedback? Is their review made available to prospective participants? If so, how?
- Do you have processes in place to address complaints in a timely and fair manner and how is this process available to participants? If so, how?
- Is the course quality assessed by external reviewers regularly? If so, how?

The data from the degree courses was collated separately to the data from the CPD courses. For each knowledge or skill attribute, the percentage of courses that had LOs that fully met or partially met the attribute was calculated.

Approach to collect information for recommendations

In addition to discussing the project and its objectives with the regulatory toxicology experts and the education providers who contributed data to phase 1, additional experts who had experience in education and training in toxicology were contacted for their insights. These included Professor Robert Chilcott, the lead for the International Diploma in Toxicology, Dr Britta Gadeberg, vice chair of the UK Register of Toxicologists (UKRT) and Dr Ruth Bevan and Professor Len Levy from the Interdepartmental Group on Health Risks from Chemicals.

5. DEFINITION OF THE GAPS IN EDUCATION AND TRAINING PROVISION FOR REGULATORY TOXICOLOGISTS

Knowledge and skill requirements in regulatory toxicology

Regulatory toxicology experts across different organisation types contributed their opinions on knowledge and skill requirements (Figure 3). In round 1 they described 754 knowledge and skill attributes which were consolidated to 189 attributes across 28 areas (Tables 2-8, Appendix 2).

Regulatory experts from across different sectors agreed that 17 knowledge and skill attributes were important or necessary at entry level, 110 attributes at intermediate level and 164 attributes at expert level.

In round 2, the experts from across different sectors agreed that 17 knowledge and skill attributes were important or necessary at entry level (Table 2), 110 attributes were important or necessary at intermediate level (Tables 3-6) and 164 attributes (Tables 7-8) were important or necessary at expert level. Full descriptions of all the knowledge and skill attributes, average scores and percentage agreement is available in Appendix 2. Experts explained that the depth of knowledge and skill would also be expected to increase from entry to expert level. Of the 164 attributes, **63% were knowledge attributes (Knowledge and understanding of …) vs 37% skill attributes (To be able to …)** illustrating the necessity of both education and training.

Education and training provision in toxicology

The search for toxicology education provision revealed that there are no UG degrees in toxicology in the UK. There are however 141 life science UG degrees from 70 universities that may include a component of toxicology, including 36 UG degrees in Pharmacology, one of the subjects most closely aligned with toxicology.

There are six PG master's degrees in toxicology (toxicology, medical toxicology, analytical toxicology, drug toxicology and safety pharmacology and drug discovery and toxicology). There are

also master's in forensic toxicology that led to a career analysing and reporting forensic toxicology cases. There is one toxicology PG doctoral training programme which includes a taught toxicology component (MRC ITTP). It should be noted that there will also be other PhD studentships in toxicology research, but without a formal taught toxicology component.

Three recurrent CPD courses with assessed LOs were found. Two in the UK and one extensive CPD training programme in the Netherlands which is open to UK based scientists (Appendix 3). All are recognised by EUROTOX. There may be additional commercial courses but these were not found through the internet searches and consultation of the BTS and UKRT websites. It should be noted that there are also a number of excellent non-recurrent non-assessed CPD courses, seminars and webinars in toxicology to keep those already in the field up to date, many ran by the BTS (www.thebts.org/courseandwebinars), but these are outside the scope of this project.

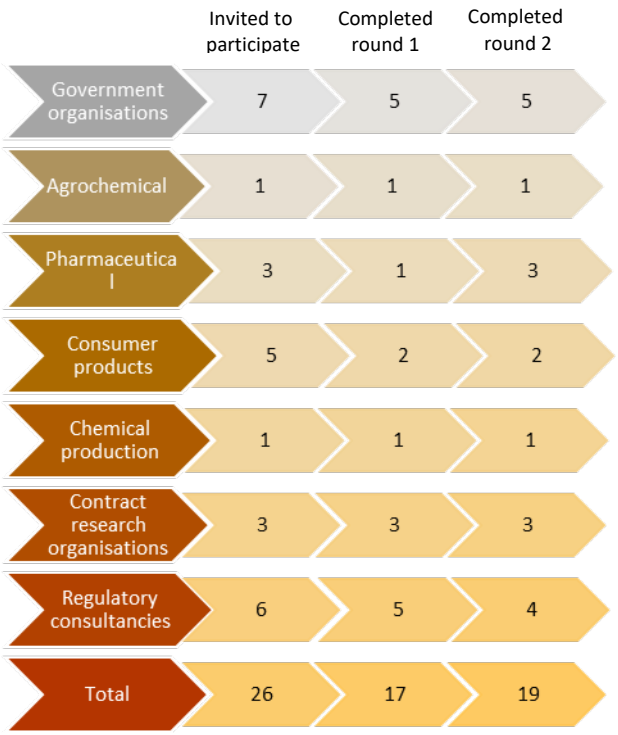

Figure 3. The number of regulatory toxicology experts who provided opinions on knowledge and skill requirements

Regulatory toxicology knowledge and skill requirements met by the learning objectives of current education provision

A sample of the degree courses (7 UG, 3 PG) and CPD courses (2) were evaluated to determine the regulatory toxicology knowledge and skill requirements met by the LOs of current education provision.

Degree course LOs fully or partially met the majority of regulatory toxicology knowledge and skill requirements at entry level (Table 3) but not the requirements at intermediate and expert level (Tables 4-8). UG and PG degree courses were particularly strong in providing knowledge and skills that would be needed for a career in toxicology research (mechanistic and mode of action toxic, scientific method, laboratory skills, graduate transferable skills).

CPD course learning objectives, in particular the extensive programme (Appendix 3), met some of the knowledge and skill requirements not met by degree courses but not all.

Degree courses fully or partially provided the majority of the entry level requirements for regulatory toxicology but not the requirements at intermediate and expert level. CPD courses met some of the knowledge and skill requirements not met by degree courses but not all.

Knowledge and skills expected at entry level (> 70% consensus all experts)		% experts agree important or necessary	% degree courses		% CPD courses	
			Fully met	Partially met	Fully met	Partially met
Principles of mechanistic and mode of action toxicology	Knowledge and understanding of **normal cellular biology and physiology of organs**	95	80	20	50	0
	Knowledge and understanding of the molecular, biochemical and cellular **mechanisms initiating toxicity**	79	60	40	50	0
	Knowledge and understanding of **target organ toxicity**	79	50	50	50	0
Principles of exposure assessment	Knowledge and understanding of the **principles of absorption, distribution, metabolism and excretion**	74	80	20	50	50
Principles of hazard identification	Knowledge and understanding of **testing for different toxicities**	79	30	50	0	100
In vivo data interpretation	Knowledge and understanding of **in vivo measurements which can be suggestive of early adverse events**	74	0	60	50	0
	Knowledge and understanding of **normal and abnormal variability in in vivo data**	72	0	40	50	0
Dose response assessment	Knowledge and understanding of the **derivation of toxicology endpoints / points of departure from dose response data**	79	20	60	0	0
Good laboratory practice	Knowledge and understanding of **how to determine if a study has followed the principles of GLP**	74	0	20	50	0
Presentation skills	To be able to **prepare and deliver information in a clear, concise, organised format and demonstrate technical breadth, depth and attention to detail using presentation software**	84	80	0	0	50
Writing skills	To be able to **write clearly and concisely and pay attention to detail**	89	90	0	50	0
	To be able to evaluate, review, and **summarise information from a study report**	95	70	20	50	0
	To be able to **use effective literature searching strategies and identify sources of authoritative evidence**	89	100	0	50	0
	To be able to **write a literature review**	84	80	20	0	0
Project management skills	To be able to **manage time**	84	60	30	50	0
	To be able to **work within a multidisciplinary team**	95	60	40	50	0
Career development skills	To be able to **write a CV**	79	80	10	50	0

Table 2. Regulatory toxicology knowledge and skills which experts (n = 19) agree are important / necessary at entry level (graduate) and the percentage of courses with learning objectives that fully or partially meet each attribute. A sample of UK undergraduate (with a toxicology component) and toxicology postgraduate taught degree courses (n = 10), and a sample of toxicology CPD courses (n = 2) contributed. Full descriptions for each knowledge and skill attribute are in Appendix 2.

Knowledge and skills expected at intermediate level (> 70% consensus all experts) (Part A)		% experts agree important or necessary	% degree courses		% CPD courses	
			Fully met	Partially met	Fully met	Partially met
Principles of mechanistic and mode of action toxicology	Knowledge and understanding of **carcinogenicity, mutagenicity and non-genotoxic carcinogenicity**	95	50	40	50	0
	Knowledge and understanding of **Teratogenicity, reproductive and developmental toxicity**	100	20	60	50	0
	Knowledge and understanding of **Adverse Outcome Pathways and Mode of Action frameworks**	95	30	40	50	50
	Knowledge and understanding of **new technologies to generate mechanistic knowledge**	79	10	60	50	0
	Knowledge of toxicity **risks from new modalities**	79	0	60	0	0
Principles of regulatory toxicology	Knowledge and understanding of the **history and development of regulatory toxicology**	89	20	40	50	0
	Knowledge of UK, EU and international **regulatory bodies (Competent authorities) and their differing regulatory policies**	95	30	50	50	0
	Knowledge and understanding of the **risk assessment process**	100	60	10	50	0
	Knowledge and understanding of **perceptions, beliefs, uncertainties and realities in risk assessment**	89			50	0
Regulatory and policy knowledge	Knowledge of **currently accepted risk assessment approaches and principles and models**	74			0	50
	Knowledge of **OECD** guidelines	89	0	50	50	50
	Knowledge of **ICH** guidelines	74			0	100
Principles of exposure assessment	Knowledge and understanding of **toxicokinetic parameters**	100	60	40	0	50
	Knowledge of **direct and indirect sources of exposure**	83			50	0
	Knowledge and understanding of the **test material purity and impurity profile, and its relevance to the substance registered / to be approved / authorised**	84	10	10	50	0
	Knowledge of assessment of the **toxicology of metabolites**	95	20	40	50	0

Table 3. Regulatory toxicology knowledge and skills which experts (n = 19) agree are important / necessary at intermediate level (graduate plus 5 years' experience) and the percentage of courses with learning objectives that fully or partially meet each attribute (Part A). A sample of UK undergraduate (with a toxicology component) and toxicology postgraduate taught degree courses (n = 10), and a sample of toxicology CPD courses (n = 2) contributed. Degree provision was evaluated for some but not all intermediate/expert level attributes (white spaces). Full descriptions for each knowledge and skill attribute are in Appendix 2.

Knowledge and skills expected at intermediate level (> 70% consensus all experts) (Part B)		% experts agree important or necessary	% degree courses		% CPD courses	
			Fully met	Partially met	Fully met	Partially met
Hazard identification in vivo studies	Knowledge and understanding of **existing in vivo tests for different toxicities and their limitations**	100	0	70	50	0
	Knowledge and understanding of **animal welfare, NC3Rs and Home Office Licence regulations**	94	10	50	50	0
	Knowledge and understanding of **how to design an appropriate in vivo study to measure relevant endpoints reproducibly, reliably and integrate animal welfare measures**	94	20	40	0	50
	Knowledge and understanding of **in vivo substance administration**	89	10	60	0	50
	Knowledge and understanding of **in vivo test measurements**	95	0	60	0	50
	Knowledge and understanding of **sampling from animals**	84	0	40	0	50
	Knowledge and understanding of animal/**necropsy room procedures used in clinical and toxicological pathology**	89	0	40	0	50
	Knowledge and understanding of **deficiencies and failures of in vivo legacy data which would trigger new studies**	84			0	0
	Knowledge of **how long it takes to undertake studies, from placement to protocol generation, concentration selection, data review, draft report and finalisation**	79			0	50
In vivo data interpretation	Knowledge and understanding of the **impact of species, strain, sex, developmental stage and maternal toxicity on the interpretation of in vivo data**	95	0	40	0	0
	Knowledge and understanding of the **impact of dose selection on interpretation of in vivo data**	100	0	40	0	0
	Knowledge and understanding of the **interrelationship and consistency between in vivo assessments parameters**	89	0	30	0	0
	To be able to **determine if the in vivo study is valid for the question being asked and complies with 3Rs principles and UK home office legislation for animal experiments**	100	10	10	0	50
	To be able to **analyse and interpret different types of in vivo data using best practice**	94			50	0
	To be able to **interpret in vivo data using statistics but not exclusively rely on statistics**	95	0	50	0	0
	To be able to **use historical control data in data interpretation**	95	0	30	0	0
	To be able to use in vivo data to **define an adverse effect level**	95	0	50	50	0
	Knowledge and understanding of the **translation and clinical relevance of in vivo data to humans**	95	0	40	50	0
	Knowledge and understanding of how in vivo data can be **used in read across for hazard assessment of other chemicals**	100	0	20	0	0
Hazard identification in vitro studies	Knowledge and understanding of **existing in vitro tests and what is measured**	89	10	80	50	0
Hazard identification in vitro studies	Knowledge and understanding of **in vitro hazard assessment test limitations and issues**	74	0	60	50	0
	Knowledge and understanding of **new in vitro tests and technologies and their limitations**	72	10	50	50	0
	Knowledge of **how to design an appropriate in vitro study** to measure **relevant endpoints reliably and reproducibly**	79	10	50	0	0
	Knowledge and understanding that **deficiencies and failures of legacy in vitro data which would trigger new studies**	74			0	0
	To be able to **determine if the in vitro study is valid for the question being asked**	74			0	0
	To be able to **analyse and interpret different types of in vitro data**	79			0	0
	To be able to **interpret in vitro data and not ignore extraordinary results**	89			0	0
	To be able to **interpret in vitro data in the context of in vivo data; including (Quantitative) in vitro to in vivo extrapolation (QIVIVE/ IVIVE)**	72			50	0
	Knowledge and understanding that **deficiencies and failures of legacy in vitro data which would trigger new studies**	79			0	0

Table 4. Regulatory toxicology knowledge and skills which experts (n = 19) agree are important / necessary at intermediate level (graduate plus 5 years' experience) and the percentage of courses with learning objectives that fully or partially meet each attribute (Part B). A sample of UK undergraduate (with a toxicology component) and toxicology

postgraduate taught degree courses (n = 10), and a sample of toxicology CPD courses (n = 2) contributed. Degree provision was evaluated for some but not all intermediate/expert level attributes (white spaces). Full descriptions for each knowledge and skill attribute are in Appendix 2.

Knowledge and skills expected at intermediate level (> 70% consensus all experts) (Part C)		% experts agree important or necessary	% degree courses		% CPD courses	
			Fully met	Partially met	Fully met	Partially met
Hazard identification in silico studies	Knowledge and understanding of **in silico modelling tools, their current uses and their limitations**	79	0	50	100	0
	Knowledge and understanding of **chemical structural and physiochemical properties for use in computational models**	74			50	50
In silico data interpretation	To be able to interpret in silico data to **define a threshold of concern / point of departure**	72			50	0
Qualitative data assessment	Knowledge and understanding of the **techniques used to assess qualitative data**	89	0	60	0	0
	Knowledge of the **impacts of qualitative versus quantitative risk assessment on risk management measures**	84			0	0
Dose response assessment	Knowledge of currently **accepted and emerging dose response assessment approaches and their advantages and disadvantages**	74	0	70	50	0
	Knowledge and understanding of **dose response curves**	95	10	70	50	0
	To be able to **compare data against controls and predose phase**	89	0	50	50	0
	To be able to **calculate the benchmark dose using benchmark dose software and interpret BMD analysis**	78	10	20	0	0
Uncertainty analysis	Knowledge and understanding of **uncertainty and sources of variability in risk assessment data**	79	10	50	50	0
	Knowledge and understanding of **uncertainty between species**	84	10	50	50	0
	Knowledge and understanding of the **application of uncertainty and uncertainty factors in risk based-decisions**	83	0	50	50	0
	To be able to **communicate uncertainty associated with a risk assessment**	79	0	30	50	0
Integrated approaches to risk assessment	Knowledge of currently **accepted integrated approaches**	79	0	20	50	0
	Knowledge and understanding of **when and how to apply integrated approaches** to testing and assessment	74	0	20	50	0
	To **be able to apply integrated approaches to integrate in vitro, in vivo, multiple endpoints and external literature**	89			50	0
	To be able to **include appropriate subpopulations in the evaluation**	72			50	0
	Knowledge and understanding of **safety windows in integrated approaches to assess data**	74	0	0	50	0
Risk Characterisation	To be able to **interpret test data for risk characterisation using the appropriate approach**	79	0	50	50	0
	To be able to **perform a risk characterisation**	79	0	20	50	0
	To be able to **derive a threshold of toxicological concern**	94	0	10	50	0
	To be able to **derive safety margins**	89	0	30	50	0
	Knowledge and understanding of **route to route extrapolation**	84	0	30	0	0
	Knowledge and understanding of **risk assessments for identified susceptible populations**	79	0	40	0	0
	Knowledge of **safety margins and their application to understand risk**	79	0	40	50	0
	Knowledge and understanding of **reference values for different chemical regimes**	74	0	30	0	50

Table 5. Regulatory toxicology knowledge and skills which experts (n = 19) agree are important / necessary at intermediate level (graduate plus 5 years' experience) and the percentage of courses with learning objectives that fully or partially meet each attribute (Part C). A sample of UK undergraduate (with a toxicology component) and toxicology postgraduate taught degree courses (n = 10), and a sample of toxicology CPD courses (n = 2) contributed. Degree provision was evaluated for some but not all intermediate/expert level attributes (white spaces). Full descriptions for each knowledge and skill attribute are in Appendix 2.

Knowledge and skills expected at intermediate level (> 70% consensus all experts) (Part D)		% experts agree important or necessary	% degree courses		% CPD courses	
			Fully met	Partially met	Fully met	Partially met
The scientific method and statistical analysis	To be able to **formulate a problem and generate a testable hypothesis and design a robust experiment to test the null hypothesis including validation and positive and negative controls.**	84	80	20	0	0
	Knowledge and understanding of the **use of statistics in study design**	89	60	40	50	0
	Knowledge and understanding of the **selection of the appropriate statistical test for analysis of different types of data**	84	70	30	0	0
	To be able to i**nterpret the statistical test results and distinguish between a statistically significant result and a biologically relevant result / adverse effect**	95	80	20	0	0
	Knowledge and understanding of the **generation of historical control data, and statistical methods used to interpret it**	89	20	30	0	0
Basic laboratory skills	To be able to competently **perform common laboratory techniques, use common laboratory equipment and work safely in the laboratory**	74	70	10	0	0
Good laboratory practice	Knowledge and understanding of the **principles of GLP, why it is important and GLP roles and responsibilities**; including the implications of GLP system failures and the roles of role study monitor and study director	84	20	30	0	0
	Knowledge and understanding of **GLP procedures and study conduct and what it means in reality in the laboratory**	79	20	20	0	0
	Knowledge and understanding of **which studies are done to GLP**	89	0	10	0	0
	Knowledge of **GLP documents**	79	0	10	0	0
Data management	Knowledge and understanding of **the principles and importance of data curation**	84	10	50	0	0
	To be able to **record data and ensure the integrity and quality**	74	20	40	0	0
	To be able to **analyse and visualise data using electronic tools**	79	40	30	0	0
	To be able to **use fielded databases and chemical substance databases**	84			0	0
Presentation skills	To be able to **prepare and deliver different types of presentations to different audiences**	89	60	40	0	0
Writing skills	To be able to **write a study report**	89	60	10	0	0
	To be able to **evaluate, integrate and summarise information for a policy question**	84			0	0
	To be able to **write a scientific article for journal publication**	74	50	60	0	0
	To be able to **explain complex scientific issues to a non-expert audience**	89	30	40	0	0
Project management skills	To be able to **plan, coordinate and progress different aspects of a project**	95	60	30	0	0
	To be able to work **manage and negotiate with stakeholders**	89			0	0
	To be able to **advocate**	79			0	0

Table 6. Regulatory toxicology knowledge and skills which experts (n = 19) agree are important / necessary at intermediate level (graduate plus 5 years' experience) and the percentage of courses with learning objectives that fully or partially meet each attribute (Part D). A sample of UK undergraduate (with a toxicology component) and toxicology postgraduate taught degree courses (n = 10), and a sample of toxicology CPD courses (n = 2) contributed. Degree provision was evaluated for some but not all intermediate/expert level attributes (white spaces). Full descriptions for each knowledge and skill attribute are in Appendix 2.

Knowledge and skills expected at expert level (> 70% consensus all experts) (Part A)		% experts agree important or necessary	% degree courses		% CPD courses	
			Fully met	Partially met	Fully met	Partially met
Regulatory and policy knowledge	Knowledge of **REACH** history, current and future	89	0	0	50	50
	Knowledge of **EFSA, JECFA, JMPR, Codex Alimentarius, WHO** principles / guidelines	95			50	50
	Knowledge of global **regulatory requirements for pharmaceutical development**	79			50	0
	Knowledge of **EMA/MHRA** regulatory guidance and procedures	74	20	70	50	50
	Knowledge of **plant protection regulation**	79			0	100
	Knowledge of **biocidal product regulation** requirements	89			0	100
	Knowledge of **classification and labelling regulations**	89			0	0
Principles of exposure assessment	Knowledge and understanding of **experimental exposure measurements**	78			0	50
Principles of hazard identification	Knowledge of national and international **hazard assessment test guidelines and guidance**	95	10	40	0	0
In vivo data interpretation	Knowledge and understanding of how in vivo data can be **used to define clinical start dose, stopping dose/exposure in clinical trials**	79	0	30	50	0
Hazard identification Analytical methods	Knowledge and understanding of the **analytical methods used to assess analytes and what is measured**	95			0	0
	Knowledge and understanding of how to **validate analytical methods for sensitivity and specificity and compliance**	74			0	0
In vitro data interpretation	To be able to **determine the robustness of the laboratory and use this to interpret the in vitro data**	84			0	0
	To be able to **determine if in vitro data is reproducible and coherent with data from other in vitro studies**	89			0	0
	Knowledge and understanding of the **application of in vitro high-throughput screening assay data** in regulatory assessments	84			0	0
	Knowledge and understanding of the **translation and clinical relevance of in vitro endpoints**	89			0	0
Hazard identification in silico studies	To be able to **use in silico models**; including performing sensitivity analysis	84			50	50
In silico data interpretation	To be able to **determine if an in silico study method is appropriate for the question being asked and whether it meets legislative information requirements**	89	0	10	100	0
	To be able to **analyse and interpret different types of in silico study data using best practice**	89			100	0
	Knowledge and understanding of how in silico data can be **used in AOPs and read across**	79	0	10	100	0
	To be able to apply different approaches to **classify mixtures under CLP** (with data, without data on the mixture)	74			50	50
	Knowledge and understanding of how in silico **data can be used for in vivo predictions and used in in vivo study design / negate the need of an in vivo study**	84	0	10	50	50
Hazard identification human studies	Knowledge and understanding of **epidemiology / observational study designs and conduct and limitations**	79			50	0
	Knowledge and understanding of **clinical / experimental trial designs and conduct**	84			50	0
	Knowledge and understanding of **prospective and retrospective studies**; pros and cons	84			0	50
	Knowledge and understanding of **case reports** including their limitations	74			0	0
Human study data interpretation	To be able to determine if the data from a **human study is relevant to the application of concern** and reliable	89	0	50	0	0
	To be able to identify **genetic variation** in treatment response and biomarkers from human study data	72	0	0	0	0
	To be able to **integrate human study data with other data types**	83	0	0	0	0

Table 7. Regulatory toxicology knowledge and skills which experts (n = 19) agree are important / necessary at expert level (graduate plus 10 years' experience) and the percentage of courses with learning objectives that fully or partially meet each attribute (Part A). A sample of UK undergraduate (with a toxicology component) and toxicology postgraduate taught degree courses (n = 10), and a sample of toxicology CPD courses (n = 2) contributed. Degree

provision was evaluated for some but not all intermediate/expert level attributes (white spaces). Full descriptions for each knowledge and skill attribute are in Appendix 2.

Knowledge and skills expected at expert level (> 70% consensus all experts) (Part B)		% experts agree important or necessary	% degree courses		% CPD courses	
			Fully met	Partially met	Fully met	Partially met
Exposure assessment	Knowledge and understanding of **effective methods / modelling tools for internal and external exposure assessment**	84	0	10	50	0
	Knowledge and understanding of **deterministic exposure modelling tools**: oral, dermal and inhalation routes.	84	0	0	50	0
	Knowledge and understanding of **probabilistic exposure modelling tools**: e.g. ConsExpo, FAIM, PACEM, Crème, 2-box	74	0	0	50	0
	Knowledge and understanding of **estimating the internal dose**	95			50	0
	Knowledge of **refinement options** to exposure assessments e.g. in silico options	78	0	0	0	0
	To be able to **develop and define realistic exposure scenarios**	79	0	0	50	0
	To be able to **define exposure-specific endpoints** and separate portal of entry and systemic effects	94	0	10	50	0
	To be able to **estimate dietary exposure**	84			0	50
Dose response assessment	Knowledge and understanding of **how the dose response (shape) can be used to determine dosing in clinical trials**	72			50	0
Integrated approaches to risk assessment	To be able to **assess and weigh individual lines of evidence**	89			50	0
Integrated approaches to risk assessment	To be able to conduct a **meta-analysis or systematic review of relative data**	84			50	0
Risk Characterisation	Knowledge and understanding of **risk / benefit analysis in risk-based decisions**	83			0	50
The scientific method and statistical analysis	Knowledge and understanding of **occupational risk assessments**	79			50	0
	Knowledge and understanding of **how to derive NESIL** (no expected sensitization induction level)	84	0	0	0	0
	Knowledge and understanding of **risk characterisation ratios**	79	0	20	0	0
	Knowledge and understanding of **risk management measures**	79	0	10	50	0
	Knowledge and understanding of the **use of post market/clinical data to address specific toxicological risks**	78			50	0
	To be able to **conduct basic statistical analysis and use statistical analysis software**	84	80	20	0	0
	Knowledge and understanding of **data mining**	84			0	0
	Knowledge and understanding of **Bayesian approaches in risk assessment**	74			0	0
Basic laboratory skills	To be able to perform **peer reviews of laboratory practices**	74			0	0
Presentation skills	To be able to **present evidence at an audit committee/inquiry**	79			0	0
	To be able to **act as an expert witness**	84			0	0
Writing skills	To be able to **write regulatory submission documents and meet regulatory reporting requirements**	84			0	0
	To be able to **communicate risk to policy colleagues and members of the public**	79			0	0

Table 8. Regulatory toxicology knowledge and skills which experts (n = 19) agree are important / necessary at expert level (graduate plus 10 years' experience) and the percentage of courses with learning objectives that fully or partially meet each attribute (Part B). A sample of UK undergraduate (with a toxicology component) and toxicology postgraduate taught degree courses (n = 10), and a sample of toxicology CPD courses (n = 2) contributed. Degree provision was evaluated for some but not all intermediate/expert level attributes (white spaces). Full descriptions for each knowledge and skill attribute are in Appendix 2.

6. DISCUSSION OF THE KNOWLEDGE AND SKILLS REQUIRED IN REGULATORY TOXICOLOGY AND THE GAPS IN EDUCATION AND TRAINING PROVISION.

Prior to this study there was not a clear understanding of the specific knowledge and skill requirements in regulatory toxicology across sectors. Through the contributions of industry representatives we now have a consensus on the knowledge and skills requirements, and this can be used to develop "industry relevant" curricula for courses.

Regulatory toxicology requires an exceptional number of knowledge and skill attributes at intermediate and expert level. At entry level (graduate), there were 17 knowledge and skill attributes but at intermediate level an additional 93 knowledge and skills attributes are required, and a further 54 at expert level. Whilst all of the attributes would not be expected in one individual it does demonstrate the level of expertise and skills needed for effective chemical safety assessment and regulation. The government recognises regulators as "deep specialists" [10].

Of the attributes required at expert level, 63% were knowledge attributes (Knowledge and understanding of …) and 37% were skill attributes (To be able to …) indicating the need for both education and training.

Degree courses fully or partially provided the majority of the entry level requirements for regulatory toxicology and were strong at meeting the knowledge and skills attributes usually associated with a career in toxicology research; knowledge of mechanistic and mode of action toxicology, pharmacokinetics / toxicokinetics, the scientific method, statistical analysis, laboratory skills and graduate transferable skills.

However, degree courses do not currently meet most of the knowledge and skills needed for hazard identification and characterisation, exposure assessment, risk characterisation, regulatory policy knowledge and GLP. Therefore the gap in education and training provision at degree level is in the knowledge and skills needed to perform the role of a regulatory toxicologist. This is unlike the gaps in emerging skills e.g. digital, reported in other sectors [11]. It is in fact a knowledge and skill gap, not just a skill gap.

This gap in regulatory toxicology education and training provision at degree level is not unique to the UK.

> "The SOT Education Committee, Graduate Subcommittee, and the Career Resources and Development Committee recognize that training in regulatory toxicology is usually not part of graduate programs" [12]

Consequently, a graduate, or even a postdoctoral research scientist with years of toxicology experience and extensive data interpretation experience (Figure 2), will need additional education and training to meet the intermediate and expert knowledge and skill requirements in regulatory toxicology.

Some of this could be achieved with investment in Degree and Higher Degree Apprenticeships. Some employers have already invested in a degree apprenticeship scheme, so the majority of the training is with their employer but the apprentice also studies a part of their time at university to achieve a full bachelor's or master's degree. The disadvantage currently is that they are limited to places available.

CPD courses, in particular the Dutch Postgraduate education in toxicology programme, met some of the regulatory toxicology needs not met by degree courses, but not all. It should be noted that although the Dutch programme is open to UK based scientists there were only 2 UK participants enrolled on the yearly programme in 2019, and there has been none since 2020. It is not clear why UK scientists are not enrolling on the programme, especially given the lack of education and training

provision specifically for regulatory toxicologists in the UK. The reasons underlying this should be taken into account when considering future education provision.

Discussions with regulatory toxicology employers indicated the vast majority rely on in-house to meet the intermediate and expert knowledge and skill requirements in regulatory toxicology. One reason indicated is the lack of CPD courses that would adequately fulfil their requirements in terms of knowledge and skills they require, cost and timing. This places an enormous training burden on employers. To counteract this, efforts have been made in the past by employees to co-ordinate some of this training between themselves, e.g Interdepartmental Group on Health Risks from Chemicals, but it requires on-going investment of time and funds.

An additional critical issue, highlighted by the experts, is the loss of employees after investing in their regulatory toxicology training (Figure 2). The loss appears to be from government agencies towards the private sector and is likely to be due to differences in salaries. Indeed, 8/14 experts employed by private companies agreed “Knowledge and understanding of working in government agencies” is important or necessary. The movement of trained regulatory experts between organisations will continue but should be taken into consideration when planning future education provision.

In summary, this study has provided a clearer understanding of specific knowledge and skill requirements in regulatory toxicology across sectors which will allow providers to develop industry-relevant courses. It has also demonstrated that degrees fill the majority of the education and training requirements at entry level. However, discussions with employers indicate that education and training in the vast number of knowledge and skill attributes required for intermediate and expert level regulatory toxicology has to be done in-house, and one reason for this is lack of appropriate education and training provision.

The regulatory toxicology knowledge and skills list generated by the employers contributing to this study can provide a basis for a curriculum but an on-going partnership between employers and education providers will be required, as well as on-going investment, in order to provide quality education and training that meets employers needs in terms of the knowledge and skill learning outcomes, and is time and cost effective.

7. DISCUSSION OF BROADER TOXICOLOGY EDUCATION AND TRAINING PROVISION IN THE UK AND THE SUPPLY OF STUDENTS

Whilst considering how we provide future education and training for intermediate and expert level knowledge and skills in regulatory toxicologists, we also need to consider the supply of students to these courses and the profession, and education and training provision for toxicology more generally.

Over recent years some programmes providing education in toxicology have closed due to a myriad of reasons including costs, lack of funding, viability and a change in student’s perspectives on what the job market will offer dictating their choice of degree programme. These are discussed below. It is not due to the quality of the education provided as academic programmes are accredited by the QAA which provides confidence in the sector for consistency of the standards of all programmes offered by UK Universities

Currently there are only six PG master’s degrees in toxicology and one toxicology PG doctoral training programme which includes a taught toxicology component available across the UK. Potential reasons for this are discussed below.

Barriers to those entering the discipline of Toxicology: Student retention

There are approximately 33,000 – 35,000 students who graduate each year from undergraduate degrees in "Biological and Sport Sciences", which includes pharmacology, biochemistry and other life sciences [13]. In 2020/21 7,965 enrolled on taught PG master's degrees in "Biological and Sport Sciences"; PG master's degrees in toxicology typically have 10-20 students per year.

The reality is very few graduate students are attracted to a career in toxicology, especially regulatory toxicology [14]. There is also a lack of funding for students wanting to undertake a full Master's degree and with the cost of educational programmes the number of students that could afford to self-fund a place on a Master's Programme is limited. Together, this means it is highly unlikely there will be sufficient self-supported students to fill the skills gap.

Many more graduates would be attracted to regulatory toxicology if employers offered training opportunities. Most graduates plan for a future in research but the majority of early career scientific research staff in academia end up transitioning out due to lack of funding and employment opportunities (Figure 2). Offering training may attract scientists with sought after relevant experience e.g. *in vivo* experience.

Due to costs, both financial and time, companies may be reluctant to fund employees to attend a PG degree either full or part-time. However, in the past companies did pay for employees to attend stand-alone modules on the masters' course at the University of Surrey, so may do so again if the timing and costs are appropriate.

From the survey one key message was that most students entering university, and even those on some life science and chemistry courses, **will not understand what the subject is and its wide-ranging societal impact**; it is not a component of A-level Biology or Chemistry curricula (www.aqa.org.uk). A student may first come across the term toxicology whilst searching on the Universities and Colleges Admissions Service (UCAS) website under the subject guide "Pharmacology, toxicology and Pharmacy" [7]. However, the description of toxicology and toxicology degrees on the page is limited,

> "Toxicology degrees are similar to pharmacology, but instead focus on the toxic (rather than the healing) properties of venoms, poisons, and drugs".
>
> "As a pharmacologist or toxicologist, you'll be at the forefront of medical research, fighting new diseases and illnesses as they occur. You'll also be working to ensure that current medicines remain effective, keeping the population healthy."

Even at university, it appears that some students may not fully understand the profession. There are no UG courses in toxicology, only UG courses with a toxicology component, such as Pharmacology. Consequently, during the course of the degree **more emphasis is placed on alternative careers** and PG study areas for example, in drug discovery. Alternative careers are also emphasised in the initiatives to attract students by professional societies such as the British Pharmacology Society and the Association of the British Pharmaceutical Industry.

A career in chemical regulation appears to be particularly unattractive to students as they know they do not possess the required knowledge. This is illustrated clearly in a recent UK UG student blog [14]

> "I was reluctant to apply for regulatory affairs positions – why would I apply for something I have incredibly limited knowledge about? Surely someone else would be a better candidate? I wasn't alone in this mindset; most of my peers were similarly interested in lab-orientated roles and were intimidated by the idea of reg affairs. We were concerned that it'd be boring and deviate from science too much. As March approached, I was running out of time and started to apply for everything I could –

including regulatory affairs. Much to my surprise, this was the best decision I could've made!" [14]

Furthermore, **students look for courses recognised by the profession, to increase "employability".** New courses like the MSc in Pharmaceutical Industry Advanced Training (PIAT) at the University of Manchester [15], have been developed with this in mind. Courses can also be formally accredited by a professional society. For example, TORPA, the Organisation for Professionals in Regulatory Affairs, identified skills gaps in their profession, and now accredit degrees or modules at universities to raise awareness of the profession in students.

Accreditation does require resources from the professional society, although some of the financial cost could be recovered through the accreditation fees (£1000 + VAT for annual module accreditation; £250 + VAT for review of major changes, TORPA). An alternative, less resource intensive, initiative used by other societies, such as EUROTOX and the Royal Society of Biology, is approval of CPD courses.

Degree courses can also demonstrate employability by providing the content for students to obtain a professional society qualification. The new Ecotoxicological Risk Assessment Towards Sustainable Chemical Use Doctoral Training programme [13], funded by the Natural Environment Research Council (NERC), provides content to pass phase 1 of the Society of Environmental Toxicology and Chemistry Certified Risk Assessor qualification.

Retention of Toxicology Expertise at Universities

Academics with expertise in toxicology are needed to teach on degree courses. Whilst there is not a definitive number of research active academics in toxicology, there does appear to be a continuing decline in numbers [16].

An academic's position in a university, and the support they receive from university management, relies primarily on research funding income, although providing an "industry relevant" course, and making a societal impact is starting to be recognised. The lack of research funding in toxicology has been highlighted previously[16, 17]. Success appears to be most strongly associated with those working in pharmaceutical toxicology with industrial collaborations or those developing alternative methods to animals, whereas funding applications for investigating environmental chemicals, mechanistic toxicology and using *in vivo* models appear less successful [16].

A decrease in research funding using *in vivo* models is indicative of the sector's efforts to move away from use of mammals in toxicity studies. This is clearly positive, but it does mean students, and increasingly university staff, will not have expertise in *in vivo* experimentation. This creates a paradox, as knowledge and understanding of *in vivo* experimentation and data interpretation is a necessary requirement at entry, intermediate and expert levels in regulatory toxicology now and over the next 5 years.

Whilst the state of toxicology research funding is outside the scope of this project, it has very direct consequences on education and training.

What can be done to make Toxicology more attractive from entry at Degree level to those employed and looking for upskilling

Whilst a number of UK degrees with modules in toxicology are accredited by the Royal Society of Biology or the Institute of Biomedical Sciences, there are no degree courses or modules in toxicology, to my knowledge, that are formally recognised by professional bodies for toxicology [18]. Accreditation or approval of a course by the toxicology profession is likely to raise awareness of the toxicology profession at UG level.

There is a need for Higher Education Institutions and Industry to work together to offer Toxicology in a way that is attractive to those coming into the discipline. As an example engineering degrees are supported by the Professional Bodies and Industry. Universities

offering an MEng work with external partners to ensure that degree programmes are kept abreast of new developments. These bodies accredit the programmes for their professional input and students on these programmes continue after gaining their degree to undertake a professional qualification to become Chartered.

Another option is for Industry to partner with Universities to look at the options of Degree and Higher Degree Apprenticeships

8. FUTURE EDUCATION AND TRAINING PROVISION

Toxicology is a unique discipline; the necessity for scientists from the private sector, government agencies and academia to work together to safely assess and regulate chemicals, together with the relatively small number of toxicologists, **has led to a long-established and highly interactive society of scientists in the UK.**

As well as the BTS there are also other societies and specialist interest groups with a vested interest in future toxicology education provision. These include the Royal Society of Chemistry, the Royal Society of Biology who administer the International Diploma in Toxicology and the UK register of toxicologists, the British Pharmacology Society, the United Kingdom Environmental Mutagen Society and the Cambridge Academy of Therapeutic Sciences. These groups should be involved when planning future education provision.

It is now an appropriate time for us to work together across the sectors to consider what we can do to bridge the education and training gaps and build on what we currently offer.

There are a number of factors that need to be considered when planning future education provision.

The format of education and training provision

Formalised taught PG courses with stand-alone modules have been popular previously, such as the master's in toxicology at University of Surrey. The recently launched MSc in Pharmaceutical Industry Advanced Training [15] at the University of Manchester has stand-alone modules, and illustrates some universities may be supportive if a course is industry relevant; key to this would be partnership with industry. Universities have the infrastructure to administer such courses, thus being cost-effective, and have the well-established quality assurance processes in place.

Explore the opportunity for Higher Education and Industry to work together to consider developing Degree and Degree Apprenticeship programmes in Regulatory Toxicology.

Industry-relevant Centres for doctoral training either from one institution, or between multiple universities [19] similar to the new NERC-funded Ecotoxicological Risk Assessment Towards Sustainable Chemical Use Doctoral Training programme. A multi-centre approach would help retain research active toxicology university staff in different universities and an emphasis on less represented areas such as environmental chemical toxicology would be especially beneficial. Many Centres leverage additional studentships from other sources (e.g. university funding, EU funding, industrial funding, private funding etc). Research councils, such as ESPRC, fund centres and this may be one way of leverage of funds for both education, training and meeting the needs for the breadth of the industry represented in the area of Toxicology. However, it is unclear if the numbers on these courses would be sufficient to meet the skills gap in regulatory toxicology as graduates may remain in research.

Government run-training programme to meet its needs. The NHS Scientist Training Programme [20] is an example of a training programme established to meet a scientific need in the public sector. People are employed and trained at the same time, so very similar to the current situation in government agencies, except it is formalised. The government has stated it must build an enduring capability (in government science and engineering) [10].

Industry relevance

It was very clear from all experts that the production of industry-relevant courses will be of significant benefit to employers, education providers and students. There are already many excellent examples of individuals from chemical production companies, contract research organisations and regulatory consultancies contributing to courses, sharing their expertise, often for free. However, there is concern that due to staff shortages and cost pressures, this may not continue. It will be critical that industry invest in and support courses. Training courses developed truly in partnership with industry to embed industry-relevant knowledge and skills in all parts of the curricula and understand the emerging trends will be more likely to ensure an appropriate level of teachers and ultimately students are available to meet demand of our emerging science.

Assessment of knowledge and skills

Various stakeholders considered the value of professional examinations, with differences in opinion. Education and training could be recognised through additional qualifications such as the International Diploma in Toxicology examination. This could ensure that successful candidates have adequate knowledge of toxicology outside their own speciality and that they are able to apply the skills learnt for the examination when dealing with toxicological problems. This can also be linked to the UKRT. This would need to be considered and in line with the requirements for EUROTOX. Consideration should also be given to introducing phases to the exam, so degree courses can demonstrate employability by providing the content for students to pass phase 1.

Commercial CPD courses

Recognise the value and working together with high quality commercial CPD courses providing unique education and training for upskilling. Three recurrent CPD training courses with assessed LOs were found for this study. There may be additional commercial courses but these were not found through the internet searches and consultation of the BTS and UKRT websites. If there are others available, better signposting would be beneficial.

Funding of Training and Education Programmes

We will need to look for innovative ways for education and training providers to work to bridge the gap between funding in the public and private sector.

One possibility is government funding opportunities for education and training, and so it would be beneficial if the BTS monitored schemes and brought them to the attention of BTS members. The government has recognised that there is a national skills shortage and has set up the National Skills Fund, investing £1.6 billion in the next 3 years [21]. A government review of Post-18 education and funding [22] highlighted the requirements to reskill and upskill during our lifetimes and recommended funding be available to encourage retraining and flexible learning. Whilst the initiatives launched so far appear to mainly focus on Level 3-5 skill courses (Table 1), there does appear to be some provision for level 6, for example the Higher education short course (HESC) trial [23]. The Department for Education and Office for students launched this two million pound initiative in 2021 to fund higher education providers collaborating with industrial partners to develop short courses to address skill needs. Short courses include provision of level 6 (undergraduate degree equivalent) skill training. For example, Newcastle University in collaboration with Newcastle Health Innovation Partners will provide Digital Healthcare, two short courses to be studied across one or two academic years to address the acute digital health training needs of health professionals. A further 2.5 million pounds is available as bursary grants for students who need extra financial support to attend the HESCs.

Another is exploring research councils funding, for multi-centres for doctoral education, training and meeting the needs for the breadth of the industry represented in the area of Toxicology.

Summary

This study provides a clear understanding of the knowledge and skill requirements in regulatory toxicology through expert representative consensus, and the gaps in education and training provision for these. Regulatory toxicology requires an exceptional number of knowledge and skills attributes. There are only a few toxicology degrees now offered by Higher Education Institutions. Whilst these are validated by the QAA, and beneficial for a research career in toxicology and entry level regulatory toxicology, there are gaps in the provision of both the fundamental and thus applied understanding necessary for an intermediate and expert level career in regulatory toxicology. There were a very small number of accredited and assessed CPD courses found, and although they met some of the intermediate and expert level requirements in regulatory toxicology they did not meet all. There is no central hub that can signpost individuals and companies to quality education and training programmes. These findings are consistent with BTS member reports that there is a decrease in the number of skilled applicants for toxicology roles, and this appears to be particularly acute in regulatory toxicology applicable to human health.

From discussions with educators and industry representatives, it is clear that future education and training provision to fill the gaps identified must meet the needs of industry in terms of knowledge and skill requirements, but also be time and cost-effective, for industry to consider supporting them rather than running their own internal courses. Thus, any new programme or pathway offered to existing programmes would need to have the due diligence undertaken, full marketing done to ensure these would be financially viable and attract sufficient students to them and that there were employment opportunities available.

Consideration must also be given as to how we attract the best students, or trained scientists in other areas, to courses and the profession of regulatory toxicology and toxicology more broadly. Toxicology, and in particular regulatory toxicology, is not an attractive subject or profession. This is likely due to a number of factors including lack of understanding of the profession, more emphasis on other careers, and limited courses endorsed by the profession as industry-relevant.

In considering the above the next phase of this project could be instrumental in:

- designing and developing a programme/pathway to meet the actual gaps identified in phase 1. This would be working across the Higher Education Sector considering multiple different formats for a balanced (fundamental and applied) education including full time education programmes, Degree and Higher Degree Apprenticeships, On-line learning or a hybrid approach to education, stand-alone CPD courses and modules, multicentre doctoral training programmes.
- identifying key stakeholders who could provide support (time/money) to establish this
- identifying and communicating a development strategy for education and training programmes based on consultation of key stakeholders from across the membership spectrum.
- working with all stakeholders to ensure the success of the programme.
- considering applying for funding opportunities to pump prime these programmes through a Doctoral Training Centre for example.

RECOMMENDATIONS

Short to Medium Term

1. A “Hub” could be established, through the British Toxicology Society, to hold the data on all education and training courses available. A cost to “advertise” all courses could be levied which would help to fund this activity.

2. Consider how to improve prospective students’ understanding of toxicology and the global impact of toxicology.

3. The Advisory Board should review the evidence provided in this report and consider action that could be taken through the stakeholder group to address the knowledge and skill concerns identified.

4. In areas where evidence suggests that high level and professional skills are concerns across both industry and academia, action should be sought through all stakeholders including the Research Councils and appropriate Professional Bodies.

5. The pipeline for the development of appropriate knowledge and skills must be considered.

6. The stakeholders should monitor the critical disciplines in their area and raise concerns when it is becoming more difficult to recruit people with the skills required or when new needs are identified, so education and training provision can be focussed.

7. Ensure that the fundamentals required by employers are provided to students so they are able to be aware of the requirements for employment as a scientist in regulatory toxicology.

8. Creation of a network of toxicology educators, to offer mutual support and share best practice and tools would benefit those currently teaching which could be facilitated through an academic advisory group.

9. Secure knowledge and understanding of *in vivo* experimentation and data interpretation in courses, without the need for unnecessary animal experimentation, the BTS should try to facilitate the provision of teaching tools for this specific area.

10. Facilitate the provision of effective education and training through consultations with key stakeholders in Phase 2/ 3 of this work. In particular consulting with Early-Stage Toxicologists on their experiences on requirements needed to secure employment after leaving University.

11. Consider expanding the project to include identification of skills gaps in other regulatory toxicology areas including environmental toxicology and veterinary medicines.

Medium to Longer term recommendations

12. Consider a model for all stakeholders to come together to develop an industry relevant training programme. One idea would be a hub and spoke approach. In Phases 2/3 the advisory group should explore how to develop with relevant stakeholders which training courses in toxicology, or courses with a toxicology module, demonstrate that they are “industry relevant” and what is needed to help bridge gaps in the requirements to make these courses industry relevant. By doing so this would raise the profile of the profession to students and help academics justify their course and role. Options could include 1) course or module accreditation, or recognition using the knowledge and skills list in this project 2)

provision of a professional certificate, or working with other organisations to facilitate its provision, for example Phase 1 of the International Diploma in Toxicology.

13. Monitor government funding opportunities for education and training and bring them to the attention of the Advisory Group. Funding will be key to the next phases.

14. Consider how Industry can provide support for a training programme.

15. Working with stakeholders the Advisory Group should explore format and funding options for education provision that would

    - effectively meet the regulatory toxicology knowledge and skill requirements
    - attract people to the profession
    - be beneficial to the wider toxicology community, for example retaining research-active toxicologists
    - secure knowledge and understanding of *in vivo* experimentation and data interpretation in toxicology, without the need for unnecessary animal experimentation, which is an aim for Phase 2/3 where the provision of teaching tools for this specific area can be established and made available.

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Acknowledgements

I am very grateful to the members of the BTS Education and Training Advisory Group, Dr Phil Botham, Dr Emma Barnes, Dr David Gott, Dr Cath Mulholland and Professor Shirley Price, for their support and advice during phase 1 of this project. I am also very grateful to the experts below who contributed their time and expertise to the project

Dr Minako Allen	Exponent
Dr Camilla Alexander-White	RSC, MKTox & Co Ltd
Dr Kerry Broom	UKHSA
Dr Maria Baltazar	Unilever
Dr Damian Bowen	ERM
Lorraine Britton	Sequani
Dr Emma Barnes	Syngenta
Dr Phil Botham	Syngenta
Dr Ruth Bevan	IGHRC, IEH Consulting
Dr Jonathan Brown	University of Surrey
Dr John Clements	MHRA
Dr Philip Clay	Chorley Consulting
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Dr Frances Hill	BEIS
Mrs Laura Hunn	LabCorp
Dr Nik Hodges	University Of Birmingham
Dr Kirsti Hornigold	MRC Toxicology Unit ITTP
Dr Martin Hawes	University of Surrey
Dr Adeel Irfan	Shell
Dr Miriam Jacobs	UKHSA
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Dr Paul Russell	Unilever
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Dr Jason Shearer	UCB
Dr Scott Samuels	ERM
Dr Carol Strepka	Charles River
Professor Steve Tucker	University of Aberdeen
Dr Sarah Trinder	University of Surrey
Dr Karin van Ede	Postgraduate Education in Toxicology (PET)
Dr Lindsay Wright	AstraZeneca
Dr Ed Whittle	SC Johnson
Dr Simon Wilkinson	Newcastle University
Professor Matthew Wright	Newcastle University

Glossary

BTS	British Toxicology Society
CPD	Continuing professional development
CRO	Contract Research Organisation
EUROTOX	Federation of European Toxicologists and European Societies of Toxicology
GLP	Good laboratory practice
LOs	Learning objectives
NAMs	New approach methodologies
PG	Postgraduate
SOT	Society of Toxicology
UG	Undergraduate

Appendix 1. Template of Step 1 form to list knowledge and skill requirements

	Knowledge/skill Categories	
Core theoretical knowledge	Principles of mechanistic and mode of action toxicology	
	Principles of regulatory toxicology	
	Priniciples of hazard assessment	
	Principles of risk assessment	
	Principles of exposure	
Core experimental techniques	The scientific method (hypothesis formulation, hypothesis testing, experimental design, experimental analysis)	
	Basic laboratory bench practical skills	
	Computational modelling skills	
	Good laboratory practice	
	Data management	
	Statistical analysis	
Hazard Identification / Characterisation	Structure-activity relationships (NAMs) - study design and conduct	
	Structure-activity relationships (NAMs) - interpret data	
	Analytical methods	
	In vitro toxicity tests - study design and conduct	
	In vitro toxicity tests - interpret data	
	In vivo tests - study design and conduct	
	In vivo tests - interpret data	
	Human data (clinical, epidemiological, poisonings, case studies) - study design and conduct	
	Human data (clinical, epidemiological, poisonings, case studies) - interpret data / meta analysis	
	Weight of evidence and Intergrative approaches	
	Qualitative assessment of data	
Risk assessment	Traditional dose response assessment	
	Emerging dose response assessment	
	Exposure assessment	
	Risk characterisation	
	Uncertainty analysis	
	Regulatory and policy knowledge	
	Weight of evidence and Intergrative approaches	
Core skills	Presentation skills	
	Report writing skills	
	Project management	

Appendix 2. Consolidated list of 189 regulatory toxicology knowledge and skill attributes provided by experts in round 1 (n = 17). Full descriptions are included. In round 2 experts were asked to rate the importance of the skills for entry, intermediate and expert level. 1 = unnecessary, 2 = unimportant, 3 = important, 4 = necessary. Average scores for each attribute and level were calculated and the percentage of experts rating an attribute important or necessary. Consensus was defined at > 70% (shown in pink).

		Average score (n = 19)			% experts agree important or necessary		
		Entry	Intermediate	Expert	Entry	Intermediate	Expert
mode of action toxicology Principles of mechanistic and	Knowledge and understanding of **normal cellular biology and physiology of organs**	3.4	3.8	3.9	95	95	95
	Knowledge and understanding of the molecular, biochemical and cellular **mechanisms imitating toxicity; including** receptor and non receptor mediated toxicity, and site of contact effects e.g. irritation/corrosion etc which are important for acute toxicities but may underlie other adverse effects e.g. in the GI tract	2.9	3.6	3.9	79	100	100
	Knowledge and understanding of **target organ toxicity**; including toxic responses in the liver, kidney, heart, skin, blood, and nervous, respiratory, immune, cardiovascular and endocrine systems	2.9	3.6	3.9	79	95	100
	Knowledge and understanding of **carcinogenicity, mutagenicity and non-genotoxic carcinogenicity** (epigenetic mechanisms)	2.6	3.3	3.9	58	95	100
	Knowledge and understanding of **Teratogenicity, reproductive and developmental toxicity**	2.7	3.4	3.9	63	100	100
	Knowledge and understanding of **Adverse Outcome Pathways and Mode of Action frameworks** e.g. for skin sensitisation	2.6	3.4	3.8	58	95	100
	Knowledge and understanding of **new technologies to generate mechanistic knowledge** e.g. 'omics approaches, knock out animals	2.2	3.0	3.7	32	79	100
	Knowledge of toxicity **risks from new modalities** e.g. gene editing therapies, biological agents, antisense oligonucleotides, peptides, microbrobials	2.0	2.9	3.6	26	79	95
Principles of regulatory toxicology	Knowledge and understanding of the **history and development of regulatory toxicology**; including wider scientific, policy and societal developments and drivers and the difference to academic toxicology	2.5	3.3	3.8	53	89	100
	Knowledge of UK, EU and international **regulatory bodies** (Competent authorities) and their differing regulatory policies; including information requirements, acceptable approaches, 3Rs, preferences and biases	2.5	3.3	4.0	58	95	100
	Knowledge and understanding of the **risk assessment process**; including the risk assessment paradigm (hazard vs risk; assessment vs management), the implications of hazard and risk based regulation, where responsibility for different actions and activities lies (registrants, applicants, regulators, policy), differences in approach between products e.g. pharmaceuticals vs chemicals	2.7	3.6	4.0	68	100	100
	Knowledge and understanding of **perceptions, beliefs, uncertainties and realities in risk assessment**	2.2	3.2	3.9	37	89	100
Regulatory and policy knowledge	Knowledge of **currently accepted risk assessment approaches and principles and models**; including Codex principles and QRA models	2.1	2.9	3.6	26	74	95
	Knowledge of **REACH** history, current and future	2.1	2.8	3.5	21	63	89

	Knowledge of **OECD** guidelines	2.5	3.4	3.8	58	89	95
	Knowledge of **EFSA, JECFA, JMPR, Codex Alimentarius, WHO** principles / guidelines	2.2	2.9	3.6	32	68	95
	Knowledge of **ICH** guidelines (International Council for Harmonisation of Technical Requirements for Registration of Pharmaceuticals for Human Use).	2.2	2.9	3.5	37	74	84
	Knowledge of global **regulatory requirements for pharmaceutical development**; including taking into account the different types of modalities (small molecules, large molecules, new modalities)	2.0	2.8	3.3	26	63	79
	Knowledge of **EMA/MHRA** regulatory guidance and procedures	2.0	2.8	3.3	32	68	74
	Knowledge of **plant protection regulation; including** plant protection products (EC. 1107/2009)	2.2	2.8	3.3	32	58	79
	Knowledge of EU and US **medical device regulation**; including ISO test guidelines for medical device risk assessment/testing (ISO 10993/18562 etc.)	1.8	2.4	2.9	16	47	68
	Knowledge of **biocidal product regulation** requirements; including biocides (EU. 528/2012) legislation	2.2	2.8	3.4	32	63	89
	Knowledge of **classification and labelling regulations**; including thresholds and derogations, CLP, GHS, ECHA	2.2	2.8	3.5	32	58	89
Principles of exposure assessment	Knowledge and understanding of the **principles of absorption, distribution, metabolism and excretion**; including different routes of administration / exposure (dermal, oral etc) and the impact on absorption, transportation across membranes, bioavailability, drug-drug interactions and accumulation.	2.8	3.7	4.0	74	100	100
	Knowledge and understanding of **toxicokinetic parameters** (e.g. Tmax, Cmax, AUC) and factors that affect them e.g. TK multiple dosing effect, dose proportionality, TK sex differences	2.7	3.5	3.9	63	100	100
	Knowledge of **direct and indirect sources of exposure**; including intended e.g. pharma and unintended exposures e.g. food, occupational and environmental exposure; the impact of formulation and use on exposure, the persistence and motility of chemicals in the environment (eg metabolism, breakdown to smaller particles, dusts etc); differences between different populations	2.4	3.2	3.5	50	83	83
	Knowledge and understanding of **environmental and biomonitoring exposure measurements**; including the methods used in different scenarios, the limitations and how the data can be used.	1.8	2.5	2.9	16	42	68
	Knowledge and understanding of **experimental exposure measurements**; including Skin absorption testing OECD 428	2.2	2.8	3.3	33	61	78
identification Principles of hazard	Knowledge and understanding of **testing for different toxicities**; including acute toxicity, repeated-dose toxicity, genotoxicity and carcinogenicity, reproductive toxicity, skin and respiratory sensitisation, endocrine disruption	2.8	3.8	4.0	79	100	100
	Knowledge of national and international **hazard assessment test guidelines and guidance**; including ECHA and OECD test guidelines, their application, their limitations (e.g. The Bovine Corneal Opacity and Permeability Test Method (BCOP) can only be used to identify substances for Cat 1 and not classified but not Cat 2), and development and awareness these change over time and impact on interpretation of legacy data	2.2	3.1	3.6	42	68	95
	Knowledge and understanding of the **test material purity** and impurity profile, and its relevance to the substance registered / to be approved / authorised	2.4	3.4	3.8	53	84	100
	Knowledge of assessment of the **toxicology of metabolites**	2.5	3.5	3.9	53	95	100
Hazard identificati on in vivo	Knowledge and understanding of **existing in vivo tests for different toxicities** and their limitations e.g. endocrine disruption, carcinogenicity, developmental and reproductive toxicity, immunotoxicity	2.7	3.7	3.9	63	100	100

	Knowledge and understanding of **animal welfare, NC3Rs and Home Office Licence regulations**; including animal breeders, colony maintenance, screening for disease, shipping of animals, husbandry, acclimatisation, minimising animal suffering, enrichment requirements, recording keeping and GLP principles, Home Office Project, Personal, and Establishment Licence regulations	2.8	3.4	3.7	68	94	95
	Knowledge and understanding of **how to design an appropriate in vivo study** to measure relevant endpoints reproducibly, reliably and integrate animal welfare measures; including selection and justification of an appropriate species, selection of appropriate dose level setting (limit dose), regimen (toxicokinetic informed, half-life, accumulation, dose spacing), dose route and dose volume (consideration of non-physiological dose volume effects), knowledge of dose setting guidance documents e.g. ECHA guidance documents on acceptable doses for repeat dose studies and acceptability for hazard identification, timepoint for collection of data, appropriate comparison groups, vehicle control/water control, randomisation & allocation of animals to cages/groups, animal room set up and position of cages, number of animals per cage, position of cage on rack, acclimatisation procedures, recovery periods, monitoring health status, clinical signs, humane endpoints, combining endpoints e.g. bone marrow micronucleus bolt on to repeat dose toxicity study, appropriate statistics.	2.4	3.3	3.9	47	94	100
	Knowledge and understanding of **in vivo substance administration**; including oral in diet, water, or gavage, dermal, inhalation administration and experimental set-up	2.7	3.5	3.7	63	89	95
	Knowledge and understanding of **in vivo test measurements**; including clinical observations, ECG, Stats, Micronucleus, Plethysmography, JET, JET/BP, surgery, biochemistry, haematology, other clinical pathology endpoints, biomarkers of toxicity (options and validation), Neurotox endpoints such as Functional Observation Battery (FOBs) motor activity (MA)	2.6	3.4	3.7	58	95	100
	Knowledge and understanding of **sampling** from animals	2.4	3.2	3.5	47	84	95
	Knowledge and understanding of animal/**necropsy room procedures used in clinical and toxicological pathology**; including sterile / aseptic techniques, handling and processing of tissues and cells, necropsy, histology slide preparation and appreciation of the complexity and practical aspects (time) of the activities to avoid overloading and over complicating studies with endpoints.	2.3	3.2	3.6	42	89	95
	Knowledge and understanding of **deficiencies and failures of in vivo legacy data which would trigger new studies**	2.1	3.2	3.6	37	84	95
	To be able to **handle animals**	1.7	1.9	2.1	16	21	28
	To be able to accurately **prepare dose formulation**; including dose preparation challenges and analytical methods to confirm appropriate dose formulation, storing dose preps, frequency of formulation etc	1.9	2.3	2.6	26	42	53
	Knowledge of **how long it takes to undertake studies**, from placement to protocol generation, concentration selection, data review, draft report and finalisation	2.1	3.1	3.6	32	79	89

In vivo data interpretation	Knowledge and understanding of **in vivo measurements which can be suggestive of early adverse events** e.g. haematological / serum clinical chemistry parameters	2.7	3.4	3.9	74	89	100
	Knowledge and understanding of **normal and abnormal variability in in vivo data**; including clinical observations, animal behaviour	2.7	3.4	3.9	72	100	100
	Knowledge and understanding of the **impact of species, strain, sex, developmental stage and maternal toxicity on the interpretation of in vivo data**; including animal specific pathologies that are not relevant to humans e.g. thyroid homeostasis in rats / dogs vs. that in humans and strain lesions	2.6	3.4	3.9	58	95	100

	Knowledge and understanding of the **impact of dose selection on interpretation of in vivo data**; including impact of dose/time on body weight, food consumption and post dose observations, excessive toxicity, and dose normalisation e.g. for bioanalysis sample	2.6	3.6	3.9	63	100	100
	Knowledge and understanding of the **interrelationship and consistency between in vivo assessments parameters** to gain a wider understanding of the hazard	2.5	3.3	3.8	53	89	100
	To be able to **determine if the in vivo study is valid for the question being asked and complies with 3Rs principles** and UK home office legislation for animal experiments; including humane endpoints, the dose level and regimen, species selection, selection of surrogate implant sites	2.6	3.5	3.8	63	100	100
	To be able to **analyse and interpret different types of in vivo data using best practice;** including Bioanalysis, TK, ADA, clinical pathology data, clinical chemistry, functional observational battery data, neurological observations, carcinogenicity and genotoxicity test data, reproductive and developmental toxicity tests data, target organ toxicity data, immunotoxicity data	2.5	3.4	3.9	56	94	100
	To be able to **interpret in vivo data using statistics but not exclusively rely on statistics**; including being aware of surprising effects	2.5	3.4	3.8	53	95	95
	To be able to **use historical control data in data interpretation**	2.5	3.4	3.8	63	95	100
	To be able to use in vivo data to **define an adverse effect level**; including knowledge of adverse vs non adverse / adaptive effects, general toxicity vs specific effects, on target and off target effects, local vs systemic effects	2.7	3.6	3.9	68	95	100
	Knowledge and understanding of the **translation and clinical relevance of in vivo data to humans**; including the limitations of animal species for predicting human safety - information on relative potency and biological plausibility	2.6	3.5	3.8	58	95	95
	Knowledge and understanding of how in vivo data can be **used to define clinical start dose, stopping dose/exposure in clinical trials**	2.0	2.8	3.3	26	63	79
	Knowledge and understanding of how in vivo data can be **used in read across for hazard assessment of other chemicals**; including bridging principles	2.4	3.3	3.9	47	100	100

Hazard identification Analytical methods	Knowledge and understanding of the **analytical methods** used to assess analytes and what is measured; including HPLC, GC, Mass Spec, NMR accredited techniques assessing different analytes e.g. metabolites, extractables/leachables from medical devices in different matrices e.g. blood, urine	2.1	2.6	3.3	21	63	95
	Knowledge and understanding of how to **validate analytical methods for sensitivity and specificity and compliance**; including defined LOQ, LOD, assessing cross-contamination, QC checks	1.9	2.4	3.1	16	37	74

studies Hazard identification in vitro	Knowledge and understanding of **existing in vitro tests** and what is measured; including high-throughput screening assays, genetic tox assays, alternative reprotox assays, phototoxicity, eye irritation assays, OECD 428 skin absorption, skin irritation assays, skin sensitisation assays, respiratory toxicity assays, endocrine disruption receptor based assays, toxicogenomics, CALUX assays	2.5	3.3	3.7	53	89	95
	Knowledge and understanding of **in vitro hazard assessment test limitations and issues** e.g. solubility, a specific binding, actual v nominal conc, metabolic capacity	2.5	3.2	3.6	53	74	95
	Knowledge and understanding of **new in vitro tests and technologies and their limitations**; including the use of mechanistic knowledge and 3Rs principles to develop new in vitro approaches, new technologies such as microphysiological systems, NAMs, and the relevance of these emerging in vitro tests and technologies to hazard assessment and drug discovery/development	2.4	3.1	3.6	47	72	89

	Knowledge of **how to design an appropriate in vitro study** to measure relevant endpoints reliably and reproducibly; including selection of an appropriate in vitro test system e.g. suitable cell line, selection of appropriate concentrations and duration of exposure, appropriate positive and negative controls, suitable techniques and protocol and if the protocol is not validated how to validate beforehand, conduct of replicates, impact of cytotoxicity, appropriate statistics	2.3	3.0	3.3	37	79	89
	Knowledge and understanding that **deficiencies and failures of legacy in vitro data which would trigger new studies**	2.2	3.0	3.5	26	74	89
	Knowledge of how laboratories **maintain their cell lines to ensure genetic drift is controlled**	2.0	2.4	2.8	21	32	58
	To be able to competently **perform in vitro studies**	2.1	2.4	2.6	37	47	58

In vitro data interpretation	To be able to **determine if the in vitro study is valid for the question being asked**; including study limitations / applicability domains	2.3	3.0	3.7	42	74	95
	To be able to **analyse and interpret different types of in vitro data**; including data from in vitro genotoxicity tests and endocrine disruption assessments, and new approach methodologies such as AOPs, and with the use of regulated test guidelines e.g. OECD	2.1	3.1	3.7	37	79	95
	To be able to **interpret in vitro data and not ignore extraordinary results a**s these can lead to greater understanding of a complex scenario	2.2	3.1	3.6	39	89	95
	To be able to **determine the robustness of the laboratory** and use this to interpret the in vitro data; including using historical control ranges, validation of endpoints, use of positive and negative controls	1.8	2.9	3.4	32	63	84
	To be able to **determine if in vitro data is reproducible and coherent with data from other in vitro studies**	1.9	2.9	3.5	32	63	89
	To be able to **interpret in vitro data in the context of in vivo data; including (Quantitative) in vitro to in vivo extrapolation (QIVIVE/ IVIVE)**	1.9	2.9	3.6	28	72	89
	Knowledge and understanding of the **application of in vitro high-throughput screening assay data** in regulatory assessments	1.9	2.7	3.4	32	58	84
	Knowledge and understanding of the **translation and clinical relevance of in vitro endpoints**; including consideration of Adverse data accompanied by overt exogenous factors: cytotoxicity, solubility, pH, osmolality	2.1	2.9	3.5	37	68	89
	Knowledge and understanding that **deficiencies and failures of legacy in vitro data which would trigger new studies**	1.9	3.1	3.5	26	79	95

Hazard identification in silico studies	Knowledge and understanding of **in silico modelling tools**, their current uses and their limitations; including (quantitative) structure activity relationship models including ToxCast, data clustering tools, PBPK models, read across; current use e.g. use of SAR predicting mutagenicity and applicability domains, and when they should and should not be used	2.3	2.9	3.5	47	79	84
	Knowledge and understanding of the **derivation of the data underpinning a model** and curation of data in a model; including importance of well-conducted and accessible historical information and honest data brokering of data including toxicogenomic data, data from CALUX assays etc	1.7	2.4	3.1	16	42	68
	Knowledge and understanding of **how in silico models are validated** e.g. NAMs	1.7	2.4	3.1	12	47	65
	Knowledge and understanding of **chemical structural and physiochemical properties** for use in computational models; including functional groups, reactivity etc, that can be used for chemical grouping and Knowledge key chemistries of concern in structure activity relationships e.g nitrosamines	1.9	2.8	3.2	32	74	83
	To be able to **use in silico models**; including performing sensitivity analysis	1.7	2.5	3.1	21	58	84
	Knowledge and understanding of **programming and software development**	1.5	2.1	2.3	5	32	42
	Knowledge and understanding of **AI and machine learning**	1.6	2.2	2.5	11	37	53

interpretation data In silico	To be able to **determine if an in silico study method is appropriate** for the question being asked and whether it meets legislative information requirements	1.9	2.6	3.5	32	68	89
	To be able to **analyse and interpret different types of in silico study data using best practice**; including understanding the rationale to support toxophore arguments that are deemed relevant or can be dismissed (i.e. structural hinderance)	1.9	2.7	3.3	21	68	89
	To be able to interpret in silico data to **define a threshold of concern / point of departure**	2.0	2.8	3.2	33	72	83
	Knowledge and understanding of how in silico data can be **used in AOPs and read across**	2.2	2.8	3.2	37	63	79
	To be able to apply different approaches to **classify mixtures under CLP** (with data, without data on the mixture)	1.8	2.6	3.1	16	47	74
	Knowledge and understanding of how in silico data can be **used for in vivo predictions** and used in in vivo study design / negate the need of an in vivo study	2.0	2.8	3.3	26	68	84
Hazard identification human studies	Knowledge and understanding of **epidemiology / observational study designs and conduct and limitations**; including different exposure scenarios - accidental / case studies / occupational and Spurious correlation examples to communicate the fallibility of this methodology	2.1	2.7	3.2	32	63	79
	Knowledge and understanding of **clinical / experimental trial designs and conduct**; including clear aim and objectives and principles of randomised, double blind design etc, how clinical safety data are captured for pharmaceuticals	2.1	2.6	3.2	37	68	84
	Knowledge and understanding of **prospective and retrospective studies**; pros and cons	1.8	2.4	3.1	16	53	84
	Knowledge and understanding of **case reports** including their limitations	1.8	2.4	3.1	16	47	74
	Knowledge and understanding of **confounders in human studies and population variance**	1.8	2.4	3.1	21	53	68
	Knowledge and understanding of **ethics and volunteering processes** and considerations in human studies	2.0	2.5	2.9	37	58	68
Human study data interpretation	To be able to determine if the data from a **human study is relevant to the application of concern** and reliable; including hierarchy of evidence and interpreting relevance and reliability of external data e.g. Klimisch [24]	2.1	2.9	3.5	37	68	89
	To be able to identify **genetic variation** in treatment response and biomarkers from human study data	1.7	2.6	3.0	11	50	72
	To be able to **integrate human study data with other data types**; including translation of non-clinical toxicology data to clinical data/outcomes	1.9	2.8	3.4	28	61	83
Qualitative data assessment	Knowledge and understanding of the **techniques used to assess qualitative data**; including data from in vitro, in vivo, human studies, external literature searches, public domain data and legacy data, and techniques to assess appropriateness, relevance and reliability e.g. Klimisch [24]	2.3	3.2	3.6	42	89	100
	Knowledge of the **impacts of qualitative versus quantitative risk assessment on risk management measures**	2.2	3.0	3.6	32	84	100
Exposure assessment	Knowledge and understanding of **effective methods / modelling tools for internal and external exposure assessment**; including the concepts and mathematics underpinning the tools, what to use when and the data required for them	2.2	2.8	3.3	37	68	84
	Knowledge and understanding of **deterministic exposure modelling tools**: oral, dermal and inhalation routes.	2.1	2.8	3.4	32	63	84
	Knowledge and understanding of **probabilistic exposure modelling tools**: e.g. ConsExpo, FAIM, PACEM, Crème, 2-box	1.9	2.6	3.2	21	58	74

	Knowledge and understanding of **aggregated and combined exposure modelling tools**	2.0	2.7	2.9	21	53	68
	Knowledge and understanding of **estimating the internal dose**; including using forward and reverse internal dose modelling tools and route to route extrapolation	2.2	3.0	3.5	26	68	95
	Knowledge and understanding of **pesticides exposure modelling tools**	1.9	2.5	2.8	16	37	58
	Knowledge of **refinement options** to exposure assessments e.g. in silico options	2.1	2.8	3.3	28	67	78
	Knowledge and understanding of **using epigenetics and historical exposure in exposure assessments**; can it be applied, does it work.	1.9	2.5	2.8	21	53	63
	To be able to **develop and define realistic exposure scenarios**; including consideration of patterns of the cohort to be modelled, vulnerable populations (age etc), acute vs chronic, acceptable mitigation measures and regulatory guidelines e.g. REACH/CLP	2.1	2.7	3.3	26	58	79
	To be able to **define exposure-specific endpoints** and separate portal of entry and systemic effects	2.1	2.8	3.5	33	61	94
	To be able to **estimate dietary exposure**; including use of surveys (e.g. consumption) and occurrence	2.1	2.8	3.3	26	63	84
	To be able to **estimate exposure and release dynamics for substances leaching from medical devices**	1.6	2.3	2.8	11	42	58
Dose response assessment	Knowledge of currently **accepted and emerging dose response assessment approaches** and their advantages and disadvantages; including using new "omics" and pathway approaches, considering dose response in terms of pharmacokinetics (importance of Cmax and AUC) and approaches for threshold vs non-threshold effects	2.4	3.1	3.6	47	74	100
	Knowledge and understanding of **dose response curves**; including thresholds and hormesis, and the impact of study design on dose response curves	2.7	3.5	3.9	68	95	100
	Knowledge and understanding of the **derivation of toxicology endpoints / points of departure from dose response data**; including NOAEL, NOEL, LOAEL, LOEL, DNEL, MTD (maximum tolerated dose) from different types of data including NAMs, and understanding the practical difficulties in dose selection e.g. selecting the correct reference point for different populations and exposure durations	2.8	3.6	3.9	79	95	100
	To be able to **compare data against controls and Predose phase**	2.6	3.4	3.8	63	89	95
	To be able to **calculate the benchmark dose** using benchmark dose software and interpret BMD analysis	2.3	3.1	3.6	44	78	89
	Knowledge and understanding of **how the dose response (shape) can be used to determine dosing in clinical trials**; including the start dose and MABEL vs NOAEL	2.0	2.6	2.9	33	61	72
Uncertainty analysis	Knowledge and understanding of **uncertainty and sources of variability in risk assessment data**; including understanding uncertainty vs variability, data gaps, uncertainty in the point of departure (e.g., NOAEL/LOAEL versus BMDL), impact and relevance of exposure data percentiles, sensitivity analysis e.g. in modelling	2.6	3.2	3.8	63	79	100
	Knowledge and understanding of **uncertainty between species**; including allometric scaling and human relevance, concordance and translation	2.5	3.3	3.8	63	84	100
	Knowledge and understanding of the **application of uncertainty and uncertainty factors in risk based decisions**; including appropriate application under different circumstances, mixture assessments and different approaches, global approaches / legislative requirements to application of safety assessment factors and use of the precautionary principle / conservatism	2.4	3.3	3.7	56	83	94
	To be able to **communicate uncertainty** associated with a risk assessment	2.6	3.2	3.8	58	79	100

Integrated approaches to risk assessment	Knowledge of currently **accepted integrated approaches**; including Integrated approaches to testing and assessment (IATAs) from OECD, EFSA, SETE and case studies,	2.2	3.1	3.6	32	79	89
	Knowledge and understanding of **when and how to apply integrated approaches** to testing and assessment; including knowledge of IPS frameworks and AOP's to pull together expected and unexpected evidence	2.2	3.0	3.5	32	74	89
	To be able to **assess and weigh individual lines of evidence**; including interpreting complex "standard" and "non-standard" information e.g. from NAMs, and not relying exclusively on statistics, evaluating the individual lines of evidence for biological plausibility and coherence, reproducibility and reliability and understanding the uncertainties e.g. primary vs secondary effects and activity in in vitro systems vs adverse effects in intact organisms, and finally assigning weight of evidence	2.2	2.9	3.6	32	68	89
	To **be able to apply integrated approaches** to integrate in vitro, in vivo, multiple endpoints and external literature; including A0Ps	2.3	3.2	3.7	42	89	100
	To be able to **include appropriate subpopulations in the evaluation**	2.1	2.9	3.5	28	72	89
	Knowledge and understanding of **safety windows in integrated approaches** to assess data; including exposure multiples	2.3	3.0	3.4	32	74	89
	To be able to conduct a **meta-analysis or systematic review** of relative data; including understanding bias	1.9	2.7	3.1	21	63	84
	Knowledge and understanding of **environmental toxicology and exposure of the general population through emissions into air/water/soil, in relation to medicines**	1.9	2.5	2.8	21	53	68

Risk Characterisation	To be able to **interpret test data for risk characterisation using the appropriate approach**; including adverse vs non adverse / adaptive effects, local vs systemic effects, threshold vs non-threshold substances, primary vs secondary effects, on target vs off target effects	2.5	3.3	3.7	58	79	95
	To be able to **perform a risk characterisation;** including selecting the appropriate endpoint of concern , applying the route and/or endpoint specific PoD, incorporating the degree / likelihood of exposure, putting toxicology endpoints and reference values in context and using AOPs and MOAs in risk assessment	2.3	3.3	3.7	47	79	95
	To be able to **derive a threshold of toxicological concern**	2.4	3.4	3.9	50	94	100
	To be able to **derive safety margins**; including application of PODs e.g. from NAMs, and application of theoretical / measured exposure in the safety margin derivation	2.4	3.4	3.9	47	89	100
	Knowledge and understanding of **route to route extrapolation**	2.4	3.2	3.8	58	84	100
	Knowledge and understanding of **risk assessments for identified susceptible populations** e.g. juvenile vs adult	2.3	3.3	3.7	53	79	95
	Knowledge of **safety margins and their application to understand risk**; including Margin of Safety, Margin of exposure and Margin of internal exposure, Health based guidance value approaches and their application e.g. in pharmaceutical development	2.6	3.4	3.7	68	79	100
	Knowledge and understanding of **Category 4 Screening levels**(C4SLs) for risk characterisation of contaminated land	1.4	1.9	2.4	0	26	47
	Knowledge and understanding of **reference values** for different chemical regimes (REACH, pesticides, biocides)	2.4	3.1	3.5	47	74	89
	Knowledge and understanding of **risk / benefit analysis in risk based decisions;** risk benefit for pharmaceuticals and how it applies to different patient populations	2.0	2.7	3.1	22	56	83
	Knowledge and understanding of **additional considerations in risk assessment for pharmaceuticals**; including monitorability, reversibility and the patient population	2.1	2.5	2.9	33	39	61
	Knowledge and understanding of **risk assessments in emergency situations**	2.0	2.5	3.0	26	47	63
	Knowledge and understanding of **risk assessment for medical devices**	1.9	2.3	2.8	16	32	58

	Knowledge and understanding of **occupational risk assessments,** including WELs, COSHH, Chemical & Mutagens Directive, ALARP, difference between WELs and DNELs	1.9	2.5	3.1	16	58	79
	Knowledge and understanding of **how to derive NESIL** (no expected sensitization induction level)	2.1	2.7	3.4	37	58	84
	Knowledge and understanding of **risk characterisation ratios**	2.1	2.8	3.3	37	58	79
	Knowledge and understanding of **risk management measures**	1.9	2.6	3.2	32	63	79
	Knowledge and understanding of the **use of post market/clinical data to address specific toxicological risks**	1.7	2.3	3.1	22	50	78
statistical analysis The scientific method and	To be able to **formulate a problem and generate a testable hypothesis and design a robust experiment** to test the null hypothesis including validation and positive and negative controls.	2.6	3.2	3.5	63	84	89
	Knowledge and understanding of the **use of statistics in study design** e.g. using power calculations to determine sample size	2.6	3.2	3.5	68	89	95
	Knowledge and understanding of the **selection of the appropriate statistical test for analysis of different types of data**; including parametric vs non-parametric data and statistical tests generally used for organ weights, clinical pathology and microscopic pathology	2.3	3.2	3.5	53	84	100
	To be able to **conduct basic statistical analysis and use statistical analysis software**; including normal / non-normal distributions, parametric and non-parametric approaches, ANOVA, pairwise comparisons, two sample t-tests, correlation / regression analysis	2.3	2.8	3.2	47	68	84
	To be able to i**nterpret the statistical test results and distinguish between a statistically significant result and a biologically relevant result / adverse effect**	2.5	3.3	3.7	53	95	100
	Knowledge and understanding of the **generation of historical control data, and statistical methods used to interpret it**	2.4	3.1	3.7	53	89	100
	Knowledge and understanding of **data mining**	2.0	2.7	3.1	32	63	84
	Knowledge and understanding of **Bayesian approaches in risk assessment**	2.1	2.6	3.1	32	58	74
Basic laboratory skills	To be able to competently **perform common laboratory techniques, use common laboratory equipment and work safely in the laboratory**; including pipetting, weighing, centrifugation, HPLC	2.5	3.0	3.1	58	74	74
	To be able to perform **peer reviews of laboratory practices**; including pathology peer review	1.6	2.2	2.9	11	47	74
	To be able to **safely handle radiochemical and follow radiochemical handling regulations**	1.5	1.9	2.2	5	21	32
	Knowledge and understanding of **GMO regulations**	1.7	2.1	2.4	16	21	42
Good laboratory practice	Knowledge and understanding of the **principles of GLP, why it is important and GLP roles and responsibilities**; including the implications of GLP system failures and the roles of role study monitor and study director	2.6	3.4	3.7	68	84	95
	Knowledge and understanding of **GLP procedures and study conduct and what it means in reality in the laboratory**; including training records, SOPs, experimental records, audits, test article requirements, multisite studies and archiving principles	2.6	3.4	3.6	68	79	95
	Knowledge and understanding of **how to determine if a study has followed the principles of GLP**; including approaches to assess quality e.g. Klimisch system to help score relevance and reliability [24]	2.6	3.5	3.8	74	84	100
	Knowledge and understanding of **which studies are done to GLP** e.g. 28 day and 90 day, and why GLP may not be instigated for some studies e.g. no available TG, bespoke mechanistic work	2.5	3.5	3.7	63	89	100
	Knowledge of **GLP documents** e.g. UK, OECD consensus documents and advisory documents relevant to tox studies	2.4	3.2	3.5	53	79	95

Data management	Knowledge and understanding of **the principles and importance of data curation**; including clear data recording, data retention, understanding copyright if external information, maintaining data integrity and security and quality control checks	2.4	3.2	3.5	47	84	89
	To be able to **record data and ensure the integrity and quality**; including paper data and use of electronic data capture / study management and monitoring software e.g. Pristima system,	2.3	3.1	3.3	47	74	79
	To be able to **analyse and visualise data using electronic tools**	2.6	3.2	3.5	58	79	89
	To be able to **use fielded databases and chemical substance databases** e.g. EINECS (European Inventory of Existing Commercial chemical Substances), International Nomenclature of Cosmetic Ingredients (INCI), IUCLID (International Uniform Chemical Information Database), CAS (Chemical Abstracts Service)	2.2	2.9	3.2	32	84	89
	To be able to **produce Standardization for Exchange of Nonclinical Data (SEND) submissions** to the Food and Drug Administration (FDA)	1.4	1.8	2.3	0	21	47
Presentation skills	To be able to **prepare and deliver information in a clear, concise, organised format and demonstrate technical breadth, depth and attention to detail using presentation software** e.g.PowerPoint	3.0	3.7	4.0	84	100	100
	To be able to **prepare and deliver different types of presentations to different audiences**; including elevator pitches for effective networking, 10-15 minute conference presentations, 45-60 minute lectures to experts, non-scientists/public, stakeholder management and business i.e. translating science into money	2.6	3.5	3.9	58	89	100
	To be able to **present evidence at an audit committee/inquiry**	1.6	2.6	3.2	11	58	79
	To be able to **act as an expert witness**	1.4	2.3	3.2	0	53	84
Writing skills	To be able to **write clearly and concisely and pay attention to detail**	3.4	3.8	4.0	89	100	100
	To be able to **write a study report**; including presenting data and interpretation with clarity, and integrating information internal to a study / external information, your information in context with current knowledge	2.7	3.5	3.6	68	89	84
	To be able to evaluate, review, and **summarise information from a study report**	3.3	3.8	4.0	95	100	100
	To be able to **use effective literature searching strategies and identify sources of authorative evidence**	3.3	3.8	3.9	89	100	100
	To be able to **write a literature review**	3.2	3.6	3.8	84	100	95
	To be able to **evaluate, integrate and summarise information for a policy question**; including weight of evidence position papers, technical briefs for policy makers	2.3	3.1	3.8	37	84	95
	To be able to **write regulatory submission documents and meet regulatory reporting requirements**; including comprehensive technical safety dossiers for ECHA/HSE or the SCCS or EFSA/FSA, complete an IUCLID file for REACH	2.0	2.9	3.4	26	68	84
	To be able to **write a scientific article for journal publication**	2.6	3.2	3.6	53	74	95
	To be able to **explain complex scientific issues to a non-expert audience**; including explaining the rationale behind decision making	2.5	3.3	3.8	53	89	100
	To be able to **communicate risk to policy** colleagues and members of the public	2.1	2.9	3.5	37	68	79
Project management skills	To be able to **manage time**; including organising schedules, multi-tasking numerous projects and prioritising work to meet tight deadlines while maintaining the highest standards of quality.	3.1	3.6	3.8	84	95	95
	To be able to **plan, coordinate and progress different aspects of a project**; including use of management tools available	2.6	3.4	3.6	58	95	95
	To be able to **work within a multidisciplinary team**	3.3	3.7	3.9	95	100	100
	To be able to work **manage and negotiate with stakeholders**	2.4	3.3	3.8	42	89	100

	To be able to **advocate**	1.9	3.0	3.6		26	79	95
Career	To be able to **write a CV**	3.2	3.4	3.4		79	89	79
	Knowledge and understanding of **working in government agencies** e.g. HSE, HSA, EA	1.9	2.5	2.9		21	53	63
					> 70%	17	110	164
					<70%	172	79	25

Appendix 3. Curricula from Postgraduate Education in Toxicology Curriculum (Netherlands) **https://www.toxcourses.nl/curriculum/** Accessed March 2022.

Module in Human exposure assessment Learning objectives

- Understand the basic principles of exposure assessment, including how exposure routes impact on toxicokinetics and internal dose
- Understand the strengths and limitations of exposure measurements and modelling in human health risk assessment
- Be able to statistically analyse and interpret the data from exposure measurements and exposure modelling in risk assessment
- Be able to apply exposure assessment in multiple contexts

Module in Human exposure assessment content

- Scenarios, determinants and routes of exposure
- Exposomics
- Strategies and design for exposure studies
- Measuring external and internal (biomonitoring) human exposures
- Quality assurance in exposure studies
- Statistical methods to analyse exposure measurement data
- Deterministic vs. probabilistic modelling approaches
- Modelling of exposure and dose/ Toxicokinetics and PBK modelling
- Aggregate and cumulative exposures to chemical substances
- Assessing exposures with biological markers

Module in Legal and Regulatory Toxicology Learning objectives

- have obtained knowledge on the general approach of regulatory toxicology of chemical substances;
- have learned how to apply the science behind the risk-based decision making;
- have obtained knowledge on the practical aspects of the interpretation and presentation of experimental results in the framework of standard setting, notification and registration of substances;
- have obtained insight in the role of different (inter)national authorities in the field of regulatory toxicology;
- have obtained insight in the role of toxicologists in the field of regulatory toxicology, either working for a national or international regulatory authority, for industry or for other stakeholders

Module in Laboratory Animal Science Learning objectives

- possess the necessary knowledge for responsible animal handling and also obtained some practical experience in this respect;
- have knowledge of the possible impact of environmental and procedural factors on experimental results;
- have knowledge of the impact of diseases in laboratory animals on the experimental approach and knows about possible health monitoring;
- know about safety aspects and occupational health when working with laboratory animals;
- know about the specific demands that are necessary for a correct preparation and performance of animal experimental techniques and research;
- know the possibilities that statistics can offer to optimize the use of laboratory animals;
- know about the possibilities and limitations of alternative techniques;
- are familiar with legislation concerning the use of laboratory animals;

- know about basic principles, which guide towards the ethical judgement of animal experiments

Module in risk assessment Learning objectives

- have acquired general knowledge and understanding of the methods and procedures used in environmental and human health risk assessment and the interpretation of toxicological data that form the basis of a risk assessment;
- have acquired insight in how to perform risk assessments in specific areas of chemical applications;
- have insight in computer models for estimating exposure and risk;
- have shown to be able to handle a case study on a risk assessment and to communicate this to fellow-participants.

Module in risk assessment content

- General aspects of toxicological risk assessment
- Risk assessment in the environment
- Risk assessment of crop protection agents
- Risk assessment of industrial chemicals
- Risk assessment of food, food components and food additives
- Risk assessment of drugs
- Risk assessment of cosmetics
- Risk assessment of household chemicals
- Models on risk in consumer exposure

Appendix 4. British Pharmacology Society Undergraduate Curriculum
https://www.bps.ac.uk/education-engagement/teaching-pharmacology/undergraduate-curriculum-(1)/undergraduate-curriculum Accessed January 2022

Core knowledge
Having successfully completed an undergraduate degree in Pharmacology, graduates will have knowledge and understanding of:

Related disciplines
- Life sciences e.g. molecular biology, physiology
- Relevant mathematics
- The basics of medicinal chemistry, including the principles behind structure activity relationships
- How related disciplines can yield insights in pharmacology and vice versa

Theoretical principles of drug action
- Drugs that can be used in health and disease, giving examples from body systems
- How drugs interact with their targets, including drug-receptor theory
- Pharmacodynamics (molecule to whole organism)
- Pharmacokinetics (absorption, distribution, metabolism and excretion)
- How physiological and pathophysiological processes are affected by drug action
- Pharmacogenomics
- Principles of toxicology and their application in safety pharmacology
- Principles of translational research and experimental medicine

Methodological principles
- Qualitative and quantitative statistical tools and analytical methods used to interpret pharmacological data
- The scientific method (hypothesis formulation, hypothesis testing, experimental design, experimental analysis)
- Appropriate and emerging methods for interrogating the pharmacodynamic effects of drugs
- Appropriate and emerging methods for interrogating the pharmacokinetic effects of drugs
- Drugs as pharmacological tools in scientific research
- The principles of reduction, refinement and replacement in the use of animals in research

Drug discovery & development
- The multidisciplinary nature of drug discovery and development and the pivotal role played by pharmacology
- The stages of drug discovery and development
- Principles of clinical trial design
- How knowledge of pathophysiology can yield insights into drug targets and new therapeutic avenues
- Emerging therapeutic avenues
- The use of gene modification techniques in drug discovery and development
- Commercial drug discovery techniques
- How medicine formulation impacts on drug action
- Regulatory processes to include medicine quality, safety and effectiveness
- The challenges associated with developing and assessing the efficacy and safety of new therapeutic approaches

The societal impact of the discipline
- The ethical principles of research, including clinical trials and animal research (design, implementation and reporting)
- How pharmacology relates to social challenges and public health

- The impact of pharmacology on patient care with respect to the safe and effective use of medicines
- The various career paths and opportunities afforded by a pharmacology degree

CORE SKILLS

Experimental techniques

- Be able to formulate a scientific hypothesis
- Implement principles of good experimental planning and design
- Identify the most appropriate statistical approach
- Be able to make appropriate decisions about methodology when designing a study
- Be precise and accurate when performing core laboratory skills
- Carry out experiments following principles of Good Laboratory Practice
- Be able to use quantitative methods to collect, process and present data
- Be able to use in vitro techniques in pharmacology
- Have the necessary theoretical and/or practical training to be able to use in vivo techniques in pharmacology

Data handling & analysis

- Identify and use information from appropriate and reliable sources
- Integrate information from a range of sources and critically evaluate it
- Apply and interpret appropriate statistical tests correctly
- Use a common statistical software package
- Accurately record and reference source material
- Analyse and interrogate large data sets

Working practices

- Keep up to date with the relevant literature and developments in pharmacology
- Perform research efficiently through good planning and management
- Organise and accurately record information, for example, in a laboratory book
- Work independently
- Work constructively in small groups or teams
- Communicate effectively to scientific and non-scientific audiences (including written and oral forms)