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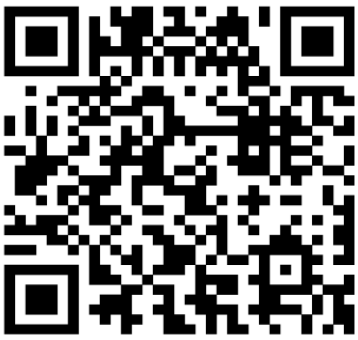

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ТЕОРЕТИЧНІ ТА ПРИКЛАДНІ ПРОБЛЕМИ СУЧАСНОСТІ

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Інженерно-технологічні та інфраструктурні рішення (IT, комп'ютерні науки, інженерія, … 139

3.1. Теоретико-технологічні основи трафаретного друку та особливості його застосування у сучасних виробничих процесах
Савченко Ольга Михайлівна ... 139

3.2. Modern trends, principles, and approaches to the development of effective organizational structures in the investment and construction sector
Vitrovyy Andriy ... 143

Розділ четвертий
Медико-біологічні та фізкультурно-оздоровчі аспекти (фізична культура, спорт, медицина, фармація) ... 156

4.1. Fiber optic drone cable waste as a resource for pharmaceutical, organic and bioorganic chemistry education
Lyudmyla Antypenko, Oleksii Antypenko, Tetiana Brytanova ... 156

Післямова ... 178

Розділ четвертий
Медико-біологічні та фізкультурно-оздоровчі аспекти (фізична культура, спорт, медицина, фармація)

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4.1. Fiber optic drone cable waste as a resource for pharmaceutical, organic and bioorganic chemistry education

Fiber optic-guided drone operations in the war in Ukraine have generated a distributed and persistent form of technological waste whose principal components are poly(methyl methacrylate) (PMMA) cores and per- and polyfluoroalkyl substance (PFAS)-bearing fluoropolymer cladding. A recent bilateral assessment by the present authors estimated combined material accumulation on the order of 13,080 tonnes (±35% uncertainty), of which roughly 523 tonnes is PFAS-bearing fluoropolymer, deposited across an operational area of approximately 40,000-65,000 km². This chapter does not revisit the quantification; rather, it asks a different question: how can a problem of this kind be converted into structured teaching and research activity at a university department of pharmaceutical, organic and bioorganic chemistry. The chapter consolidates a catalogue of 36 integrated university projects spanning six tiers – undergraduate education, graduate research, medical device education, clinical education, public health education, and advanced pharmaceutical sciences – and translates the most tractable of these into three proposed course modules for the Department of Pharmaceutical, Organic and Bioorganic Chemistry. Drawing on the documented pedagogical value of problem-based and case-based learning in chemistry, the chapter argues that the near-term value of the contamination is overwhelmingly educational and investigative rather than material: the recovered cable itself is unlikely to enter pharmaceutical use given current regulatory trajectories, but the scientific problem it poses – polymer degradation, PFAS detection and treatment, biomarker development, and contamination-aware pharmaceutical care – maps onto the analytical, organic and bioorganic competencies the Department already teaches. The specific contribution advanced here is that a regionally grounded contamination problem – one embedded in the farmland, watercourses and communities around Zaporizhzhia, in front-line southeastern Ukraine – can be converted into a structured teaching resource available to the city's universities now, without awaiting a material-reuse pathway that current regulation renders improbable. The framework is presented as a set of proposals requiring institutional adaptation, ethical scrutiny, and empirical validation, not as established practice. Keywords: PFAS; fiber optic drone waste; pharmaceutical education; problem-based learning; organic chemistry curriculum; bioorganic chemistry; contamination literacy; green chemistry.

4.1.1. INTRODUCTION

4.1.1.1. A new category of conflict-derived contamination

Armed conflict has long been recognised as a driver of environmental change, with effects that frequently outlast the cessation of hostilities (Certini et al., 2013; Hupy, 2008; Lawrence et al., 2015). The war in Ukraine has added a category of waste that does not fit comfortably within established frameworks for either munitions residue or fixed-installation contamination. Fiber optic-guided first-person-view drones maintain an unjammable control link through a physical cable that unspools during flight and is not recovered after the mission. Each sortie therefore deposits the full length of cable on the terrain surface, and the cumulative result is a dispersed, thread-like polymer network across agricultural land, grassland, forest margins and watercourses (CEOBS, 2025; Antypenko & Antypenko, 2026).

Two material facts give this waste its environmental and, as argued here, its pedagogical interest. First, the cables consist of PMMA cores surrounded by fluoropolymer cladding; fluoropolymers belong to the PFAS class, and several lines of evidence indicate environmental half-lives measured in centuries (Chamas et al., 2020; Henry et al., 2018; Lohmann et al., 2020). Second, the contamination is distributed rather than point-source, which means that the

assessment and remediation protocols developed for fixed military installations transfer poorly (Morales et al., 2025). Independent commentary through early 2026 continues to describe the scientific understanding of this waste stream as preliminary, with long-term effects on soil, agriculture and wildlife still uncharacterised (CEOBS, 2025).

The contamination is, in absolute terms, modest. Cumulative global plastic waste since 1950 is of the order of thousands of megatons, with recycling rates below one tenth (MacLeod et al., 2021), and a single aqueous film-forming foam facility may hold a comparable mass of PFAS at one location. What distinguishes fiber optic cable waste is not its tonnage but its geometry: it is dispersed across tens of thousands of square kilometers, it degrades slowly and continuously rather than through discrete events, and it intersects directly with habitats, farmland and water resources. These properties make it a poor candidate for conventional engineering remediation and, for the same reasons, an unusually rich subject for teaching.

4.1.1.2. From environmental liability to educational resource

The central proposition of this chapter runs against the intuitive reading of the problem: a contamination of this kind is worth more to a university as an object of study than as a recoverable feedstock. The claim has particular force in Zaporizhzhia, an industrial and university city on the Dnipro in southeastern Ukraine, in a region directly affected by the war, whose farmland, watercourses and inhabitants lie within the very landscape this waste contaminates. For the Department of Pharmaceutical, Organic and Bioorganic Chemistry, the cable is therefore not a distant case study but a local one, and that proximity is precisely what turns it into a teaching resource rather than an abstraction. Two arguments support the position. The first is regulatory and is developed in Section 3: the trajectory of PFAS regulation in the European Union and elsewhere is toward restriction rather than expanded use, so any scheme that envisaged feeding recovered, PFAS-bearing military cable into the pharmaceutical or medical-device supply chain would face escalating, and in several applications prohibitive, compliance requirements. The second argument is pedagogical and is developed in Sections 4 to 6: the scientific questions raised by the cable – how polymers fragment under ultraviolet and mechanical stress, how PFAS are detected at nanogram-per-litre concentrations, how exposure biomarkers are designed, how contamination alters pharmaceutical care – align closely with the analytical, organic and bioorganic chemistry that a pharmacy-oriented department already teaches.

This reframing matters because it changes the standard of evidence required. A claim that recovered cable could serve as a pharmaceutical excipient would demand toxicological and regulatory validation that does not presently exist and may never be obtainable for a PFAS-bearing material. A claim that the contamination scenario can anchor a problem-based laboratory course in PFAS analysis requires only that the underlying chemistry is sound and that the pedagogy is defensible – conditions that current literature on chemistry education supports (Vaz et al., 2025; Sonmez & Palomas, 2025). The chapter is therefore careful to separate what can be taught now from what would require a long and uncertain path to material reuse.

4.1.1.3. Aim and scope

The aim of this chapter is to provide a usable basis for course development at the Department of Pharmaceutical, Organic and Bioorganic Chemistry of Zaporizhzhia State Medical and Pharmaceutical University, and, through its higher tiers, a point of departure for collaboration with the medical, public-health and technical faculties of the city's wider university community. It consolidates and reorganises a catalogue of integrated university projects originally compiled as supplementary material to the authors' quantitative assessment, and it translates the most tractable projects into concrete teaching structures. The chapter draws the contamination figures and material characterisation from that prior work (Antypenko & Antypenko, 2026) and treats them as established context rather than re-deriving them. The contribution here is the educational architecture: a project catalogue, a set of course modules, a mapping of projects to learning outcomes, and a candid account of what is and is not feasible.

Three boundaries should be stated at the outset. First, the project catalogue is a set of proposals; the majority of the listed projects have not been implemented and would require institutional approval, resourcing and ethical review. Second, the chapter does not advocate handling of contaminated battlefield material in teaching laboratories; where physical material is referenced, it is decontaminated surrogate or commercially obtained polymer optical fiber of equivalent composition, not recovered cable. Third, several quantitative parameters carried over from the source assessment retain wide uncertainty, and these are flagged where they appear rather than presented as settled values.

4.1.2. MATERIAL BASIS: COMPOSITION, PERSISTENCE, AND CONTAMINATION SCALE

4.1.2.1. Cable composition and the PFAS question

The deployed cable is polymer optical fiber rather than glass optical fiber, a choice driven by flexibility and durability under field conditions (CEOBS, 2025). Cross-sectionally, the dominant component is a PMMA core, with a fluoropolymer cladding layer that provides the refractive-index contrast required for waveguiding. After accounting for the density difference between PMMA (approximately 1.18 g cm^{-3}) and fluoropolymer (approximately 2.1 g cm^{-3}), the source assessment estimated the fluoropolymer fraction conservatively at about 4% of total mass, within a 4–7% range; this value requires confirmation through analysis of recovered cable and should be treated as provisional (Antypenko & Antypenko, 2026). Reported cable diameters cluster around 0.25 mm for Ukrainian systems, with thinner fibers (often below 0.1 mm) and mixed thicknesses described elsewhere, and a representative linear mass of about 1.2 g m^{-1} (±0.5 g m^{-1}).

The fluoropolymer cladding is the component of toxicological interest because fluoropolymers are PFAS. The relevant distinction for teaching is between the intact, high-molecular-weight polymer and the lower-molecular-weight species that may be released during manufacture or environmental breakdown. High-molecular-weight fluoropolymers exhibit limited bioavailability owing to their size (Henry et al., 2018), and regulatory assessments of fluoropolymers in medical devices have, on this basis, characterised the intact polymer as low concern. However, this characterisation is contested: gradual degradation may liberate processing aids, residual monomers and lower-molecular-weight PFAS with greater mobility and bioaccumulation potential, and the framing of fluoropolymers as a class apart from other PFAS has been challenged on both environmental-release and end-of-life grounds (Lohmann et al., 2020). This unresolved tension – a material that is plausibly inert as deployed yet potentially hazardous as it ages – is precisely the kind of question that rewards classroom analysis.

Table 1

Principal components of deployed polymer optical fiber cable and their relevance to teaching. Values are provisional and require confirmation through analysis of recovered cable (after Antypenko & Antypenko, 2026; Chamas et al., 2020; Henry et al., 2018; Lohmann et al., 2020)

Component	Approx. mass fraction	Persistence and degradation behaviour	Teaching relevance
PMMA core	~96%	Estimated environmental persistence of the order of 400-1,200 years; degrades by photo-oxidative chain scission, hydrolysis of ester bonds and mechanical fragmentation	Radical chemistry, ester hydrolysis, polymer chain scission, structure–property relationships in organic chemistry
Fluoropolymer cladding (PFAS class)	~4% (range 4-7%)	Persistence on geological timescales; intact polymer of limited bioavailability, but degradation may release lower-molecular-weight PFAS	C-F bond strength, fluorine chemistry, bioavailability and molecular-weight effects, regulatory classification debates
Residual monomers / processing aids	trace	Greater mobility and bioaccumulation potential than the parent polymer	Trace analysis, detection limits, exposure assessment, pharmaceutical impurity reasoning

4.1.2.2. Persistence, degradation, and microplastic formation

The environmental behaviour of the cable is governed by surface degradation. Polymers with carbon-carbon backbones degrade principally at exposed surfaces, initiated by ultraviolet radiation and oxygen, with chain scission generating progressively smaller and more degradable fragments (Ward et al., 2019; Zhang et al., 2021). The thin geometry of the cable produces a high surface-area-to-volume ratio that, in principle, accelerates fragmentation relative to bulk polymer, and combined ultraviolet exposure and mechanical abrasion produce far more microplastic than either stressor alone (Song et al., 2017). The continental climate of eastern Ukraine – marked temperature cycling, summer ultraviolet intensity, and freeze–thaw cycles – supplies the conditions under which these processes proceed.

Quantitative degradation rates for these specific materials under field conditions have not been measured, and the source assessment is explicit that its microplastic projections are order-of-magnitude estimates carrying uncertainty in excess of ±50% (Antypenko & Antypenko, 2026). Applying a generalized surface degradation rate to the bilateral mass and then a conservative mobile-fragment fraction yielded an indicative figure of roughly 26 tonnes of mobile

microplastic per year; this number should be read as a teaching illustration of how compounding assumptions propagate uncertainty, not as a measured rate. Counter-drone measures that deliberately sever cables, together with artillery fragmentation, make the deposited material more fragmented than intact-length models assume, which would tend to increase fragment generation. The honest position – that the direction of effect is known but the magnitude is not – is itself a valuable lesson in environmental modelling (Rykiel, 1996; Suter, 2007).

4.1.2.3. Magnitude of the contamination and its uncertainty

For completeness, Table 2 summarises the bilateral accumulation estimate that motivates the educational programme. The estimate combines production data with field-observed deployment rates and is bounded by an independent field-based density assessment; the two approaches converge within about 20% when compared at equivalent operational scope, while the larger ratio in absolute terms reflects the inclusion of contamination not reachable by front-line field observation (Antypenko & Antypenko, 2026). These figures are reproduced here as context; the chapter's contribution lies downstream of them.

Table 2

Summary of bilateral material accumulation estimates for 2024–2025 (condensed from Antypenko & Antypenko, 2026). Values carry an overall uncertainty of approximately ±35% on bilateral totals; figures are provisional pending post-conflict field verification

Quantity	Production-based estimate	Independent cross-check
Cable deployed	~10,900,000 km	field density along contact line
Total cable mass	~13,080 tonnes (±35%)	~4,176 tonnes (field-based, accessible sectors)
PFAS-bearing fluoropolymer	~523 tonnes	~167 tonnes (field-based)
Operational area	~40,000–65,000 km²	–
Indicative mobile microplastic	~26 t yr^{-1} (>±50% uncertainty)	~8 t yr^{-1} (field-based basis)

4.1.2.4. Why the material is pedagogically valuable, and why literal reuse is constrained

Three features make this contamination an effective teaching vehicle. It is local and salient: students at a Ukrainian university are studying a problem in their own landscape, which supports engagement in a way that abstract case material does not. It is genuinely interdisciplinary: a single cable fragment connects organic chemistry (PMMA and fluoropolymer structure and degradation), analytical chemistry (PFAS detection), bioorganic chemistry (interaction with biological systems and biomarker design), toxicology, regulation and clinical pharmacy. And it is unresolved: because the science is at an early stage, student projects can address real gaps rather than rehearse settled answers.

Against these advantages stands a firm constraint. The recovered material is PFAS-bearing and would be recovered from a contaminated battlefield carrying unexploded ordnance and unknown co-contaminants. The source catalogue itself assigns pharmaceutical applications the longest timelines (of the order of four to eight years) and flags regulatory qualification and PFAS removal as limiting factors. Realistically, the cable will not become a pharmaceutical material; the educational programme should therefore use commercially obtained polymer optical fiber or decontaminated surrogates as physical teaching material, and reserve the recovered-cable scenario for analysis, modelling and method development. This separation – between studying the problem and handling the hazard – is maintained throughout the catalogue in Section 5.

4.1.3. REGULATORY AND SAFETY CONTEXT RELEVANT TO TEACHING

4.1.3.1. Evolving PFAS regulation, 2024-2027

A course that uses PFAS as its organising case must teach the regulatory context, both because regulation shapes the feasibility of any recovery scheme and because regulatory literacy is itself a graduate competency. The relevant developments span jurisdictions. In April 2024, the United States Environmental Protection Agency finalised national primary drinking-water regulation setting enforceable maximum contaminant levels of 4 ng L^{-1} for perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS), with maximum contaminant level goals of zero, reflecting a determination that no exposure level is demonstrably safe (U.S. EPA, 2024a). These limits are roughly an order of magnitude stricter than the 2016 advisory levels and establish the nanogram-per-litre sensitivity that any analytical teaching must target.

In the European Union, the universal PFAS restriction proposal submitted under REACH in January 2023 by Denmark, Germany, the Netherlands, Norway and Sweden has progressed through committee evaluation. An updated proposal in August 2025 increased the number of proposed derogations and introduced a third regulatory option permitting controlled continued use of certain fluoropolymer applications under strict emission conditions. The Committee for Risk Assessment adopted its final opinion in March 2026, and the Committee for Socio-Economic Analysis published a draft opinion in the same month, opening public consultation through late May 2026, with a final socio-economic opinion anticipated by the end of 2026 and a Commission decision and possible adoption thereafter (ECHA, 2026). Separately, the restriction on PFAS in firefighting foams adopted in October 2025 begins to apply in 2030. The direction of travel is toward restriction; the open questions concern the scope and duration of derogations, including those for medical and fluoropolymer applications.

Table 3

Selected PFAS regulatory milestones relevant to course content (compiled from U.S. EPA, 2024a; ECHA, 2026). Dates after early 2026 are anticipated and subject to change

Date	Development	Teaching relevance
Jan 2023	Universal PFAS restriction proposal submitted under EU REACH	Class-based regulation; >10,000 substances in scope
Apr 2024	U.S. EPA sets MCLs of 4 ng L^{-1} for PFOA/PFOS; MCLGs of zero	Defines analytical sensitivity target; introduces hazard-index reasoning
Aug 2025	Updated EU proposal; derogations expanded; third controlled-use option introduced for some fluoropolymer uses	Distinction between class bans and use-specific derogations
Mar 2026	ECHA RAC final opinion adopted; SEAC draft opinion published; public consultation opened	Risk vs socio-economic assessment; stakeholder process
Oct 2025 → 2030	EU restriction on PFAS in firefighting foams adopted, begins to apply	Worked example of a finalised, phased restriction
End 2026 → 2027 (anticipated)	SEAC final opinion; Commission proposal and possible adoption	Regulatory horizon scanning; compliance planning

4.1.3.2. Decontamination technologies and the limits of reuse

Teaching the disposal end of the problem requires familiarity with the treatment technologies that could, in principle, destroy the PFAS fraction. Three are documented in the recent literature. Cold atmospheric plasma generates reactive species that attack carbon–fluorine bonds at ambient temperature and pressure, with reported degradation of PFOS approaching 99% within tens of minutes and progressive defluorination toward fluoride, carbon dioxide and water rather than persistent transformation products (Mbanugo et al., 2025). Electrothermal mineralisation uses rapid resistive heating of biochar-amended soil to exceed 1,000 °C within seconds, achieving greater than 99% removal and greater than 90% mineralisation of PFAS to calcium fluoride while largely preserving soil properties (Cheng et al., 2024). Bioelectrochemical systems employing electroactive microorganisms reach removal efficiencies reported up to about 96% at lower energy cost, though they require further development for scale (Noori et al., 2025).

These technologies matter for the curriculum in two ways. They are concrete illustrations of physical-organic and electrochemical principles – bond dissociation energies, radical mechanisms, mineralisation pathways – and they delimit what reuse could mean. Even where treatment achieves high removal efficiency, the economic and logistical barriers to collecting dispersed cable from a post-conflict landscape, the presence of co-contaminants, and the regulatory burden together make material reuse a marginal prospect. A recurring point of replacement-chemistry caution reinforces this: several PFAS substitutes introduced to replace legacy compounds have shown comparable or greater toxicity and persistence (Mišľanová & Valachovičová, 2025; Post, 2025). Students should leave the course understanding that 'remove the PFAS and reuse the polymer' is far easier to state than to achieve.

The three treatment routes also lend themselves to a structured comparison that is itself a teaching exercise. Each can be characterised along the same axes – the chemistry by which it attacks the carbon-fluorine bond, its reported removal and mineralisation efficiency, its energy and infrastructure demands, the matrices to which it is suited, and its readiness for deployment at scale – and asking students to construct that comparison from the primary literature teaches both the underlying chemistry and the habit of evaluating competing technologies on explicit criteria rather than on

novelty. Cold atmospheric plasma operates at ambient conditions but faces questions of throughput; electrothermal mineralisation achieves high mineralisation but at high transient temperatures and energy input; bioelectrochemical approaches promise lower energy cost but remain comparatively immature. None is a settled solution, and the comparison reinforces the chapter's recurring lesson that destruction of these materials is technically possible but neither simple nor cheap. The exercise connects the regulatory framing of this section to the organic and physical chemistry of Module A and gives students a transferable framework for technology appraisal.

4.1.3.3. Implications for course content

Two design consequences follow. First, the analytical component of any course must aim at trace-level detection and must address the matrix complexity that makes PFAS quantification difficult; teaching to a part-per-trillion target is not optional given the regulatory limits. Second, the curriculum should treat regulation as a living, contested process rather than a fixed body of rules, because the EU restriction is, at the time of writing, still in formation. The pedagogical literature supports embedding exactly this kind of regulatory and ethical reasoning: discussion of the discovery, delayed disclosure and eventual regulation of PFAS has been used elsewhere to teach timely testing, monitoring, and the limits of individual responsibility (Times Higher Education Campus, 2026). The contamination scenario allows these themes to be taught with local specificity.

4.1.4. PEDAGOGICAL FRAMEWORK FOR AN INTEGRATED PROJECT-BASED CURRICULUM

4.1.4.1. Problem-based and case-based learning as the organising logic

The catalogue presented in Section 5 is built on problem-based learning (PBL), in which students work from an authentic, ill-structured problem toward solutions they construct themselves, rather than receiving pre-digested content. The choice is evidence-informed. A systematic review of pedagogical methods in green chemistry education found problem-based and collaborative interdisciplinary learning to be the most frequently reported approaches, associated with gains in conceptual understanding, critical thinking and environmental awareness. A recent controlled implementation of PBL in a higher-education green chemistry course reported improved recognition and justification of green chemistry principles when students analysed real industrial redesign cases (Vaz et al., 2025), and a student-startup model using poly(ethylene terephthalate) as a case study reported high engagement and progression into sustainability-focused careers (Sonmez & Palomas, 2025). The fiber optic contamination scenario is well suited to this method: it is authentic, locally salient, and genuinely unresolved.

Case-based learning complements PBL by anchoring abstract chemistry in a concrete narrative. PFAS has become a recurring case in chemistry teaching precisely because it connects molecular structure to toxicology, regulation and public health, and because students typically arrive with no prior knowledge and therefore must reason from evidence (Times Higher Education Campus, 2026; Beyond Benign, 2025). The cable scenario extends this established case into a new and underexplored setting, allowing the Department to contribute teaching material rather than only import it.

4.1.4.2. Constructive alignment: outcomes, activities, and assessment

Each project in the catalogue is specified by an identifier, a duration, the departments it integrates, a primary objective, and an expected outcome. These elements are deliberately chosen to support constructive alignment, in which intended learning outcomes, teaching activities and assessment are designed as a single coherent system. In practice this means that a project whose stated outcome is 'students able to quantify PFAS at regulatory limits' must be paired with laboratory activities in trace analysis and with assessment that tests that capability directly, rather than testing recall of unrelated content. Section 6 develops this alignment for three proposed course modules; the catalogue itself provides the raw outcomes from which alignment is built.

Assessment in a PBL course shifts away from terminal examinations toward authentic products: a validated analytical protocol, a risk assessment, a degradation model with explicit uncertainty, a structured argument about a regulatory derogation. This is consistent with practice reported in the green chemistry education literature, where students are assessed through analysis of recent publications using green metrics and principles, and through structured argument about ethical dilemmas (Times Higher Education Campus, 2026). For a pharmacy-oriented department, authentic assessment also serves an accreditation purpose, because it generates evidence of the applied competencies that pharmacy and medical curricula are expected to demonstrate.

4.1.4.3. Interdisciplinary integration across the Department's three pillars

The Department of Pharmaceutical, Organic and Bioorganic Chemistry spans three teaching pillars that the contamination scenario links naturally. Organic chemistry supplies the account of how PMMA and fluoropolymers are built and how they break down: ester linkages and their hydrolysis, the high bond-dissociation energy of the carbon–fluorine bond, radical chain scission under ultraviolet light, and the structure-property relationships that explain why these materials persist. Pharmaceutical and analytical chemistry supplies the methods for detecting and quantifying PFAS and their degradation products at trace levels, and the impurity-reasoning framework that pharmacists apply to contamination of any kind. Bioorganic chemistry supplies the interface with biological systems: how persistent organics and microplastics interact with tissues and microbiota, and how exposure biomarkers are designed and validated.

Integration is not merely thematic. A single student cohort can move a problem across the three pillars in sequence: characterising the material (organic), developing a method to measure it and its breakdown products (analytical/pharmaceutical), and then asking what those breakdown products do in a biological matrix and how exposure might be detected in a patient (bioorganic). This sequence mirrors the logic of contamination science and gives students a connected rather than compartmentalised view of their discipline.

4.1.4.4. Safety, ethics, and contamination literacy

Because the case concerns a hazardous material recovered from an active conflict, safety and ethics are not peripheral but central learning outcomes. The curriculum must teach, and enforce, that teaching laboratories handle commercially obtained polymer optical fiber or certified decontaminated surrogates, never recovered battlefield cable, and that any work approaching real samples occurs only in appropriately licensed facilities under risk assessment. Beyond laboratory safety, the case raises ethical questions worth explicit treatment: the responsible communication of uncertainty to affected communities; the tension between documenting an adversary's contribution to contamination and the legal restrictions on citing certain sources; and the distinction between legitimate environmental accountability and the instrumentalisation of science. These themes connect the chemistry to the public-health and clinical tiers of the catalogue and give students practice in the kind of reasoning that distinguishes a professional from a technician.

4.1.4.5. Evaluating a pilot and gathering evidence of learning

Because the pedagogical claims advanced here are drawn from the broader green- and sustainable-chemistry teaching literature rather than from implementations of this specific case, a pilot should be designed from the outset to generate evidence about whether those claims transfer. The relevant literature has tested problem-based approaches on small cohorts and reported gains against stated learning outcomes (Vaz et al., 2025; Sonmez & Palomas, 2025), which suggests both that a small first cohort is a legitimate test and that evaluation should be built into the design rather than added afterward. A defensible evaluation specifies in advance the outcomes it expects the module to produce, identifies how each will be evidenced, and compares the result against the constructively aligned assessment artefacts described in Section 6.6 rather than against impressions of student satisfaction alone.

Three categories of evidence are appropriate. The first is direct evidence of competency, drawn from the assessment artefacts themselves – the degradation study, the validated protocol, the biomarker concept – scored against explicit criteria. The second is evidence of conceptual change, which can be gathered through pre- and post-module instruments that probe whether students reason differently about persistence, trace analysis and uncertainty after the module than before it. The third is evidence about the teaching process itself: the instructional time required, the points at which students encountered difficulty, and the resource demands actually incurred, all of which inform whether and how the module should be scaled. Treating the first cohort as a source of evidence rather than as a finished product is consistent with the scholarly humility the framework requires, and provides the Department with the empirical basis it would need before committing to a standalone course.

4.1.5. THE INTEGRATED UNIVERSITY PROJECT CATALOGUE

4.1.5.1. Structure of the catalogue

The catalogue comprises 36 proposed projects organised into six tiers by educational level and professional orientation: undergraduate education (Ug, eight projects), graduate research and education (Gr, eight projects), medical device and technology education (Med, five projects), clinical education (Clin, five projects), public health education

(Ph, five projects), and advanced pharmaceutical sciences (Pharm, five projects). Tables 4 to 9 present each tier. To keep the tables legible on the page, each project is summarised by identifier, title, duration, the departments it integrates, and a combined statement of its primary objective and expected outcome; the richer detail on educational innovation and equipment requirements, present in the originating supplementary material, is discussed in the surrounding text and in Section 6 rather than tabulated.

Several cautions apply across the catalogue. The projects are proposals, not implemented programs; most would require institutional approval, funding and ethical review before delivery. The medical, clinical and pharmaceutical tiers in particular describe long-horizon aspirations whose feasibility depends on regulatory pathways that do not currently exist for PFAS-bearing recovered material. Throughout, the defensible near-term value is the use of the contamination as a teaching and research problem, with physical work conducted on surrogate materials. Readers should interpret 'using military material' in the project titles as 'using the military-contamination scenario and equivalent surrogate materials', consistent with the safety position stated in Section 4.4.

The six tiers are best read not as independent lists but as a progression in two dimensions. Along the first dimension, educational level, the catalogue moves from undergraduate exercises that build foundational competencies, through graduate research that generates new findings, to professional and clinical applications that demand external partnership and regulatory engagement. Along the second dimension, proximity to the material, the catalogue moves from projects that engage the contamination chiefly as an analytical and conceptual problem to those that would, in an unconstrained future, involve the recovered material directly – a proximity that is inversely related to near-term feasibility, since the projects closest to material reuse are precisely those most constrained by the regulatory and safety considerations of Section 3. Reading the catalogue along these axes clarifies why the three modules of Section 6 are drawn from the undergraduate and graduate tiers and from the analytically oriented end of the pharmaceutical tier: these are the projects that combine educational value with present deliverability. The higher tiers retain value as a map of where the work could lead, and as a means of situating the immediate teaching within a longer institutional trajectory, but they are deliberately not presented as near-term commitments.

4.1.5.2. Undergraduate education projects (Ug)

The undergraduate tier targets clinical pharmacy and chemistry students and is the most readily implementable, because its projects rest on established analytical and synthetic techniques and on low-risk surrogate materials. The strongest candidates for early adoption are the organic-chemistry project on polymer degradation (Ug-03) and the pharmaceutical-analysis project on PFAS detection (Ug-04), both of which map directly onto existing laboratory infrastructure and onto the regulatory sensitivity targets discussed in Section 3. Projects addressing medication safety and pharmaceutical care in contamination-exposed populations (Ug-01, Ug-08) introduce the clinical dimension at an appropriate level for undergraduates, while the compounding, bioorganic-biomarker, crisis-manufacturing and medicinal-chemistry projects (Ug-02, Ug-05, Ug-06, Ug-07) extend the case across the curriculum.

Table 4

Undergraduate education projects (Ug): clinical pharmacy and chemistry education. After the integrated university project catalogue (Antypenko & Antypenko, 2026, Supplementary Table S7.1a)

ID	Project title	Departments integrated	Primary objective and expected outcome
Ug-01	Medication safety assessment for environmental contamination exposure	Clinical pharmacy + pharmaceutical chemistry	Train students in medication-safety protocols while examining interactions relevant to PFAS exposure; outcome: contamination-aware pharmaceutical care and evidence-based protocols for affected populations
Ug-02	Pharmaceutical compounding education using material-safety analysis	Clinical pharmacy + pharmaceutical technology	Teach compounding safety through analysis of contamination challenges; outcome: compounding-safety skills and protocols for contaminated environments
Ug-03	Organic chemistry through polymer degradation analysis	Organic chemistry + environmental chemistry	Teach organic-chemistry principles via polymer degradation pathways; outcome: understanding of chain scission, hydrolysis and environmental polymer chemistry
Ug-04	Pharmaceutical analysis using PFAS detection methods	Pharmaceutical analysis + analytical chemistry	Train students in trace analysis through PFAS detection method development; outcome: analytical capability at regulatory sensitivity levels

ID	Project title	Departments integrated	Primary objective and expected outcome
Ug-05	Bioorganic chemistry through contamination biomarker development	Bioorganic chemistry + clinical chemistry	Teach bioorganic chemistry via exposure-biomarker development; outcome: skills in biomarker design and clinical-chemistry reasoning
Ug-06	Pharmaceutical technology through crisis-adapted manufacturing	Pharmaceutical technology + crisis innovation	Train students in manufacturing under resource constraints; outcome: crisis-adapted pharmaceutical technology competencies
Ug-07	Medicinal chemistry through contamination treatment development	Medicinal chemistry + therapeutic development	Teach medicinal chemistry via development of treatments for exposure; outcome: medicinal-chemistry skills applied to contamination therapeutics
Ug-08	Public-health pharmacy through environmental health	Public-health pharmacy + environmental health	Train students in public-health pharmacy through environmental contamination challenges; outcome: population-level pharmaceutical and environmental-health competencies

4.1.5.3. Graduate research and education projects (Gr)

The graduate tier couples original research with research training and spans two to four years per project. The projects most aligned with the Department's existing strengths are organic-synthesis research for remediation chemistry (Gr-06) and pharmaceutical-chemistry research on material processing (Gr-07), both of which generate methods while training synthetic and analytical chemists. Biomarker development (Gr-01) and clinical-pharmacology research in exposed populations (Gr-03) extend toward the medical faculty, while the pharmaceutical-intervention, medical-device, nanomedicine and biochemistry projects (Gr-02, Gr-04, Gr-05, Gr-08) are longer-horizon and more speculative. As with the undergraduate tier, the physical work uses surrogate materials and the recovered-cable scenario serves as the research framing.

Table 5

Graduate research and education projects (Gr): advanced research and educational innovation. After Antypenko & Antypenko (2026, Supplementary Table S7.1b)

ID	Project title	Departments integrated	Primary objective and expected outcome
Gr-01	PFAS biomarker development for diagnosis and education	Clinical chemistry + medicine + research	Develop exposure biomarkers while training graduate researchers; outcome: candidate diagnostic markers and trained clinical-chemistry researchers
Gr-02	Pharmaceutical intervention development for contamination	Pharmaceutical sciences + clinical medicine + drug development	Create candidate interventions while establishing a graduate programme; outcome: early-stage intervention leads and a contamination-focused training track
Gr-03	Clinical pharmacology for PFAS-exposed populations	Clinical pharmacology + medicine + pharmacokinetics	Study medication effects in exposed populations; outcome: evidence-based medication protocols and clinical-pharmacology specialists
Gr-04	Medical device development and engineering education	Biomedical engineering + medicine + materials science	Develop devices from surrogate materials while training engineers; outcome: device concepts and engineers versed in materials utilisation
Gr-05	Pharmaceutical nanotechnology for contamination treatment	Nanomedicine + pharmaceutical sciences + clinical medicine	Develop nanoparticle approaches while establishing nanomedicine training; outcome: candidate nanomedicine approaches and trained researchers
Gr-06	Organic synthesis and research for remediation chemistry	Organic chemistry + environmental chemistry + remediation science	Develop remediation chemistry while training organic chemists; outcome: remediation methods and environmentally literate synthetic chemists
Gr-07	Pharmaceutical chemistry for material processing	Pharmaceutical chemistry + materials processing + safety science	Research processing and decontamination while establishing training; outcome: processing methods and pharmaceutical chemists versed in material safety
Gr-08	Biochemistry and research on contamination health effects	Biochemistry + toxicology + clinical research	Study contamination biochemistry while training biochemists; outcome: mechanistic understanding and trained contamination-health researchers

4.1.5.4. Medical device and technology education projects (Med)

The medical-device tier is oriented toward healthcare-engineering education and is, with the pharmaceutical tier, among the longest-horizon and most regulatory-constrained. Its projects use the development of devices for conflict and contamination settings as a training vehicle. None should be read as proposing the use of recovered PFAS-bearing cable in implants or patient-contacting devices; the regulatory and biocompatibility barriers described in Section 3 make that prospect remote. The defensible educational content is the design reasoning – biocompatibility assessment, materials traceability, sterilisation, contamination-safety – conducted with compliant surrogate materials.

Table 6

Medical device and technology education projects (Med): healthcare innovation education. After Antypenko & Antypenko (2026, Supplementary Table S7.1c)

ID	Project title	Departments integrated	Primary objective and expected outcome
Med-01	Biomedical engineering training via conflict-adapted device development	Biomedical engineering + clinical medicine + conflict studies	Train engineers through device development for conflict settings; outcome: engineers prepared for conflict healthcare and candidate device designs
Med-02	Device-safety education via PFAS-free implant development	Medical device engineering + surgery + materials safety	Educate engineers in contamination safety via implant development from decontaminated surrogates; outcome: contamination-aware engineers and cost-effective implant concepts
Med-03	Emergency-medicine education via contamination-response equipment	Emergency medicine + biomedical engineering + contamination response	Train emergency providers through response-equipment development; outcome: providers trained in contamination response and specialised equipment concepts
Med-04	Telemedicine education via post-conflict healthcare system development	Telemedicine + public health + technology development	Educate telemedicine specialists via post-conflict delivery systems; outcome: specialists trained for crisis healthcare and system designs
Med-05	Therapeutic-device engineering via contamination-treatment development	Therapeutic device engineering + pharmaceutical sciences + clinical medicine	Train device engineers via treatment-device development; outcome: engineers trained in contamination treatment and specialised device concepts

4.1.5.5. Clinical education projects (Clin)

The clinical tier addresses direct patient-care education and is most relevant to the medical faculty with which a medical and pharmaceutical university is co-located. Its projects train medical and pharmacy students and residents in the clinical management of contamination exposure across the lifespan, from general clinical medicine and pharmaceutical care to maternal-fetal and paediatric protocols. These projects are valuable for contamination literacy even where the underlying exposure data remain incomplete, because they teach a structured approach to managing uncertain environmental exposures – a transferable clinical skill.

Table 7

Clinical education projects (Clin): direct patient-care education. After Antypenko & Antypenko (2026, Supplementary Table S7.1d)

ID	Project title	Departments integrated	Primary objective and expected outcome
Clin-01	Clinical medicine through contamination-exposure management	Clinical medicine + environmental health + patient care	Train students and residents in clinical management of exposure; outcome: providers trained in exposure management and evidence-based protocols
Clin-02	Clinical pharmacy through care for PFAS-exposed populations	Clinical pharmacy + public health + patient care	Train pharmacy students in pharmaceutical care for exposed populations; outcome: pharmacists trained in contamination care and care protocols
Clin-03	Medical education through long-term contamination health monitoring	Medical education + environmental health + longitudinal care	Train students through long-term monitoring systems; outcome: students trained in environmental-health monitoring and management

ID	Project title	Departments integrated	Primary objective and expected outcome
Clin-04	Obstetrics/gynaecology through maternal-fetal contamination medicine	Ob/gyn + environmental medicine + maternal-fetal health	Train residents through maternal-fetal exposure protocols; outcome: providers trained in maternal-fetal contamination care
Clin-05	Paediatrics through contamination paediatric-medicine protocols	Paediatrics + environmental medicine + child health	Train residents through paediatric exposure protocols; outcome: providers trained in paediatric contamination care

4.1.5.6. Public health education projects (Ph)

The public-health tier addresses population-level education in epidemiology, intervention design, risk communication, health-system resilience and community medicine. These projects connect the molecular and clinical content to the social context in which contamination is experienced, and they provide a natural home for the ethics and communication themes identified in Section 4.4. The epidemiology and risk-communication projects (Ph-01, Ph-03) are particularly well suited to integration with the analytical and clinical tiers, because they consume the data those tiers generate and translate it for affected communities.

Table 8

Public health education projects (Ph): population health education. After Antypenko & Antypenko (2026, Supplementary Table S7.1e)

ID	Project title	Departments integrated	Primary objective and expected outcome
Ph-01	Epidemiology through technology health-impact studies	Epidemiology + environmental health + population research	Train epidemiology students through contamination health-effect studies; outcome: epidemiologists trained in contamination research
Ph-02	Public-health intervention through population programmes	Public health + environmental medicine + community health	Train students through intervention development; outcome: specialists trained in contamination intervention and effective programmes
Ph-03	Health communication through risk communication	Health communication + public health + risk communication	Train students through risk-communication strategy development; outcome: specialists trained in effective contamination communication
Ph-04	Healthcare administration through system resilience	Healthcare administration + public health + emergency management	Train administrators through resilience-strategy development; outcome: administrators trained in healthcare-system resilience
Ph-05	Community medicine through post-conflict population assessment	Community medicine + public health + post-conflict health	Train students through post-conflict health-assessment methods; outcome: providers trained in post-conflict population assessment

4.1.5.7. Advanced pharmaceutical sciences projects (Pharm)

The pharmaceutical-sciences tier is the natural lead for the Department of Pharmaceutical, Organic and Bioorganic Chemistry. Its projects address decontamination research, treatment development, contamination detection, crisis-adapted manufacturing and pharmaceutical risk assessment. The detection and safety projects (Pharm-03, Pharm-05) are the most immediately deliverable and align with the analytical course module proposed in Section 6, while the decontamination and manufacturing projects (Pharm-01, Pharm-04) connect to the treatment technologies of Section 3.2. The treatment-development project (Pharm-02) is the most speculative and longest-horizon.

Table 9

Advanced pharmaceutical sciences education projects (Pharm): specialised pharmaceutical education. After Antypenko & Antypenko (2026, Supplementary Table S7.1f)

ID	Project title	Departments integrated	Primary objective and expected outcome
Pharm-01	Pharmaceutical sciences through PFAS decontamination research	Pharmaceutical sciences + environmental chemistry + safety science	Train scientists through decontamination research on surrogate materials; outcome: scientists trained in decontamination and safe processing methods

ID	Project title	Departments integrated	Primary objective and expected outcome
Pharm-02	Drug development through contamination-treatment research	Drug development + clinical medicine + therapeutic research	Train students through treatment-focused research; outcome: specialists trained in contamination treatment and candidate therapeutics
Pharm-03	Pharmaceutical analysis through contamination detection	Pharmaceutical analysis + analytical chemistry + contamination detection	Train students through detection-method development; outcome: analysts trained in contamination detection methods
Pharm-04	Pharmaceutical technology through crisis-adapted manufacturing	Pharmaceutical technology + manufacturing science + crisis innovation	Train students through crisis-manufacturing development; outcome: specialists trained in crisis-adapted manufacturing
Pharm-05	Pharmaceutical safety through contamination risk assessment	Pharmaceutical safety + risk assessment + contamination science	Train students through pharmaceutical risk assessment; outcome: specialists trained in contamination risk assessment and safety protocols

4.1.5.8. Equipment and infrastructure by tier

Decisions about which projects to implement turn substantially on equipment and infrastructure. The undergraduate tier is deliverable with the instrumentation common to organic and analytical teaching laboratories, supplemented by inexpensive commercial polymer optical fiber as the surrogate teaching material. The graduate and advanced-pharmaceutical tiers carry the principal instrumentation burden, because trace PFAS quantification depends on LC-MS/MS and rigorous contamination control, and degradation and biomarker research require characterisation instrumentation. The medical-device and clinical tiers depend less on chemistry instrumentation than on biocompatibility, fabrication and clinical-simulation facilities held by partner faculties. Table 10 organises these requirements so that the Department can match ambition to available resource, and so that shared-facility and partnership arrangements can be identified where in-house capacity is absent.

Table 10

Equipment and infrastructure considerations by catalogue tier (after Antypenko & Antypenko, 2026, Supplementary Tables S7.1a–f). Items marked surrogate-only must use commercially obtained polymer optical fiber or certified decontaminated material, never recovered battlefield cable

Tier	Principal equipment / infrastructure	Sourcing strategy
Undergraduate (Ug)	Controlled ultraviolet exposure apparatus; mechanical-abrasion setup; surface-characterisation tools; standard analytical instrumentation; PFAS detection consumables; surrogate polymer optical fiber	In-house teaching laboratories; commercial surrogate consumables; pilot within existing courses
Graduate research (Gr)	LC-MS/MS with PFAS-free configuration; isotope-dilution standards; polymer characterisation instrumentation; biomarker-development platforms; remediation-chemistry reactors	Shared regional facilities; external research partnership; competitive instrumentation grants
Medical device (Med)	Device-fabrication equipment; biocompatibility testing facilities; sterilisation infrastructure; simulation systems	Partnership with biomedical engineering and clinical faculties; surrogate materials only
Clinical (Clin)	Clinical-simulation systems; exposure-assessment tools; longitudinal monitoring infrastructure	Partnership with medical faculty and affiliated clinics; long approval timelines
Public health (Ph)	Population-data systems; risk-communication and modelling tools; community-engagement platforms	Partnership with public-health bodies; data-access agreements
Advanced pharmaceutical (Pharm)	Analytical and processing instrumentation; PFAS-decontamination systems; pharmaceutical safety infrastructure	Alignment with Module B instrumentation; safety licensing; shared facilities

4.1.5.9. Expanded specifications for the priority projects

Five projects are judged most deliverable in the near term, on the joint criteria of low material hazard, alignment with existing departmental competencies, and modest infrastructure demand: the undergraduate projects in polymer-degradation organic chemistry (Ug-03), PFAS detection (Ug-04) and exposure biomarkers (Ug-05); the graduate remediation-chemistry project (Gr-06); and the advanced-pharmaceutical detection project (Pharm-03). Table 11 expands these into the fuller specification carried in the originating supplementary material, restoring the educational-innovation and equipment detail condensed from the tier tables above. These five projects form the principal substrate for the three modules, which also draw on Gr-01 and Pharm-05.

Table 11

Expanded specifications for the five priority projects (after Antypenko & Antypenko, 2026)

ID	Project	Educational innovation	Equipment and resources
Ug-03	Organic chemistry through polymer degradation analysis	Uses polymer degradation as the framework for teaching chain scission, ester hydrolysis and radical photo-oxidation, anchoring abstract mechanisms in a local material	Controlled ultraviolet exposure apparatus; mechanical-abrasion setup; surface-characterisation tools; surrogate polymer optical fiber
Ug-04	Pharmaceutical analysis using PFAS detection methods	Reframes trace analysis as an extension of pharmaceutical impurity reasoning; teaches to externally validated reference methods at regulatory sensitivity	Solid-phase extraction consumables; LC-MS/MS access or shared-facility arrangement; PFAS-free labware; isotope-dilution standards
Ug-05	Bioorganic chemistry through biomarker development	Teaches molecular-weight and bioavailability reasoning through a biomarker-design task; conceptual rather than wet-laboratory at undergraduate level	Literature and modelling resources; optional biochemistry facilities for wet-laboratory extension
Gr-06	Organic synthesis and research for remediation chemistry	Couples remediation-chemistry research with synthetic training; connects bond chemistry to PFAS destruction pathways	Synthetic chemistry laboratory; environmental-chemistry reactors; analytical support for product characterisation
Pharm-03	Pharmaceutical analysis through contamination detection	Develops contamination-detection methods within a pharmaceutical-analysis frame; emphasises method validation and greenness	LC-MS/MS; detection-method consumables; method-greenness evaluation tools; safety infrastructure

4.1.6. TRANSLATING PROJECTS INTO COURSES AT THE DEPARTMENT OF PHARMACEUTICAL, ORGANIC AND BIOORGANIC CHEMISTRY

4.1.6.1. Three proposed course modules

The 36 projects are too many, and several too speculative, to implement at once. A workable starting point is to extract from the catalogue three course modules that map onto the Department's three teaching pillars and onto the projects judged most deliverable in Section 5. Module A treats the organic chemistry of polymer degradation and draws on Ug-03 and Gr-06. Module B treats pharmaceutical and analytical chemistry of PFAS detection and draws on Ug-04, Pharm-03 and Pharm-05. Module C treats bioorganic chemistry and biomarkers of exposure and draws on Ug-05 and Gr-01. Together the three modules can be taken as a connected sequence or delivered independently. Table 12 maps the modules to their source projects, the pillar they serve, and their principal learning outcomes.

Table 12

Proposed course modules for the Department, mapped to catalogue projects and intended learning outcomes. Modules are proposals requiring departmental approval and resourcing

Module	Source projects	Principal intended learning outcomes
A. Organic chemistry of polymer degradation	Ug-03; Gr-06	Explain PMMA and fluoropolymer structure; predict degradation by photo-oxidation, hydrolysis and chain scission; rationalise environmental persistence from bond chemistry; design a laboratory degradation study with controls

Module	Source projects	Principal intended learning outcomes
B. Pharmaceutical and analytical chemistry of PFAS detection	Ug-04; Pharm-03; Pharm-05	Develop and validate a trace-analysis workflow targeting regulatory sensitivity; evaluate method greenness; perform a pharmaceutical-style risk assessment; interpret PFAS in a regulatory context
C. Bioorganic chemistry and biomarkers of exposure	Ug-05; Gr-01	Describe interactions of persistent organics and microplastics with biological systems; reason about molecular-weight and bioavailability effects; outline a biomarker concept and its validation requirements

Three considerations guided the selection of these three modules from the larger catalogue. The first is deliverability: each draws on competencies the Department already teaches and can be mounted with surrogate materials and, for Module A and much of Module C, with existing infrastructure. The second is coherence: taken in sequence the modules reconstruct the path of the contaminant from material to measurement to biological consequence, so that a student who completes all three acquires a connected rather than fragmented understanding of the problem. The third is honesty about scope: the three modules are precisely those whose educational value does not depend on the speculative material reuse that the higher catalogue tiers would require, which keeps the proposal within the bounds the evidence and the regulatory environment support. The remaining tiers of the catalogue are not discarded but deferred, to be revisited as partnerships, facilities and the regulatory picture allow.

4.1.6.2. Module A: organic chemistry of polymer degradation

Module A uses the cable as a worked example of structure-driven reactivity. The teaching narrative begins with the two polymers as organic structures: the methacrylate ester repeat unit of PMMA, and the fluorinated backbone of the cladding. From these structures the module derives degradation behaviour. PMMA is presented as susceptible to photo-oxidative chain scission under ultraviolet light below about 320 nm, to hydrolysis of its ester linkages under moisture, and to mechanical fragmentation, with these pathways combining to set its multi-century persistence (Chamas et al., 2020; Zhang et al., 2021). The fluoropolymer is presented through the carbon–fluorine bond: its strength explains both the material's chemical resistance and the difficulty of its eventual destruction, and it provides a natural bridge to the treatment chemistry of Section 3.2.

The laboratory component, conducted on commercially obtained polymer optical fiber, has students subject samples to controlled ultraviolet exposure and mechanical abrasion and then characterise surface change. The experimental design teaches that combined stressors produce more fragmentation than either alone (Song et al., 2017), and that thin geometries fragment faster because degradation is a surface process (Ward et al., 2019). The assessment is the degradation study itself: a design with controls, a stated hypothesis, characterised outcomes, and an explicit treatment of uncertainty. This authentic deliverable aligns the module with the constructive-alignment principle of Section 4.2 and connects directly to the graduate remediation-chemistry project Gr-06.

A further teaching thread extends the module from degradation toward recovery chemistry. PMMA is one of the comparatively few commodity polymers that can be thermally depolymerised toward its constituent monomer, methyl methacrylate, by an unzipping mechanism in which the chain ends sequentially release monomer units; this distinguishes it from polymers that fragment only into intractable mixtures. The contrast is pedagogically useful, because it allows the organic-chemistry teaching to hold two ideas in tension: the core polymer is in principle chemically recoverable, whereas the fluoropolymer cladding is not, and any recovery scheme must contend with that asymmetry alongside the contamination of the recovered material. Treated as a discussion and design exercise rather than a laboratory operation, the depolymerisation thread connects structure-driven reactivity to the design-for-degradation principle of green chemistry (Anastas & Warner, 2000) and to the broader question of why some plastics are more amenable to chemical recycling than others, without implying that recovery of battlefield-derived cable is presently practical or safe.

On completion of Module A, a student should be able to: relate the molecular structure of PMMA and of fluorinated polymers to their degradation behaviour; predict the relative susceptibility of these materials to photo-oxidative, hydrolytic and mechanical degradation from structural reasoning; design and conduct a controlled degradation study on surrogate material with appropriate controls and uncertainty analysis; and explain why the polymer core is in principle chemically recoverable while the cladding is not. These outcomes are stated so that teaching activities and the assessed degradation study can be aligned to them explicitly.

- Relate polymer structure to degradation pathway and persistence.
- Design a controlled degradation study with stated hypothesis, controls and uncertainty treatment.
- Interpret characterisation data against predicted structure–reactivity behaviour.
- Articulate the recovery-chemistry asymmetry between core and cladding and its design implications.

4.1.6.3. Module B: pharmaceutical and analytical chemistry of PFAS detection

Module B is the analytical core and the most directly vocational module for pharmacy students. Its organising target is the regulatory sensitivity established in Section 3: detection and quantification of PFOA and PFOS at the nanogram-per-litre level. The module teaches the analytical chain – sampling, extraction and clean-up, separation, detection, calibration and validation – with explicit attention to the matrix effects and contamination-control problems that make PFAS analysis demanding. Because pharmacists are trained to reason about impurities and limits, the module frames PFAS quantification as an extension of pharmaceutical impurity analysis rather than as a foreign technique, which lowers the conceptual barrier.

Two cross-cutting themes distinguish this module from a conventional instrumental-analysis course. First, method greenness is assessed as a design criterion, not an afterthought: students evaluate sample-preparation and analysis procedures against published greenness metrics, a practice now established in analytical teaching (Times Higher Education Campus, 2026). Second, the module integrates regulatory interpretation: students place a measured concentration against the relevant maximum contaminant level and reason about the consequences, linking the number to the regulatory milestones of Table 3. The module's assessment products – a validated protocol, a greenness evaluation, and a short regulatory interpretation – feed directly into the pharmaceutical detection and safety projects Pharm-03 and Pharm-05.

The analytical content can be taught against published reference methods, which gives students an externally validated target rather than an arbitrary in-house procedure. For aqueous matrices, two United States compliance methods define current practice: Method 537.1, which uses styrene-divinylbenzene solid-phase extraction followed by liquid chromatography with tandem mass spectrometry (LC-MS/MS) and quantifies eighteen PFAS, and Method 533, which uses weak anion-exchange solid-phase extraction with an isotope-dilution quantification approach and extends coverage to twenty-five compounds, including the short-chain species and fluorotelomer sulfonates that the earlier method retains poorly (U.S. EPA, 2019; U.S. EPA, 2020). For the solid and tissue matrices more representative of contaminated soil and biota, Method 1633, in its current revision (1633A), applies LC-MS/MS across aqueous, solid, biosolids and tissue samples (U.S. EPA, 2024b). These methods provide a ready scaffold for teaching: students learn why anion-exchange sorbents are required for polar short-chain analytes, why isotopically labelled internal standards reduce quantification uncertainty, and why holding times, preservatives and contamination control are not incidental details but determinants of a defensible result.

The isotope-dilution principle deserves particular emphasis because it generalises beyond PFAS. Students learn that adding a known quantity of an isotopically labelled analogue of each target, carried through the entire extraction and analysis, corrects for losses and matrix suppression and thereby tightens the uncertainty of the final figure. This is a transferable concept in pharmaceutical analysis, where recovery and matrix effects routinely compromise trace quantification, and it allows the module to connect a contamination case to the quality-control reasoning that underpins pharmacopoeial assay validation. Where the necessary mass spectrometry is unavailable in-house, the module can be delivered through method-design and data-interpretation exercises built on published chromatograms and validation data, reserving instrument time for demonstrations or for partnership with a regional facility; the design competency does not require that every student run every analysis to completion.

The matrix problem is the second teaching pillar of Module B. PFAS analysis is unusually vulnerable to background contamination, because fluoropolymers are ubiquitous in laboratory consumables and instrumentation; the discipline of identifying and excluding these sources is itself a transferable skill in trace analysis. Students are taught to construct procedural blanks, to substitute PFAS-free labware where required, and to interpret a result against the relevant maximum contaminant level with appropriate caution about detection and quantification limits. This connects the analytical chemistry to the regulatory framing of Section 3 and to the pharmaceutical safety project Pharm-05.

On completion of Module B, a student should be able to: select and justify an analytical method for trace PFAS quantification appropriate to a stated matrix and sensitivity target; explain the role of solid-phase extraction sorbent chemistry and of isotope-dilution quantification in achieving a defensible result; construct and execute a contamination-control regime including procedural blanks; evaluate the greenness of an analytical procedure as a design criterion; and interpret a measured concentration against the relevant regulatory limit with appropriate caution. The assessed protocol, greenness evaluation and regulatory interpretation are aligned to these outcomes.

4.1 6.4. Module C: bioorganic chemistry and biomarkers of exposure

Module C carries the case into biological systems and is the most exploratory of the three, appropriately so given the state of the evidence. It begins from the molecular-weight argument introduced in Section 2.1: why intact high-molecular-weight fluoropolymer is of limited bioavailability, and why lower-molecular-weight degradation products are of greater concern (Henry et al., 2018; Lohmann et al., 2020). It then surveys the evidence base for biological interaction with persistent organics and microplastics, drawing on documented effects such as altered gut microbiota in wild seabirds carrying microplastic loads (Fackelmann et al., 2023), the capacity of microplastics to concentrate and carry PFAS (Scott et al., 2021; Parashar et al., 2023), and the broader entanglement and ingestion literature (Blettler & Mitchell, 2021; Townsend & Barker, 2014). The teaching point is mechanistic reasoning under incomplete data, not the assertion of established harm.

The biomarker component is conceptual rather than wet-laboratory at the undergraduate level: students design a biomarker concept for exposure, specify what it would need to measure, and articulate the validation it would require before clinical use. This trains the bioorganic-chemistry reasoning that underlies clinical diagnostics and connects the module to the graduate biomarker project Gr-01 and, through it, to the clinical tier of the catalogue. The honest framing – that a defensible biomarker requires substantial validation not yet performed – is itself the lesson.

The module also gives students a structured way to reason about exposure routes, which is where bioorganic chemistry meets public health. Intact high-molecular-weight fluoropolymer and the bulk PMMA core are physically large and chemically inert, so the more credible exposure pathway runs through the lower-molecular-weight degradation products and the microplastic fraction, which can act as carriers for sorbed substances (Scott et al., 2021; Parashar et al., 2023). Students are asked to trace a plausible route from environmental compartment to biological compartment – fragmentation, transport, ingestion or inhalation, and partitioning – and to identify at each step what is known, what is assumed, and what would need measurement. This exercise teaches the partition-and-transport reasoning that underlies pharmacokinetics without overstating the strength of the evidence, and it links Module C to the public-health tier of the catalogue and to the contamination-scale estimates of Section 2. The deliverable remains a concept and an argument, not a claim of demonstrated harm, which keeps the module within the bounds the evidence supports.

On completion of Module C, a student should be able to: explain why molecular weight governs the bioavailability of polymeric and oligomeric species; evaluate the evidence base for biological interaction with persistent organics and microplastics and distinguish established effect from plausible mechanism; trace a defensible exposure route from environmental to biological compartment, identifying knowns, assumptions and measurement gaps; and design an exposure-biomarker concept with an explicit validation plan. The assessed biomarker concept document is aligned to these outcomes.

4.1.6.5. Laboratory and equipment considerations

The three modules differ markedly in their resource demands. Module A is the least demanding: controlled ultraviolet exposure, mechanical abrasion and surface characterisation can be accomplished with equipment common to an organic-chemistry teaching laboratory, and the consumable is inexpensive commercial polymer optical fiber. Module B is the most demanding, because trace PFAS quantification at regulatory limits requires sensitive instrumentation and rigorous contamination control; where such instrumentation is not available in-house, the module can be delivered partly through shared regional facilities, simulated data exercises, and method-design assessment that does not depend on running every analysis to completion. Module C is intermediate and can be delivered largely through literature analysis, modelling and concept design, with optional wet-laboratory extension where biochemistry facilities permit. This graduated demand allows the Department to begin with Module A, add Module C, and scale Module B as instrumentation and partnerships allow.

4.1.6.6. Assessment and learning-outcome mapping

Across the three modules, assessment is built from authentic products rather than terminal examination, consistent with the pedagogy of Section 4. Table 13 maps each module to its principal assessment artefact and to the graduate competencies it evidences. The mapping is intended to support both teaching design and accreditation, by making explicit which competency each assessment generates evidence for.

Table 13

Assessment artefacts and competencies for the three proposed modules

Module	Principal assessment artefact	Competencies evidenced
A	Designed and executed polymer-degradation study with controls and uncertainty analysis	Experimental design; structure–reactivity reasoning; quantitative uncertainty; scientific writing
B	Validated trace-analysis protocol, greenness evaluation, and regulatory interpretation	Analytical method development and validation; method greenness; regulatory literacy; pharmaceutical risk reasoning
C	Biomarker concept document with validation plan and evidence review	Mechanistic reasoning under uncertainty; literature synthesis; bioorganic and diagnostic reasoning; communication of risk

4.1.6.7. Indicative teaching schedules

To move the three modules from description to a form a teaching team can evaluate, indicative week-by-week schedules are set out below. Each is framed for a single semester of approximately fifteen contact weeks, the common unit of organisation in the Department's existing courses, and each is deliberately conservative in its laboratory demands so that a pilot can be mounted within current infrastructure. The schedules are planning instruments rather than prescriptions: the allocation of weeks reflects the relative conceptual weight of each component and should be adjusted to local timetabling, cohort size and instrument availability. They are presented here to make the modules concrete enough to critique, not to fix a definitive syllabus.

Module A, summarised in Table 14, front-loads the structural and mechanistic chemistry before committing laboratory time, so that students enter the practical phase able to predict the degradation behaviour they will then attempt to characterise. The laboratory block is the longest single component because the authentic degradation study, with its controls and uncertainty analysis, is both the principal learning activity and the assessment artefact.

Table 14

Indicative fifteen-week schedule for Module A (organic chemistry of polymer degradation). Allocations are planning estimates for local adjustment

Weeks	Focus	Principal activity and deliverable
1-2	Orientation and the contamination case	Introduction to the cable as an organic-chemistry problem; PMMA and the fluoropolymer cladding as molecular structures; framing of the semester project
3-4	Degradation pathways	Photo-oxidative chain scission, ester hydrolysis and the carbon–fluorine bond; structure-driven prediction of relative stability
5-6	Persistence and kinetics	Degradation-rate literature and the basis of multi-century persistence estimates; critical reading of primary sources
7-9	Laboratory phase	Controlled ultraviolet exposure and mechanical abrasion of surrogate commercial polymer optical fiber; experimental design with controls
10-11	Characterisation and analysis	Surface characterisation of treated samples; data reduction and explicit uncertainty treatment
12–13	Synthesis and bridge	Interpretation of results against predicted pathways; bridge to treatment chemistry and to the graduate remediation project
14-15	Reporting and assessment	Completion and presentation of the degradation study as the assessed deliverable

Module B, summarised in Table 15, is the most instrument-dependent and is therefore structured so that its conceptual and method-design objectives can be met even where full instrumental access is constrained. The validation and greenness components occupy the central weeks because they carry the module's distinctive teaching load; the regulatory-interpretation exercise late in the semester returns the analytical result to the decision context that motivates it.

Table 15

Indicative fifteen-week schedule for Module B (pharmaceutical and analytical chemistry of PFAS detection). Where in-house instrumentation is limited, laboratory weeks may be delivered through demonstration, shared facilities or published-data exercises

Weeks	Focus	Principal activity and deliverable
1-2	Regulatory context and targets	Maximum contaminant levels and the nanogram-per-litre sensitivity target; PFAS analysis as an extension of pharmaceutical impurity reasoning
3-4	The analytical chain and contamination control	Sampling, holding times and procedural blanks; the ubiquity of fluoropolymers in labware as an analytical hazard
5-6	Extraction chemistry	Solid-phase extraction principles; styrene-divinylbenzene versus weak anion-exchange sorbents and their analyte ranges
7-8	Separation, detection and isotope dilution	Liquid chromatography with tandem mass spectrometry; the isotope-dilution principle for correcting losses and matrix suppression
9-10	Method validation	Calibration, recovery, detection and quantification limits; construction of a defensible validation argument
11-12	Method greenness	Evaluation of sample-preparation and analysis procedures against published greenness metrics as a design criterion
13-14	Regulatory interpretation	Placing a measured concentration against the relevant limit and reasoning about consequences; protocol drafting
15	Assessment	Presentation of the validated protocol, greenness evaluation and regulatory interpretation

Module C, summarised in Table 16, is the least instrument-dependent and is delivered largely through literature analysis, mechanistic reasoning and concept design. Its central deliverable, a biomarker concept with an explicit validation plan, is developed progressively across the semester so that the validation requirements emerge from the evidence review rather than being asserted at the outset.

Table 16

Indicative fifteen-week schedule for Module C (bioorganic chemistry and biomarkers of exposure). The module is primarily analytical and design-based, with optional wet-laboratory extension

Weeks	Focus	Principal activity and deliverable
1-2	Molecular weight and bioavailability	Why intact high-molecular-weight fluoropolymer is of limited bioavailability and why degradation products are of greater concern
3-4	Evidence for biological interaction	Microplastic and PFAS interaction literature; microplastics as carriers; documented effects in wildlife
5-6	Mechanistic reasoning under uncertainty	Distinguishing established harm from plausible mechanism; the limits of the present evidence base
7-9	Biomarker concept design	Specifying what an exposure biomarker would measure and the molecular basis for the chosen target
10-11	Validation requirements	Articulating the validation a biomarker requires before clinical use; the gap between concept and defensible diagnostic
12-13	Evidence synthesis	Integrating the literature into a coherent argument; identifying and stating the principal uncertainties
14-15	Concept document and assessment	Completion and presentation of the biomarker concept document with its validation plan

4.1.6.8. Mapping the modules to the principles of green chemistry

The three modules can be related explicitly to the twelve principles of green chemistry articulated by Anastas and Warner (2000), which provide an established organising framework for sustainable-chemistry teaching and a vocabulary that accreditation bodies increasingly recognise. The mapping serves two functions. It demonstrates to

students that the contamination case is not an isolated curiosity but an instance of a general design ethic, and it allows the Department to present the modules within the language of green-chemistry pedagogy that the recent literature has developed (Vaz et al., 2025; Beyond Benign, 2025). Not every principle is engaged with equal force; Table 17 indicates where each principle is most directly addressed and acknowledges those it touches only lightly, in keeping with the candid framing maintained throughout.

Table 17

Indicative mapping of the twelve principles of green chemistry (after Anastas & Warner, 2000) to the three proposed modules

Principle	Point of contact in the curriculum
Prevention of waste	The contamination case is itself a study in the cost of unprevented waste; analytical method design minimises reagent and sample consumption
Atom economy	Treated qualitatively through the degradation and potential depolymerisation chemistry of PMMA
Less hazardous synthesis	Addressed indirectly through preference for lower-hazard extraction reagents and procedures
Designing safer chemicals	The persistence-versus-degradability trade-off underlying fluoropolymer design is the module's conceptual entry point
Safer solvents and auxiliaries	Solvent choice in extraction and chromatography is evaluated within the greenness assessment
Design for energy efficiency	Touched lightly, through comparison of energy demands of analytical and treatment options
Renewable feedstocks	Not directly engaged; noted as outside the scope of a contamination-focused curriculum
Reduce derivatives	Method design favours direct quantification over derivatisation where analyte chemistry allows
Catalysis	Treated lightly, in the context of catalytic and advanced approaches to fluoropolymer destruction
Design for degradation	The central organising theme: why these materials resist degradation and what that implies for design and exposure
Real-time analysis for pollution prevention	Directly addressed through the analytical chain and its role in monitoring and decision-making
Inherently safer chemistry for accident prevention	Contamination control, safe handling of recovered material, and risk communication are recurring themes

The mapping should not be over-read. Several principles are engaged only qualitatively, and one – renewable feedstocks – falls outside the scope of a curriculum organised around an existing waste stream rather than around synthesis. The value of the exercise lies less in claiming full coverage than in giving students a recognised framework against which to locate the specific competencies the modules build, and in connecting a regionally specific contamination problem to the broader design principles of sustainable chemistry.

4.1.7. IMPLEMENTATION CONSIDERATIONS AND RESOURCES

4.1.7.1. Staging and resourcing

Implementation should be staged and proportionate. The undergraduate modules can be piloted within existing courses as project strands before any standalone course is created, allowing the Department to test the pedagogy on a small cohort – as the green chemistry PBL literature has done with cohorts of fewer than ten students (Vaz et al., 2025) – before committing resources. Graduate projects should follow once the undergraduate pipeline is established and supervisory capacity is confirmed. The medical, clinical and public-health tiers require partnership with the corresponding faculties and external bodies and are best treated as longer-term collaborations rather than near-term deliverables.

Resource requirements vary by tier and are summarised indicatively in Table 18. The undergraduate tier is low-cost and uses surrogate materials and existing infrastructure. The analytical and graduate research tiers carry the principal instrumentation and consumable costs and benefit most from shared facilities and external partnership. The figures are order-of-magnitude planning estimates carried over from the source assessment and require local validation; they should not be read as budgets. The originating assessment estimated cumulative resources of the order of several million euros for a full validation-and-development programme spanning multi-year timelines, but the educational subset described here is far smaller and can begin with marginal cost where it reuses existing teaching infrastructure.

Table 18

Indicative, order-of-magnitude resource considerations by tier. Figures require local validation and are planning estimates only (after Antypenko & Antypenko, 2026)

Tier	Principal considerations
Undergraduate (Ug)	Surrogate polymer optical fiber; existing organic and analytical teaching laboratories; can pilot within current courses at marginal cost
Graduate research (Gr)	Sensitive instrumentation; supervisory capacity; benefits from shared regional facilities and external partnership
Medical device (Med)	Biocompatibility and device-fabrication facilities; regulatory expertise; faculty partnership required
Clinical (Clin)	Clinical-faculty partnership; patient-simulation resources; long approval timelines
Public health (Ph)	Population-data access; community partnership; communication and modelling resources
Advanced pharmaceutical (Pharm)	Analytical and processing instrumentation; safety infrastructure; alignment with Module B

4.1.7.2. Integration with the existing curriculum

The modules are most likely to succeed if they are introduced as strands within existing courses before any of them is established as a standalone offering. Module A maps onto an existing organic-chemistry course, where the degradation chemistry of PMMA can replace or supplement a conventional polymer-reactivity unit and the laboratory exercise can substitute for an existing characterisation practical. Module B maps onto analytical and pharmaceutical-analysis teaching, where the PFAS detection problem can be introduced as an extended case within instrumental-analysis or quality-control instruction rather than as an additional course. Module C is the most naturally delivered as a seminar strand within bioorganic chemistry, because its emphasis on literature analysis and concept design fits the format of an advanced reading-and-design course. Introducing the material this way limits the institutional commitment required for a first iteration and allows each module to be evaluated against the evidence categories of Section 4.5 before its scope is expanded.

Sequencing across the curriculum also matters. The three modules are designed to be intelligible independently, but their full value is realised when a cohort encounters them in the order organic, analytical, bioorganic, because that sequence reconstructs the path of the contaminant from material to measurement to biological consequence. Where timetabling prevents a single cohort from taking all three, the connective tissue can be preserved by cross-referencing: Module A can close by posing the analytical question that Module B answers, and Module B can close by posing the biological question that Module C addresses. This preserves the integrative logic of Section 4.3 even under a fragmented delivery schedule.

4.1.8. LIMITATIONS

Several limitations qualify the framework. The project catalogue is a set of proposals; the majority have not been implemented, and the medical, clinical and pharmaceutical tiers describe long-horizon aspirations whose feasibility depends on regulatory pathways that do not presently exist for PFAS-bearing recovered material. The educational claims rest on pedagogical literature drawn mainly from green and sustainable chemistry teaching rather than from implementations of this specific case, so the transfer of reported benefits to the contamination scenario is plausible but unproven and should be tested through piloting and evaluation.

The underlying contamination figures retain wide uncertainty. The bilateral mass estimate carries an overall uncertainty of approximately ±35%, the microplastic projection exceeds ±50%, and key parameters – the fluoropolymer fraction, the deployment rates, and the degradation rates – await empirical confirmation through analysis of recovered cable and field study (Antypenko & Antypenko, 2026). These uncertainties do not undermine the educational use of the case – indeed, teaching with provisional data is part of the point – but they preclude any claim that the framework rests on settled science. Finally, the regulatory environment is in active formation: the EU REACH PFAS restriction had not been finalised at the time of writing, and course content addressing it will require periodic revision as committee opinions and the eventual Commission decision emerge (ECHA, 2026).

4.1.9. CONCLUSIONS

Fier optic drone cable waste presents a distributed, persistent and chemically distinctive contamination problem that conventional remediation frameworks address poorly. This chapter has argued that, for a department of pharmaceutical, organic and bioorganic chemistry, the problem's principal value is educational and investigative rather than material. The recovered cable is unlikely to enter pharmaceutical or medical use given the trajectory of PFAS regulation and the safety constraints of battlefield-recovered material; but the scientific questions it raises – polymer degradation, trace PFAS detection, treatment chemistry, biomarker design, and contamination-aware clinical practice – map onto the competencies the Department already teaches and can be taught with surrogate materials at modest cost.

The 36-project catalogue and the three proposed course modules are offered as a usable starting point rather than a finished program. The most deliverable elements – an organic-chemistry module on polymer degradation, an analytical module on PFAS detection targeting regulatory sensitivity, and a bioorganic module on exposure biomarkers – can be piloted within existing courses before any standalone commitment, and evaluated against the pedagogical claims that motivate them. Their implementation would require institutional approval, ethical review and, for the higher tiers, faculty and external partnership. Treated this way, a category of war-derived waste becomes a structured occasion to teach analytical rigor, regulatory literacy, mechanistic reasoning under uncertainty, and the professional ethics of communicating environmental risk – an outcome that serves the students of Zaporizhzhia's universities and the war-affected region around them alike. The contribution the chapter claims is correspondingly specific. It is not that war-derived waste can be redeemed as a material, but that a regionally grounded contamination problem, lying in the farmland and watercourses of front-line southeastern Ukraine, can be converted into a teaching resource that builds precisely the analytical, organic and bioorganic competencies a pharmacy-oriented department already exists to develop – a resource available now, to the institutions closest to the problem, and not contingent on a reuse pathway that may never arrive

Appendix. Glossary of key terms

Term	Definition
Poly(methyl methacrylate) (PMMA)	A transparent thermoplastic, the methacrylate-ester repeat unit of which forms the optical core of the cable; degradable over multi-century timescales by photo-oxidation, hydrolysis and mechanical fragmentation
Fluoropolymer	A polymer with a fluorinated carbon backbone; here the cable cladding, valued for chemical resistance arising from the strong carbon–fluorine bond, which also underlies its environmental persistence
Per- and polyfluoroalkyl substances (PFAS)	A large family of synthetic fluorinated compounds characterised by carbon–fluorine bonds; associated with environmental persistence and a growing body of regulation
PFOA / PFOS	Perfluorooctanoic acid and perfluorooctane sulfonate; two long-chain PFAS for which enforceable drinking-water limits have been set in several jurisdictions
Maximum contaminant level (MCL)	An enforceable upper limit on the concentration of a contaminant in drinking water; the enforceable counterpart of the non-enforceable, health-based maximum contaminant level goal (MCLG)
LC-MS/MS	Liquid chromatography coupled with tandem mass spectrometry; the separation-and-detection technique on which trace PFAS quantification chiefly relies
Solid-phase extraction (SPE)	A sample-preparation technique that concentrates analytes onto a sorbent; sorbent chemistry (for example styrene-divinylbenzene or weak anion-exchange) determines which analytes are retained
Microplastic	Plastic fragments below approximately five millimetres, formed here by the fragmentation of the polymer core and relevant to environmental transport of associated substances
Photo-oxidative chain scission	Light-driven breaking of polymer chains in the presence of oxygen, a principal degradation pathway for PMMA under ultraviolet exposure
Surrogate material	Commercially obtained polymer optical fiber or certified decontaminated material used in teaching in place of recovered battlefield cable, which is not used for laboratory work
Greenness metric	A structured method for scoring the environmental and safety profile of an analytical procedure, used in the curriculum as a design criterion rather than a retrospective audit
Problem-based learning (PBL)	A pedagogy in which learning is driven by engagement with an authentic, open problem rather than by transmission of content ahead of application

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