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Framework for developing an exposure science curriculum as part of the European Exposure Science Strategy 2020–2030

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ABSTRACT

Background: Evaluating and managing exposures to chemical, physical and biological stressors, which frequently interplay with psychological stressors as well as social and behavioural aspects, is crucial for protecting human and environmental health and transitioning towards a sustainable future. Advances in our understanding of exposure rely on input from well-trained exposure scientists. However, no education programmes in Europe are currently explicitly dedicated to cover the broader range of exposure science approaches, applications, stressors and receptors.
Objective: To address this challenge, a curriculum is needed that yields credible, well-defined career pathways in exposure science.
Methods: Needs and conditions for advancing exposure science education in Europe were identified. As a starting point for a way forward, harmonised learning outcomes for exposure science were defined at each level of the European Qualifications Framework. The course programme coordinators were recruited for three varying courses, with respect to the course level and the proportion of the curriculum dedicated to exposure science. These courses were assessed via our systematic course review procedure. Finally, strategic objectives and actions are proposed to build exposure science education programmes.

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Results: The ISES Europe 'Education, Training and Communication' expert working group developed a framework for creating a viable exposure science curriculum. Harmonised learning outcomes were structured under eight learning levels, categorised by knowledge, skills and competence. Illustrative case studies demonstrated how education providers integrated these learning outcomes for their educational context and aligned the overall exposure science curriculum.

Conclusions: The international recognition and adoption of exposure science education will enable advances in addressing global exposure science challenges for various stressors, from behavioural aspects from individual to population scale, and effective communication between exposure scientists and relevant stakeholders and policy makers, as part of the European Exposure Science Strategy 2020–2030.

1. Introduction

The advancement of scientific knowledge about human and environmental exposure to chemical, physical, biological and psychological stressors is vital for protecting human and environmental health, boosting green innovation, and developing sustainable technologies and products across sectors (Lioy, 2010; National Research Council, 2012; Lioy and Smith, 2013; Shin et al., 2015; Bruinen de Bruin et al., 2019; Fantke and Illner, 2019; Fantke et al., 2020b; Wood et al., 2020). Exposure science is a multidisciplinary field combining expertise from various disciplines, including epidemiology, occupational hygiene, environmental science, veterinary and agricultural sciences, toxicology, and sustainability assessment. Elements of exposure science exist in other domains, such as environmental health and public health, for understanding the environmental, toxicological, physiological and sociology adverse effects of these stressors. Exposure science links stressors with human and environmental receptors to quantify and characterize related health implications (Lioy, 2010). It plays a central role in developing effective exposure and risk management strategies, progressing sustainable-by-design (SSbD) solutions to local and global challenges (e.g. COVID-19 and other pandemics, environmental pollution, and climate change) (Kjellstrom et al., 2018; Bruinen de Bruin et al., 2020; Deziel et al., 2020; Fantke et al., 2021; Jolliet et al., 2021; Lim, 2021; Kosnik et al., 2022; Persson et al., 2022). Exposure science seeks to improve our understanding of risk through better comprehension of exposures, and reliable exposure information in health and safety, security and sustainability science and policy, is needed. There is increased demand for well-trained exposure scientists at different levels across various stakeholder groups (Cohen Hubal et al., 2011; National Research Council, 2012; Deziel et al., 2020). A scientific framework supporting regulatory risk assessment and management (e.g. data collection, data analysis, model development and application) and evaluating exposure sources, stressors, and receptors at relevant spatiotemporal scales will facilitate this growth. The importance of exposure science was very apparent during the COVID-19 pandemic, including its relevance for psychosocial and mental health issues (Gruber et al., 2021) and assisted in identifying vulnerable groups, elucidating exposure pathways and imposing mitigation factors to minimize public health impacts from the pandemic (Deziel et al., 2020).

Combining exposure and hazard information in toxicology and epidemiology is a feature of global chemical policies and decision-making frameworks. However, this has often been perceived as the most challenging (and frequently the least defined and weakest) step in different regulatory frameworks and assessment tools (Fantke et al., 2016; Greggs et al., 2019; Tickner et al., 2019).

In Europe, exposure information is needed in various regulatory frameworks (Bruinen de Bruin et al., 2022), requiring literacy in handling a large diversity of data and methods (Pleil et al., 2012; Lioy, 2015; Fantke et al., 2020a). The lack of formal education and training in exposure science in Europe poses a threat to the development of urgently needed baseline acceptance criteria for exposure data, methods and tools, and aligned use of exposure information across current and future EU legislation. A framework strategy is urgently needed to build a curriculum appropriate to European conditions to match the increasing demand (Fantke et al., 2020b). For example, in the past 20 years, the European chemical legislation has been strengthened, including REACH legislation, which requires exposure information for regulatory evaluation and an increasing need for explicitly trained exposure scientists in the respective agencies, i.e. the European Food Safety Authority (EFSA) and the European Chemicals Agency (ECHA). The need for well-trained exposure scientists will be even more pronounced to support new initiatives and policy ambitions (e.g. the European Green Deal (European Commission, 2019), PARC[3]). Furthermore, the proposed strategy will also contribute towards elevating the advancement of exposure science as independent discipline.

In the United States, some institutions already provide graduate programmes and modules in exposure science (Dvonch, 2020; Adetona, 2021). In Europe, short courses in exposure science are emerging, but no stand-alone higher educational programmes for exposure science exist. Instead, exposure science topics are integrated into education curricula of other fields (e.g. occupational health, occupational hygiene and health, toxicology and risk assessment). Differences in the science-to-policy process, including directives, regulations and practices between Europe and other continents, require tailored education and training. Commitment to professional development should advance this independent yet strongly interconnected scientific field.

Firstly, European exposure science education and training programmes need consistent and unambiguous learning outcomes within a curriculum framework that can be tailored to individual countries and decision contexts across Europe, accommodating future global guidance initiatives (e.g. via OECD's Working Party on Exposure Assessment). A harmonised European exposure science curriculum will assist in establishing exposure science as a distinct academic discipline recognized by European regulators and experts in risk assessment and other relevant fields. An important consequence of aligned, structured training will be the promising and dedicated career pathway opportunities in exposure science.

As part of the ISES Europe 'European Exposure Science Strategy 2020–2030', this paper provides a framework for advancing exposure science education and training in Europe. Three main objectives are: (a) to develop an aligned set of learning outcomes for exposure science, (b) to demonstrate in a case study and provide guidance on how to update existing and develop new training courses and (c) to propose an action plan that identifies specific tasks, resources, needs and timelines for building a full exposure science curriculum.

2. Needs for an improved exposure science education

Establishing a sustainable educational field requires several elements, including scientific recognition, defined career pathways, educational credentials, and promotion and acceptance by a professional peer group (e.g. ISES for the exposure science field) (Cohen Hubal et al., 2011; Pleil et al., 2012). ISES Europe's 'Education, Training and Communication' working group (referred to as 'Education Working

[3] The European Partnership for the Assessment of Risks from Chemicals https://anses.fr/en/content/european-partnership-assessment-risks-chemicals-parc.

Group') was created to develop a strategic framework for advancing education around exposure science.

In a themed session, the working group identified the need for increased acceptance of exposure science as a scientific field that requires education, with only specific exposure science elements being currently taught as part of adjacent educational programmes. However, a niche exists for non-segmented teaching of exposure science to foster synergies and advancing related education. Therefore, dedicated education and training programmes to foster exposure science career pathways are urgently required to respect and adapt to professional boundary conditions at national and regional regulatory contexts.

Systems thinking has been identified as a key competence essential in transitioning toward a sustainable future (Wiek et al., 2011); this is a central theme in exposure science, holistically connecting elements from environmental sciences, public health sciences, engineering, and social sciences. Thus, understanding the complexity and interactions among exposure science elements is crucial. Therefore, the Education Working Group experts, together with stakeholders from different sectors, identified current gaps and ways forward for exposure science education using a systematic strengths, weaknesses, opportunities and threats (SWOT) analysis, focusing on European conditions and regulatory settings.

Based on this analysis, the Education Working Group identified the state-of-the-art of exposure science education in Europe and exploring options for advancing current curricula, academic programmes, courses, teaching materials, instructors and institutions that fall under the broader scope of exposure science. Major strategic objectives for advancing exposure science education were identified along with specific actions and their expected timelines as part of an overarching European Exposure Science Strategy 2020–2030.

3. Towards a consistent exposure science curriculum

To develop a consistent exposure science curriculum, efforts are needed to establish the following set of critical elements, to be addressed in parallel:

- Recognition and broad awareness of exposure science as an independent yet strongly interconnected scientific field,
- Harmonised learning outcomes for exposure science that various education providers can adopt,
- Commitment from higher educational institutions to establish exposure science education programs within the institutional and national qualification framework and
- Appropriate funding mechanisms to facilitate educational advances in exposure science.

Once an overarching exposure science curriculum is developed and adopted by educational institutions, further efforts are needed to ensure the attractiveness of these related courses. One method is to provide certification as a method for course evaluation. This should ensure a minimum quality of exposure science content and alignment to expectations of global exposure science education and training.

4. The starting point: Aligned learning outcomes

4.1. Defining learning outcomes for exposure science

The Education Working Group experts began developing the requirements of exposure science in education and training in 2018. Learning outcomes have been outlined at each level of the European Qualifications Framework (EQF) (European Commission, 2017), an 8-level, learning outcomes-based framework for all types of qualifications, which serves as a translation tool between different national qualifications frameworks and links into the Bologna Process for higher education (European Commission, 2018), a European agreement across EU countries for comparability in the standards and quality of qualifications. The development of the specific learning outcomes for each learning level was inspired by guidelines from the National Framework of Qualifications from the National Qualifications Authority of Ireland (National Qualifications Authority of Ireland, 2003), which gave generic learning outcomes for each level of learning under eight different requirements. The Education Working Group used the EQF levels of learning and the generic descriptors for the learning outcomes and categorised the requirements for learning according to descriptors related to three main areas: knowledge, skill and competence (EC European Commission, 2017, Annex II). The Education Working Group experts used these three areas to develop and advance the generic descriptors to specific exposure-science descriptions for the learning outcomes (Table 1). Along with outlining the learning outcomes for each level of learning, recommendations were developed on the typical career pathway or course type, the course credits and program type, as well as any expected entry level of knowledge or qualification.

Exposure scientists work in various professions, most prominently in the areas of risk assessment, occupational health and exposure monitoring in industry, regulatory agencies or academia. Currently, most exposure scientists start as chemists, physicists, biologists, toxicologists, environmental scientists or other scientists and rely on self-study and education by peers. Hence, the knowledge expected in the professional fields mentioned above served as the basis for identifying the learning outcomes required to be implemented in courses for exposure scientists. The EQF levels (1–8) were used to assign learning outcomes. The EQF 1–4 levels were grouped together but split into two training types, as these courses can vary on their entrance requirements and desired outcomes. Therefore, we defined the first EQF 1–4 group for introductory or general short courses (1–4: I) and a second EQF 1–4 group of specialised short courses or continual professional development courses (1–4: P). Each level of learning has suggested career pathways, the total required hours, European Credit Transfer and Accumulation System (ECTS) credits, the typical type of programme that would provide these courses, the entry level and the overarching learning objectives. Learning outcomes at each level are thereby cumulative, meaning that each higher level assumes that learning outcomes of lower levels have already been met.

Following this process, specific exposure sciences learning outcomes were developed from generic descriptors (National Qualifications Authority of Ireland, 2003) and the ISES Europe Education Working Group expertise, as summarized in Table 1.

4.2. Developing curricula topics from identified learning outcomes

Building on the learning outcomes for existing exposure science courses, additional education and training needs were identified. To align with the structured EQF levels, recommended learning topics were collated and categorised based on the level of learning.

The recommended exposure science topics were grouped by generic exposure science theory and analysis, exposure science methodologies, and specific context and practical application (Fig. 1), collated and categorised under the most suitable learning level (i.e. introductory to advance learning). As progression is made through the education levels, it is envisioned that all recommended subject matter has been encompassed, unless designing a specialised training course. Introductory level in Fig. 1 would approximately correspond to EQF 1–4: I, intermediate level to EQF 5–7, and advanced level to EQF 7–8.

Once the learning outcomes and topics were outlined, it was necessary to establish the method by which course providers would establish exposure science courses. For higher EQF levels, the participants would require an initial level of expertise, and outlining the entry requirements for individual courses would be required.

Table 1
Learning outcomes for exposure science curricula at each qualification level are defined by the European qualifications framework (EQF). I: introductory or general short courses. P: specialised short courses or continual professional development courses.

	Levels as per the European Qualification Framework (EQF)					
	1–4: I	**1–4: P**	**5**	**6**	**7**	**8**
Expected career pathways	Various	Specialised professional qualifications[(1)]	Technician	Supervisory role	Junior management role/ early stage researcher	Academia/Post-doctoral researcher/ Senior management
Approximate total effort (ECTS)[(2)]	1–90 ECTS	1–5 ECTS	120 ECTS	180–240 ECTS (3–4 years)	60–120 ECTS (1–2 years)	≥90 per year (Minimum three years)
Typical program of study	Introductory or short course	Continual professional development	Higher certificate/ Diploma	Bachelor course honours & ordinary level	Master course	Doctoral degree
Prior learning requirements or entry-level knowledge	Ranging from no prior learning to specialised knowledge	Specific qualification or professional experience	Diploma/ 2–3 years of study	School/Higher certificate	Bachelor of Science (BSc)	Master of Science (MSc)
Learning outcomes	Learners will obtain knowledge, know-how & skill & competencies and would be expected to be able to:					
Knowledge	Understand the broad aims & objectives of exposure science in relation to health, society & environment Demonstrate an awareness of the relationship between the environment & health Understand & apply concepts from multiple sub-disciplines related to exposure science Define the relationships between exposure & the effects of dose response relationships	Understand specific topic aims & objectives of exposure science Demonstrate specific knowledge of the relationship between environment & health Understand and apply specific concepts & relate them to exposure science	Comprehend the fundamental principles & background theory related to exposure science & its relationship with health, society & environment Identify & understand the determinants of exposure Anticipate key health & environmental impacts pertinent to exposure science & the options for their control Identify & evaluate relationships between exposure & the effects of dose response relationships	Demonstrate a broad range of knowledge concerning the fundamental principles & knowledge base of exposure science Differentiate & comprehend the various applications of exposure science Identify relationships between exposure & effects & design strategies for the study of dose–response relationships	Demonstrate an in-depth knowledge, informed by critical evaluation of scientific literature & publications regarding the principles of assessing & managing exposures to physical stressors	Demonstrate an in-depth awareness of current knowledge gaps & associated research needs which is at the forefront of the exposure science field
Skills	Demonstrate basic practical skills relevant to exposure science Identify relevant information, and use skills & or techniques to undertake basic exposure science surveys Identify relevant contextual information for exposure assessment & to select suitable exposure controls Perform basic analysis & reporting of exposure science data	Demonstrate specific practical skills relevant to exposure science Select & apply specific exposure science methods & tools to assess & manage exposure in the relevant area	Design sampling strategies & surveys considering the scope & goal of the exposure assessment Understand the limitations of exposure science tools Interpret exposure science data & demonstrate problem solving abilities	Select & apply exposure science tools & methodologies to assess & manage exposure in a range of different contexts Analyse, interpret & report a wide range of exposure science data Characterise uncertainty & variability of exposure data & how this translates for exposure & risk assessment. Apply major components of the exposure science framework to address complex exposure science problems	Formulate hypotheses & design, choose & adapt relevant methodologies to solve complex exposure science problems & advance knowledge in the discipline Take responsibility for communicating & reporting to regulatory agencies, putting the exposure data into context & providing risk analyses to ensure the safety of the general population & workers	Formulate research questions, develop research & the execution of experiments to solve complex exposure science problems Design & develop new methodologies & exposure assessment tools Apply science & statistics to analyse, interpret data & synthesize valid conclusions to the solution of a complex exposure science problem
Competence	Exercise autonomy & judgement within a defined set of parameters. Take responsibility	Exercise autonomy & judgement on a specific exposure science topic. Take responsibility for	Demonstrate autonomy & professional judgement on a range of issues related to exposure science	Demonstrate professional autonomy & judgement on a range of complex exposure science Issues.	Lead large complex exposure science projects. Critically reflect upon central ethical &	Demonstrate an ability to work at the forefront of exposure science Recognize the impact of scientific solutions in a societal context & be

(*continued on next page*)

Table 1 (*continued*)

	Levels as per the European Qualification Framework (EQF)					
	1–4: I	1–4: P	5	6	7	8
	for completing tasks & procedures in connection with statutory requirements, codes of practice & quality assurance practice.	completing tasks & procedures in connection with statutory requirements, codes of practice & quality assurance practice.	Address defined exposure-related problems by determining, adapting & using appropriate methods & skills to analyse exposure science data Evaluate actions, methods & results with reference to the exposure science framework Evaluate scientific literature & databases to identify information needed to understand exposure science	Demonstrate ability to lead exposure science problem solving, project management & related communication Critically analyse & interpret scientific literature to identify information needed to understand & effectively communicate aspects of exposure science. Design individual research projects within an appropriate setting	scientific questions in relation to scientific work in exposure science Able to execute solutions to complex exposure science problems	able to respond effectively to the needs for sustainable development with a professional, ethical & moral responsibility.

(1) Specialised courses as part of continual professional development have learning outcomes that are very specific to the course.
(2) 1 ECTS = 10 h of learner effort.

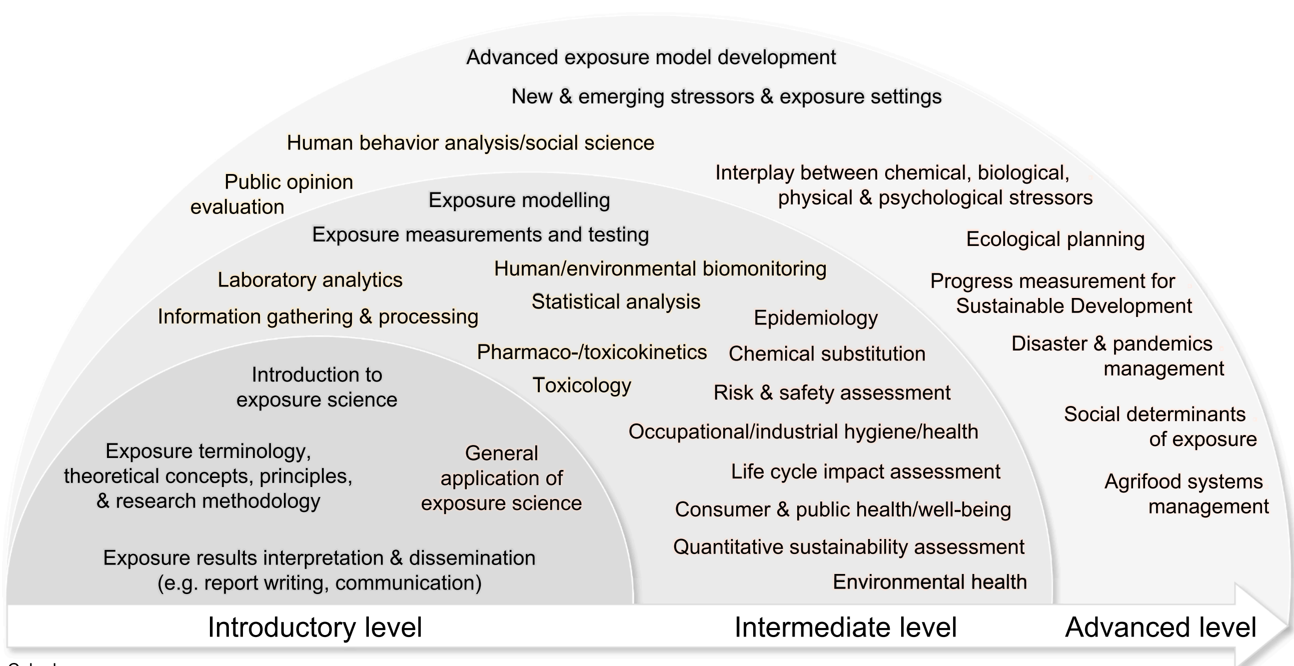

Fig. 1. A list of key topics in the field of exposure science that could be taught at various levels and modes, from introductory courses to advanced specialised courses.

4.3. *Applying learning outcomes in practice: Three case studies*

To illustrate the practical use of the harmonised learning outcomes for developing exposure science courses, three separate, existing courses that deliver exposure science training aspects have been evaluated as per the systematic course review procedure proposed (the entire procedure is described in SI and Fig. S1). The three case studies related to postgraduate training on human exposure assessment embedded in toxicology (course A), postgraduate training within health, environmental and life cycle impacts (course B), and occupational exposure training as part of a specialised toxicology programme (course C). The three courses are briefly described below, with further information provided in SI (Supplementary Information).

Course A is a newly developed postgraduate training course as part of the Dutch national postgraduate educational programme in toxicology. This joint effort of eight Dutch universities offers 21 courses (https://www.toxcourses.nl). The course focuses on exposure assessment for human health, is entitled 'Human Exposure Assessment' and qualifies for accreditation as European Registered Toxicologist (ERT) (Wilks et al., 2016). This course primarily targets PhD candidates pursuing European toxicology registration corresponding to EQF level 8. This is a one-week course corresponding to 1.5 ECTS. The learning outcome is to understand the basic principles of exposure assessment.

Course B is a postgraduate training in assessing health, environmental and life cycle impacts as part of different study lines at the Technical University of Denmark (DTU course 12774, https://kurser.dtu.dk/course/12774). This course was developed for a wide range of engineering students (e.g. environmental, chemical and architectural engineering) in the last year of their Master's studies. This course is delivered as a three-week block and is worth 5 ECTS credits. The learning outcomes focus on understanding and effectively applying assessment methods and tools for quantifying environmental, health and life cycle impacts. A large part of the course focuses on the interface between environmental fate, chemical exposure and toxicity effects.

Course C is developed for specialised toxicologists of the German Society of Toxicology (DGPT, http//https://www.helmholtz-muenchen.de/toxkurse/kurse/kursuebersicht); the 'Identification and Assessment of Exposure' course focus mainly on occupational exposure, which is delivered over one week, as part of a modular structure for advanced learning consisting of approximately 20 modules. The learning outcomes are to develop knowledge of exposure data and its application, utilise exposure assessment tools and acquire a basic understanding of consumer and environmental exposure assessment.

Fig. 2 demonstrates that the three selected courses with different objectives and curricula can be tailored to be relevant for exposure science and aligned across countries and education programmes. Case study course A, a newly developed course, aligns well with the harmonised learning outcomes (Table 1). While courses B & C had an underlying scope that overlaps with exposure science, this evaluation showed that these courses could be further adapted better to match the aligned learning outcomes for exposure science. Through this adjustment, these courses could be further strengthened by systematically incorporating objectives listed under different categories (e.g. knowledge, skill or competency) that are still specific to the scope of the addressed exposure science topics (Fig. 1). Future ambitions include an operational certification process to allow training programmes and opportunities to be evaluated and receive certification for their courses. With the above assessment process, the three illustrative case study courses would be able to seek potential certification as exposure science courses in the future.

4.4. A strategy for advancing exposure science education

To achieve the overall aim of this framework for education, training and communication, four overarching, strategic objectives (SOs) have been identified. The first strategic objective (SO1) is developing material and resources to promote the exposure science field. Advancing on this objective, SO2 is the development of materials that will build into an exposure science curriculum to ensure the availability of exposure science courses that will lead to specially qualified exposure scientists. Once specific courses are available, there will be a requirement to have a process to certify courses and give accreditation for exposure scientists. The SO3 is to establish awarding bodies for certification and accreditation to assist with developing defined career pathways for graduates and advancing the scientific field. In addition, in parallel with the aforementioned strategic objectives, SO4 would enhance the dialogue among exposure scientists, ensuring the accomplishment of the other three strategic objectives (Table 2).

The ISES Europe 'European Exposure Science Strategy' is scheduled to be fully implemented in 2030. The education, training and communication strategy has four main strategic objectives (SO1–SO4) with numerous milestones, incrementally building on each to eventually implement the overall strategy in Fig. 3.

ISES and its different regional chapters could assist as being the primary source for scientific development, educational training and instruction, and communication by using the website as a platform for all available exposure science-related courses and highlighting the career pathways for exposure science graduates. Future objectives outlined in the roadmap include advancing the exposure science field to achieve recognition and awareness of the discipline, which must be

	Case study course (A) **Human Exposure Assessment**	Case study course (B) **Assessing health, environmental and life cycle impacts**	Case study course (C) **Identification and assessment of exposure**
Needs for course	○ General human exposure competence as part of the postgraduate toxicology programme (or comparable initial training)	○ Ability of students to develop impact pathways for emissions of and exposure to chemicals and other stressors for decision support	○ Competence in an appropriate science as part of 20 modules with a toxicological focus (laboratory animal science, carcinogenesis, etc.)
Course specifications	○ Postgraduate training for toxicologists in support of MSc candidates, 1.5 ECTS, **EQF8** ○ Focus on human exposure	○ Technological specification course, MSc Eng, 5 ECTS, **EQF 7** ○ Environmental engineering, sustainable design	○ Course as part of the advanced training to become a specialist toxicologist, 1-week course, **EQF 7** ○ Focus on occupational exposure
Scope/domains	○ Exposure assessment by measurement and modelling ○ Focus on exposure to hazardous impurities and contaminants in consumer products (general public) and industrial chemicals (workers)	○ Exposure assessment as part of life cycle impact assessment and chemical substitution ○ Focus on modeling consumer exposure, population exposure and ecological exposure	○ Exposure assessment and evaluation based on measurement data and models ○ Focus on considering exposure reduction measures in the workplace
Exposure science learning outcomes	○ Understand principles of exposure assessment, including how exposure routes,toxicokinetics and internal dose ○ Strengths & limitations of exposure measurements and modelling in human health risk assessment ○ Statistically analyse and interpret exposure measurement & modelling results in risk assessment	○ Characterize human and ecological exposures ○ Quantify exposure and impact factors and rank results ○ Apply comparative exposure assessment models and data ○ **Determine and justify uncertainties in exposure results ○ **Integrate exposure results into comparative decision tools	○ Understand the theory, concepts and methods (modelling, monitoring) of occupational exposure assessment ○ Evaluate the relative importance of different exposure pathways ○ Use reports, databases and scientific literature to evaluate exposure situations for application in different regulatory contexts
Expected change in learning	○ Ability to apply exposure assessment in multiple contexts	○ Increased understanding and use of of exposure science data and tools in decision support	○ Increased knowledge of the needs for higher-tier worker exposure assessments and tool application

Fig. 2. An evaluation of three case studies illustrates courses compared to harmonised learning outcomes for exposure science. Details of the three courses are provided in the SI. **Learning outcomes that were explicitly introduced into an already existing course to address the learning outcomes for exposure science curricula as defined in Table 1.

Table 2
Overview of four strategic objectives, key actions and estimated timelines for developing a harmonised exposure science curriculum, integrating into the global exposure science context.

Key actions & relation to strategic objectives for advancing exposure science in Europe	Integration into global exposure science context	Estimated timeline
SO1: Exposure science promotion		
• Develop and publish exposure science videos of experts in the field to promote the discipline and demonstrate defined career pathways for graduates	• To develop awareness and recognition of exposure science as an independent field worldwide	2020–26
• Create a centralised online location to find information on all exposure science courses available worldwide	• Hosted on the ISES website, it will include information on qualifications, locations, costs, type of learning (e.g. online/blended learning)	2020–30
• Develop an overarching exposure science terminology, a short glossary on exposure science terminology will be published, which will be followed by a live document	• The live document will be hosted on the ISES website, and international experts will be invited to feed into a global consensus-building process for a consistent exposure science terminology	2020–30
SO2: Exposure Science Curriculum		
• Develop an outline for a master's curriculum for newly developed or adapted exposure science courses and provide guidance on the course subjects, materials and the evaluation process.	• Feed into global exposure science education and training programmes	2025–30
SO3: Recognition for exposure science courses		
• Define a framework and outline criteria of the exposure science course requirements to obtain certification and for exposure scientists to apply for accreditation	• Draw on and align with conditions of existing curricula from related disciplines and exposure science courses outside Europe	2021–25
• Define accreditation and certification progress for exposure science courses and professional accreditation and establish/appoint appropriate awarding bodies.	• Tailor criteria toward specific conditions of different world regions as part of a global certification process	2025–30
SO4: To enhance the dialogue among exposure scientists		
• Include a parallel session for education, training and communication in the ISES Europe biannual chapter meetings • Run Webinars/workshops, partly to be initiated by the WG education, training and communication	• To promote dialogue among scientists within Europe and worldwide, a number of avenues will be adopted to enhance communication, including dedicated sessions at ISES Europe and ISES meetings.	2020–30

recognised and acknowledged with professional accreditation, including continuous professional development. This can be achieved by developing a certified and tiered exposure science education and training programme in Europe that aligns with the European Credit Transfer and Accumulation System (ECTS). Furthermore, exposure science education efforts should be as much as possible aligned with "One Health" initiatives (https://www.who.int/health-topics/one-health), fostering a systemic understanding to sustainably balance and optimize the health of people, animals and ecosystems, with exposure science as a central element. Thus, in due course, ISES and the relevant chapters could facilitate the progression of education, training and communication, which could include providing guidance and certification/accreditation for exposure science courses.

5. Discussion & Recommendations

Exposure science is rapidly growing with relevance across many disciplines, but no formal educational training programme currently exists in Europe explicitly in this field. Although numerous occupational health and hygiene programmes provide good foundations, there is a need to develop programmes that cover the broader scope of exposure science aspects.

In Europe, exposure science is firmly anchored in different EU regulatory frameworks, fragmented into over 812 EU Regulations and Directives (Bruinen de Bruin et al., 2022). Each legislative requirement creates specific demands and requirements and represents a substantial challenge for practitioners and decision-makers in developing and harmonising exposure data, methods, and tools. For industry, there are many regulatory requirements for health and environmental risk assessment. While exposure assessment and hazard characterisation are equally essential components of risk assessment, hazard considerations are often the focus and decision drivers (e.g., phase-out of stressor, one chemical-one assessment perspective).

Beyond the regulatory context, exposure science is essential for several recently proposed European strategies, such as the sustainable-by-design (SSbD) framework, moving towards a circular economy and a non-toxic environment by 2050 (Joint Research Center, 2022). The need to close gaps and align regulatory and non-regulatory requirements on exposure information has put a unique demand on the European exposure science community. An increased importance on exposure considerations could lead to better informed risk-based decision-making. Unfortunately, the dearth of knowledgeable exposure scientists in industry and regulation could contribute to maintaining the current emphasis on hazards, as well as the potential for oversimplification of regulatory assessments. Therefore, European-wide support is required to develop best practices in exposure science education and training to ensure appropriate expertise is available.

Currently, there is a dearth of exposure science courses, especially across Europe. However, relevant expertise and training are available across an array of disciplines pertinent to exposure science. To develop specialised training in exposure science, many recommendations will have to be addressed, including enhancing collegiality among exposure scientists to elevate education within the field. This is especially important for a scientific field that can be embedded within a multitude of disciplines. Furthermore, it is essential to promote the awareness of the exposure science role, to raise its recognition as an independent yet interconnected field. To address these issues, the ISES Europe Education Working Group has developed the European Exposure Science Strategy, with a long-term ambition of creating an exposure science programme curriculum and establishing a framework for certification and accreditation of exposure science courses and professionals.

The first step is to build a foundation on which an exposure science curriculum could be developed, including harmonising the exposure science terminology used (Heinemeyer et al., 2022) and determining appropriate and aligned learning outcomes across all levels of learning (i.e. Bloom's taxonomy of learning objectives (Krathwohl, 2002)), where each level builds upon the previous learning level, from introductory to advance learning. For example, short or introductory courses might include a basic level of learning, while certified or accredited courses would be more advanced with specific applications. Advanced learning would be most appropriate for assessing, applying and analysing, as well as providing in-depth knowledge for decision-makers in exposure science and adjacent fields.

For the development of exposure science courses, it is imperative at the initiation stage to formulate the overall objective and remit of the course. Once decided, the course design can utilise the proposed learning outcomes (chosen in alignment with the specific remit) and select module types (e.g. Fig. 1) to develop a course plan. For adjusting existing courses, a procedure outline (e.g. Fig. S1) and examples are presented in Fig. 2. A curriculum should include exposure science theory

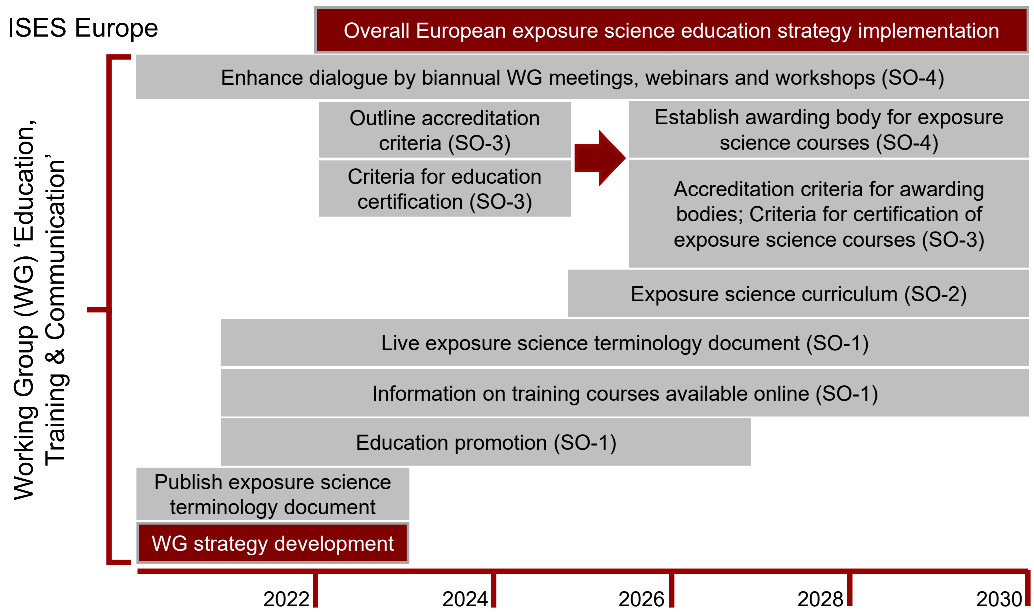

Fig. 3. Roadmap of the strategic objectives for advancing exposure science education.

and analysis, exposure science methodologies, specific context and practical application, and communication. Initially, courses will probably be short, a module within an academic programme or private training providers. However, the long-term ambitions are to build a full curriculum for an exposure science course, which educational institutions can adopt to establish relevant postgraduate programmes (e.g. Masters Exposure Science), with a motive to upskill relevant personnel to enter exposure science related sectors (e.g. regulatory risk assessor).

Education providers can extract specific learning outcomes and integrate them into their specific educational context, thus aligning the overall exposure science curriculum. Although the proposed aligned learning outcomes should be harmonised in all exposure science courses, the level of learning, the delivery method, and module types may differ across course providers based on exposure science students' knowledge, skills, and competency requirements. Additionally, it would also be essential to establish the course entry requirements. Multiple methods for evaluating a person's initial education and experience for admittance may be needed, depending on the course type, for example, an assessment by a valuator based on initial education, including certificates of initial training or an entry exam (Walker, 2009).

Further future ambitions include the recognition of educational courses and programmes (e.g. certification) and the professional status of exposure scientists in the field (e.g. accreditation), which will ultimately result in appropriately trained graduates with more defined career pathways. ISES Europe will play a central role in supporting the development and consolidation of exposure science education, training and communication. Once initial steps are accomplished, relevant learning outcomes can potentially inform initiatives outside Europe. The proposed exposure science learning outcomes and specific topics are aligned with the Bologna Process, which is recognised internationally and could make these applicable worldwide. A global approach can then be attained to certify courses and accreditation of professional status for exposure scientists.

For the successful implementation of this strategy, it is crucial to obtain funding to support projects facilitating achieving this ambitious goal. Also, to have support from agencies and relevant bodies in establishing exposure science as a recognised and established field with different career options and outlining a roadmap to achieve the aligned learning requirements for experts in this field. Furthermore, systems need to be developed to receive certification and accreditation for courses and professionals, respectively. However, it is imperative that even before the strategy is fulfilled, other advancements happen in the immediate future from scientists, policy-makers, academia, and professional bodies. Advancements in acknowledging and recognising exposure scientists, the exposure science field, and the need for a dedicated workforce is essential.

6. Conclusions

The ISES Europe Education, Training and Communication working group strategy provides a framework for developing high-quality certified education and training programmes for exposure scientists, which is crucial to advancing exposure knowledge and its uptake in policy, industry and society. To obtain this goal, a curriculum is required that covers all relevant exposure science aspects while considering complex conditions and regulatory frameworks and strengthens the link to other scientific disciplines. The strategy and underlying action plan to develop such an exposure science curriculum in Europe can serve as a role model for other world regions. Moreover, Europe's strategic plan for exposure science education will be especially relevant for addressing global challenges. Ensuring there are appropriately trained experts worldwide who develop and implement solutions for the global supply chain and risk management is required in the growing field of exposure science.

CRediT authorship contribution statement

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Appendix A. Supplementary material

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