Ethics of Chemistry:
From Poison Gas to Climate Engineering

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Ethics of Chemistry: Meeting a Teaching Need

Joachim Schummer and Tom Børsen

1. The Purpose of This Volume

Perhaps more than ever, chemical know-how is in demand for developing solutions to many global issues, including the protection of the natural environment, healthcare, nutrition for a growing world population, water treatment, energy production, waste treatment, recycling, and clean-up of environmental damages by former generations. Rather than just doing their isolated lab work, chemists are expected to engage with other disciplines and with society at large to work together on managing these issues. Of course, real-life solutions are never as simple as those for crossword puzzles. They always involve various advantages and disadvantages, improvements and drawbacks, and opportunities and risks to be discussed and balanced against each other. Thereby, chemists are inevitably involved in disputes about values. They would badly fail if they were not prepared to reflect on the values, develop and analyze moral and political arguments, build moral judgments, and perform responsible actions, all of which belong to the domain of ethics.

For many years, national and international organizations, such as UNESCO's World Commission on the Ethics of Scientific Knowledge and Technology (COMEST), have therefore recommended mandatory courses of ethics for all university students of science and engineering. Moreover, funding agencies and corporate associations increasingly require or assume that scientists are familiar with ethical issues, such as the European Responsible Research and Innovation program and the Corporate Social Responsibility agenda. While the necessary courses have been established in numerous countries and for various student groups, chemistry is still lagging behind, despite the particular importance to the discipline. One reason, or excuse, is the lack of appropriate course materials, because ethics of chemistry does hardly exist in academia, unlike, for instance, ethics of medicine, biology, computer science, engineering, and so on.

The main purpose of this volume is to fill that gap both by providing the necessary resources for teaching and by establishing ethics of chemistry as an academic field of future research. We do so by presenting a well-selected set of ethical cases that we have developed and co-edited over four years in a series of special issues of *Hyle: International Journal of Philosophy of Chemistry* (hyle.org). Our chapters are authored by the best available experts worldwide, many of which have a background both in chemistry and the humanities or social sciences. The cases are carefully selected so as to cover the most important ethical issues that have raised moral concerns in the past and have strongly shaped the public image of the discipline. They both define the scope of ethics of chemistry and narrate a cultural history that every chemistry student should be familiar with based on academic resources.

The objectives of using the book in university chemistry education is not only to transfer knowledge about ethical issues and events in chemistry, but also to facilitate the development of analytical skills and action-oriented competences so that ethical dilemmas can be identified and addressed by the next generations of chemists.

In this chapter, we introduce ethics of chemistry and guide the educational use of this volume, depending on purposes and resources. We first provide a brief outline of philosophical ethics by distinguishing it from best practice methodology or behavior, sometimes misleadingly called ‘ethics’, and then provide a brief introduction to ethical theories, followed by a discussion of their application to fields such as chemistry. Next we introduce all chapters by our typology of ethical issues according to the order of this volume. This is our recommended order of reading and teaching ethics classes to chemistry students. However, cases can also be considered and taught according to historical order, which provides a selective cultural history of chemistry; or by subject fields, which allows for integrating selected ethical issues into particular chemistry classes, for both of which we provide recommendations below.

Unlike the common theory-plus-experiment-based teaching, which depicts chemistry in radical societal isolation and improves technical skills, ethics courses enable students to act responsibly in projects that matters in society (Schummer 2018). They reestablish the long-neglected link to the humanities, and raise awareness of the simple fact, that chemical research is of the greatest societal importance, for better or for worse.

2. What Is Ethics?

2.1 Ethics of chemistry versus 'ethics in chemistry'

If a scientist fabricates data, wrongly assumes authorship of something that some colleagues have achieved before, or if senior scientists put their name first (or last, depending on the customs of the discipline) on the publication of work mostly done by junior scientists, or if someone denigrates the public image of science, the scientific community is usually upset. There is no question that all that is bad behavior. However, does it really concern general ethics?

While it is, in any regard, morally wrong to betray somebody else, like your colleagues and the general public with fabricated results, it is not so clear if the other issues scientists are usually concerned with are of ethical relevance. After all, lobbying for the image of one's profession is not an ethical issue but in the self-interest of the discipline, usually at the expense of other disciplines, nor is the question of who deserves most credit for a scientific achievement. Indeed most other societal fields do not care about intellectual priority claims of, say, business ideas, as long as there is no legal protection. And if they do so, like in art, copying the style of others is considered poor art rather than moral failure.

Many issues that scientists sometimes call 'ethical issues' are actually violations of methodological or epistemic norms. There are a wealth of methodological rules in science proposing, for instance, how to produce and interpret data correctly, how to publish and review scientific results, and so on. These so-called 'best practice' rules ensure that results are reproducible by anyone else, such that the scientific community can build further research on them. Any violation could harm scientific progress when others credulously rely on these results. Of course, they are upset then because they have wasted time and efforts, and because the scientific quest for knowledge was misguided. However, it depends on the specific circumstances whether such violation of methodological norms additionally violates ethical norms. While there is an overlap area between both topics to be discussed in Chapter 2, this volume is not about methodological issues but about ethical issues proper. What then is ethics of chemistry about?

There is a double meaning of 'ethics' as there is a double meaning of 'chemistry', like of any other science in the English language. In the vulgar meaning, 'ethics' just means the behavioral rules of a group, such as 'chemistry' means the regular behavior of molecules. In this sense, 'ethics in chemistry' describes the behavior of chemists and what they think one ought to do, which largely covers the aforementioned methodological norms. In the academic meaning, however, 'ethics' is that branch of philosophy that deals with moral values, ideally putting it on general principles that are valid for anyone at any time.

A chemical example may illustrate the difference: there is a 'chemistry' of two particular insects interacting chemically (subject matter level, the actual behavior of insects) and there is the academic field of pheromone chemistry that studies the chemical interactions between insects by various molecules (epistemic level, scientific knowledge about the insect behavior). Like academic chemistry studying substances and molecules, ethics studies moral values, norms, and judgments. Thus, ethics is not the behavior, but the study of the behavior. However, unlike science that aims at the perfect description, prediction, and explanation of its subject matter, ethical studies aim at normative ideas of what is morally right or wrong. These studies can be very general and abstract, similar to theoretical chemistry, or applied to particular fields of human activity, such as in ethics of chemistry.

What then are moral values, norms, and judgments? Moral values are general goals or goods that are morally valued and recommended to strive for or to support (as, for instance, justice, well-being, or human rights). If these values additionally meet ethical requirements detailed below, they are ethical values. Moral norms are both obligations to strive for moral values (*e.g.*, 'act so as to increase or reinforce justice, well-being, and human rights') and obligations to avoid counter-productive goals (*e.g.*, 'act so as to avoid injustice, harm, and human rights violations') also known as moral prohibitions. Moral judgments include the full range of normative statements, from blame and praise to moral recommendations pro and con, unlike scientific judgments that state whether statements are true or false. In ethics, moral judgments are usually about the actions of moral subjects, both individuals and corporations, distinguishing between doing morally right and doing morally wrong. They can come in advance as guidance (*e.g.*, 'it is morally right to do this or that') and in retrospect as verdict ('that was morally wrong'). However, moral judgments may also be about the general attitudes of moral subjects, which typically distinguish between virtues and vices and is then called 'virtue ethics' (*e.g.* 'this person is guided by justice'). The examples illustrate that values can to some extent be translated into general norms, judgments, and virtues and *vice versa*. If either of them forms the basis of an ethical system or theory, it is considered an ethical or normative principle.

Ethics of chemistry is thus the academic field that studies the moral values, norms, judgments, and virtues relevant to chemistry with the aim of providing moral guidance from a general ethics perspective. Because ethics takes, per definition (see below) an impartial stance, it may question, criticize, or confirm the moral attitudes of chemists – as individuals, corporations, or local or global scientific society – rather than taking them for granted. In ethics, like in any science, it does not matter what people believe at a certain time and place, but only what rational arguments can be provided to support or oppose a view.

2.2 A brief introduction to philosophical ethics

At the risk of over-simplification, a very brief introduction to philosophical ethics, or moral philosophy, may help setting the stage. Ethics, a major discipline of philosophy, has elaborated theories and normative principles to decide on ethical issues over many centuries. To begin with, it is useful to distinguish morality, which is what ethics is mainly about, from other normative realms (*i.e.*, realms of norms that say what one ought to do), in particular, customs and law, keeping in mind the distinction between the academic field and its respective objects of study. Ethics studies morality, while the academic field of law studies the laws, whereas social sciences, such as anthropology, describes the actual customs of particular societies.

Customs and law are both local regulations, enforced by various sanctions, from mild stigmatization to imprisonment, or even capital punishment in some countries. Morality differs from customs in that it refers to general principles that are independent of the particular group or society, whereas customs are based on the specific traditions of a culture. For instance, local customs greatly vary in their dress codes or rules of decency and politeness, hardly any of that can be justified across cultures. And some customs, like the widespread ancient religious practice of human sacrifice, are deeply questionable on ethical grounds. Law, which many mistakenly think is the most basic normative realm, requires ethical justification in parliamentary debates before its implementation, and can later be questioned and revised on ethical grounds at any time. Ideally, law harmonizes with morality at any time, but it may be based on misguided moral ideas as in many dictatorships. Moreover, law covers only those areas that the state can reasonably control and courts could possibly judge. For instance, criminal intent, although being pivotal to many legal judgments, frequently evades the judges' capacities of mind reading. Hence, morality, rather than being a residual category besides customs and law, is the most basic and most important one.

The very first principle of any ethical theory that aims at moral judgments, indeed its necessary condition or meta-principle, is impartiality, which can appear in different versions. It may just be the strict rule to disregard any partial interest and, instead, give any affected party an equal say. In the latter form, the principle is well established in democracy in the form of general elections, as well as in political philosophy (contract theories) and discourse ethics (which defines rules to solve conflicts in moral matters, such as that anyone has the right to propose rational arguments for one's own position). Or, it may demand considering the equal interest of anyone concerned, including oneself; or abstracting from one's own particular interests; or treating anyone by the same rules, regardless of heritage and social status (unlike the laws and customs in monarchic, feudal, and caste societies). In its oldest and most famous form, the so-called Golden Rule, it requires that one should treat others as one want to be treated oneself by all others, thereby dismissing the difference between me and them. The 18th-century-philosopher Immanuel Kant developed this principle into a meta-rule, that is, a litmus test to decide whether a rule is an ethical rule or not: only if I can reasonably want that my rule becomes a general rule for anyone, it is an ethical rule. (You might wish to betray others, but you certainly do not wish that 'anyone can betray others' becomes a general rule.)

The second principle of ethics says, do no harm to others and instead do good, the principle(s) of non-malevolence and benevolence. It can come as one combined principle, such that doing harm can be balanced by doing good and vice versa. Or it comes as two different principles, usually with priority for non-malevolence, as in law, because attempts at doing good frequently turns into unintended harm due to unforeseen adverse effects. Much of the classical philosophical ethics is about whether and how one can combine the first two/three principles into one. Many Kantian ethicists think that their own form of impartiality (s. a.) implies not-doing-harm, because nobody wishes to be the subject of being harmed. Utilitarian ethics, the other important tradition, unites impartiality (all people are equally considered) with the combined principle of benevolence and non-malevolence: act so as to maximize the happiness of all people, which is achieved by both doing good and avoiding harm.

Over the centuries, a variety of theories have been proposed in ethics, just as in science. They all have their pros and cons and mostly establish respectable positions for many areas, but they differ from each other in many regards of which we will introduce three important distinctions.

First, ethics may focus on different aspects of human action, both for providing moral guidance in advance and judgments in retrospect. One aspect, highlighted by consequentialist ethics, is the consequences of one's actions, such as when utilitarianism requires to maximize the happiness of all people. While scientists might take this to be the obvious approach, because it is based on familiar cause-effect relations of human action, they should consider this: if your action has unintended adverse consequences, your action is morally wrong, whatever your good intentions might have been. In contrast, deontological ethics (from Greek:

deon, duty, obligation) judges and recommends actions according to whether they are performed in accordance with moral duties, which cannot be defined in scientific terms of cause-effect relations. These duties certainly include avoiding harm and doing good. However, deontology is not an excuse for the naive good will, a major ethical problem, because it usually includes the duty to consider the best available knowledge for avoiding unintended harm.

Second, depending on their number of principles, ethical theories can be divided up in monist positions (a single principle) and pluralist positions (many principles). Utilitarian ethics is usually monist, which has the advantage of avoiding priority conflicts between different principles, whereas the Kantian meta-rule allows to derive numerous rules that might lead to conflicting recommendations and judgments. Moreover, most contemporary ethical theories include the principles of justice and human dignity that both cannot simply be derived from the principles of impartiality, benevolence, and non-malevolence. For instance, utilitarian ethics allows for the unequal distribution of happiness and harm among people, which might even include the torture and sacrifice of individuals, as long as the overall happiness rises. Once further principles are considered, they all need to be balanced against each other in every situation, which undermines the ideal of a simple algorithm for ethical judgments. That might explain why ethics is usually considered fuzzy. However, also science is fuzzy when we deal with real-world issues by models that necessarily include simplifications and approximations, rather than with mathematical simulations of idealized cases.

Third, while classical ethics was developed for local moral issues of the time, modern issues frequently affect a much broader range, both in terms of time, space, and species to be considered. In particular, technological changes, here and now, can have a global impact now and on future generations, and on nonhuman species. Thus, ethical theories differ in whether they consider only local people or also the global population, the current generation or also future generations, and only humans or also nonhuman biological species, as in environmental ethics. Many of the ethical issues discussed in this volume require considering a broader scope because chemistry has indeed an enormous impact across time, space, and biological species.

2.3 Applied Ethics: Top-down versus bottom-up

As mentioned previously, the general approach of philosophical ethics is not so different from that of theoretical science in that it tries to base its theories on a few principles. Ideally normative guidelines and judgments for a particular case are to be derived from the principles and the conditions of the case, just as scientists try to explain a particular phenomenon by applying basic theories or models to the specific context. There is a controversy about which and how many principles are needed in ethics, as there is an epistemological dispute in science if all natural phenomena can be explained by a single set of scientific principles, which theoretical physicists usually claim to be from physics in a reductionist manner.

Naturally, the epistemological distinction informs different educational approaches. According to the top-down or reductionist approach, education starts with first principles to be enriched only later by particular cases that are meant to illustrate the principles at work. In chemistry, you would start your first semester with quantum mechanics and do laboratory experiments only at the end of your study, in order to learn how to apply quantum mechanics to chemical phenomena. A corresponding ethics (of chemistry) education would begin with first principles and end up with particular cases (from chemistry) in so-called applied ethics. In contrast, the bottom-up approach, which is skeptical about a set of first principles fixed once and forever and about reductionism, at least in its current shape, starts with studying particular cases, in order to learn what matters and how to design useful distinctions, concepts, and models. Because that is how the experimental sciences, like chemistry, have successfully developed over centuries, we take this to be also the obvious approach in ethics of chemistry, both in research and education.

In philosophical ethics, skepticism of the top-down approach has a long tradition, reaching from Aristotle in the fourth century BC to the modern field of Applied Ethics (in capital letters!) that refuses to be just an application of first principles. That skepticism, as well as the bottom-up approach, is particularly strong in medical ethics. However, ethical principles can play an important role from the very beginning of exploring a new field such as ethics of chemistry. They guide our view in what matters from an ethical perspective, help introduce useful distinctions, and develop concepts and theories adjusted to chemical issues, without simply taking them as applied cases. They might even inspire us to modify or enrich them based on a deepened ethical insight of the cases. In a sense, they work as necessary instruments that we need at the start and that might be improved in the course of further research, just as chemistry has improved its models and instruments in the course of its history.

Even more so in ethics education, principle-based ethics helps sharpen important distinctions, crucial for any ethical reasoning, such as between descriptive and normative reasoning, moral arguments and rhetoric, good-for-us and morally good, and important-for-me and important in general. Discussions in Applied Ethics frequently become all too fast absorbed by personal interests, and ignoring those distinctions, and principle-based ethics is the most effective educational remedy against that.

Nonetheless, this volume favors a case-based or bottom-up approach to ethics of chemistry for various reasons. That is not only, as mentioned before, in accordance with the general epistemology of chemistry and the prevailing skepticism in Applied Ethics. Moreover, because we are at the very beginning to explore what really matters in chemistry from an ethics point of view, it is useful to start with the cases that have mostly stirred up public moral debates. There is the potential of learning something entirely new from the chemical cases because they have largely been ignored by philosophical ethicists. Furthermore, because there are a variety of different ethical theories, any top-down approach would prematurely and wrongly have to single out one theory for each and every case in chemistry. By contrast, this volume is authored by many different scholars, each one a specialist of the respective case, without following a single ethical theory.

From an educational point of view, the diversity of authors and viewpoints also provides students with a realistic view of the ethical issues and the different possible stances. What matters in ethics education is not the indoctrination of one particular view, as in dictatorships. Instead, ethics education aims at developing various moral capacities, including the ability to develop one's own moral position based on ethical arguments.

3. Cases of Chemistry According to Ethical Topics

There are various ways of ordering the cases and, correspondingly, of using the cases in class. Because our primary aim is to provide material for ethics teaching, this volume orders the cases by ethical topics. That has the additional advantage of structuring the field, that is, ethics of chemistry, right from the beginning, to provide guidance for further academic research or let others challenge and modify our still provisional ordering. Of course, there are entirely different options, such as ordering the cases by historical timeline or by chemical fields, which we will discuss in Sections 4 and 5. And there is, of course, the possibility of selecting individual cases according to specific interests, by choosing the most prominent cases or by using the table of contents along with the subject index at the end of this volume. However, for our purpose it is useful to divide the case in five groups according to the dimensions of the ethical issues.

3.1 Misuse and misconduct

The first group, *Misuse and Misconduct*, covers cases where the responsible actors clearly violate ethical norms, which they might do knowingly or unknowingly. Evil actors do this with intention, and in retrospect they are usually easy to identify and to blame, but these are the least interesting cases from an ethical point of view. Others do that apparently without intention but by sheer ignorance of ethics or of the dimension of their doings. Indeed, as we will see, in many cases of that group, actors misunderstand their ethical responsibilities and confuse it with other norms, such as patriotism or obedience to employers or governments. Others try to excuse themselves later by arguing they had not known the consequences of their actions, although ignorance or naivety is of course not an excuse per se. Instead, there is an ethical duty, of scientists as of anyone else, to inform oneself about the possible consequences of one's actions according to the best available knowledge. Naivety is no excuse but a major source of ethical misconduct and widespread harm. That is perhaps the most important lesson from this type of case.

Our volume starts with a fictitious case of scientific misconduct that Janet D. Stemwedel wrote for this occasion, drawing from various prominent historical examples, including the Sezen/Sames case from 2002 (Chapter 2). In her study, we meet a PhD student who cannot reproduce the experimental data published by a former member of the research group. As the case develops, the reader gradually realizes that data fabrication has been involved. Stemwedel analyzed her fictive case with the help of Muriel J. Bebeau's strategy for ethical decision-making. As the analysis progresses, various dilemmas faced by a number of involved people unfold, from the PhD student to the supervisor, to colleagues and university officials, illustrating the ethical complexities of typical real cases of scientific misconduct.

In the second case study, Joachim Schummer narrates the history of chemical weapons research, development, and deployment in WWI with focus on Fritz Haber in Germany (Chapter 3). The case shows how for the first time in history scientists engaged on a large scale in weapons research, established an academic-industrial-military-governmental complex, and created an unprecedented arms race that would become a model for the Cold War era. In his ethical analysis, he argues that chemical weapons research, which is widely conducted up to the present day, is morally wrong according to all major ethical theories, despite a battery of widespread but misleading excuses. The questions then arise as to why chemical societies do not condemn it in their codes of conduct, and why they instead still today consider the main weapons researchers of WWI role models for a younger generation.

The third case asks if the research, development, and production of chemical weapons can all be characterized per se as misuse of science (Chapter 4). Stephen M. Contakes and Taylor Jashinsky use the two examples of Louis Fieser, the inventor of napalm during WWII, and Dow Chemical, one of the producers of napalm during the Vietnam War. Based on Just War theories, their analysis is focused on the issue of whether the actors knew about and supported the actual military mass deployments of napalm against civilians, which by all standards count as severe war crimes. While they find Fieser, as WW II developed, increasingly guilty, they see Dow at least struggling with ethical issues and betrayed both by US politicians and the military through misleading information.

3.2 Unforeseen local consequences

The second group of cases, *Unforeseen Local Consequences*, is more intricate and distinguished from misuse particularly by the level of available knowledge at the time. While misuse disregards the best available knowledge of probable consequences, in this group the available knowledge is, at the time of making crucial decisions, indeed limited, such that the adverse consequences are unforeseen, but not totally unlikely. The ethical questions then arise if sufficient precautionary measures had been applied and how the actors respond to early alerts of potentially disastrous effects. Cases in this group typically include the three kinds of hazards of chemical industries derived from their production, their products, and their waste.

The first study deals with the worst chemical industrial disaster ever since, the leakage of methyl isocyanate in Bhopal, India in 1984 (Chapter 5). While the plant was meant to contribute to a 'green revolution' that should increase agricultural productivity through the use of pesticides, the disaster killed thousands of people and injured hundreds of thousands. Based on a detailed analysis of the historical events, Ingrid Eckerman and Tom Børsen scrutinize the responsibilities of the various actors, including the company Union Carbide Corporation and the governments of India and the local state of Madhya Pradesh. They argue that fundamental ethical values were violated and draw lessons on how future industrial catastrophes can be avoided.

The next two chapters deal with different aspects of unforeseen consequences of industrial chemicals. Klaus Ruthenberg investigates the early phases of the Thalidomide scandal in Germany that resulted in the births of thousands of malformed newborns and stillborn babies over several years (Chapter 6). In the late 1950s the company Grünenthal praised Thalidomide (brand name 'Contergan') as a 'wonder drug' that enables a good night's sleep without any side effects. However, their results were based on questionable scientific practice. Early warnings were dismissed for economic reasons. In his ethical analysis, the author discusses how the most important players in the case complied with four ethical principles: respect for autonomy, non-maleficence, beneficence, and the principle of justice.

The third case returns to chemical war efforts by investigating the notorious herbicide Agent Orange that the US military used as a strategic weapon on a grand scale during the Vietnam War to destroy possible hideaways of their enemy (Chapter 7). The industrial wartime manufacturing of the herbicide left considerable but unnoticed amounts of extremely toxic dioxins in the product, which killed or harmed a large part of the civil population of Vietnam, apart from the intended devastating environmental impact. Claus Jacob and Adam Walters use the case for discussing the responsibilities of various actors, from the chemical inventor and the industrial manufacturers to the actual user of the chemical, for the unforeseen harm.

In the fourth case of unforeseen local consequences, Ragnar Fjelland discusses the long-term effects of a former chemical waste disposal site in New York State, on which a suburban town called Love Canal was built (Chapter 8). He argues that citizen knowledge should be taken seriously in such cases. The official experts used scientific models and statistical methods with underpinning assumptions that did not capture the distribution of health problems among the citizens. Whereas the citizens themselves joined forces with other scientists to develop a model that incorporated their local knowledge. The author argues that scientists can fruitfully involve and collaborate with citizens, and should do so if they adopt the Precautionary Principle. They must not oversell their conclusions and should inform the public about uncertainties.

3.3 Global and long-term influences and challenges

Our third group of cases extends the theme of unforeseen adverse consequences toward global and long-term effects. Rather than with some local effects, we are now dealing with decisions that might affect the future of humanity or even the entire earthly environment for living beings. The fact that we find here many prominent cases illustrates the extraordinary power of chemistry on our global and future well-being or lack thereof. That role of chemistry has intuitively been acknowledged by a growing environmental movement since the early 1960s, but badly neglected by professional ethicists thus far, which has left chemistry students largely alone. They are still facing simplistic black/white schemes: either a condemnation of chemistry overall by a growing public opinion, or the promise of a rosary future by their potential employers.

Rather than just prohibiting chemical products right away because of possible adverse consequences, it is ethically advisable to balance benefits and harms, develop precautionary measures at an early state and invest in chemical research that develops less harmful substitutes, involves less harmful processes, redirects entire production chains, recognizes possible hazard as early as possible, and avoids environmental damage through recycling technologies.

Once considered the perfect remedy against both insect-borne diseases such as malaria and insect pests in agriculture, dichlorodiphenyltrichloroethane (DDT) proved to have numerous adverse effects on human and nonhuman health across the globe, most prominently pointed out already in 1962 by Rachel Carson's *Silent Spring*. In our first case of this group, Tom Børsen and Søren Nors Nielsen provide a general ethical framework to evaluate both the positive and negative aspects of industrial chemicals, which they apply to DDT in order to develop a balanced view (Chapter 9).

Next, Alistair Iles, Abigail Martin, and Christine Rosen examine the potential public health risks of Bisphenol-A (BPA), a precursor to and residual component of many plastics (Chapter 10). The compound may cause harm due to its endocrine disruptive effects, according to some experts. Also newly developed substitutes for BPA might have similar unknown adverse effects. The chapter critically discusses standard risk assessment procedures and industrial chemicals regulation in the United States. In their ethical analysis of how to deal with such uncertainties, the authors point out prototypical positions of key actor groups – managers/corporations, chemists/designers, and regulators/legislators – by distinguishing between three different regimes: deontology, consequentialism, and technocracy.

Another classic in its own right, polyvinyl chloride (PVC) is one of the oldest and still most widely produced plastics, despite various health and environmental issues. Alastair Iles and coworkers investigate its full production chain, from feedstock to consumer products such as toys. They illustrate how the historically entrenched production can be changed at various steps and by various actors to achieve a safer chemical world (Chapter 11). The case study of PVC also provides an introduction to Green Chemistry and shows how this approach can integrate ethical principles into the daily practice of applied chemistry.

Unlike compounds that can be produced in factories, elements have to be extracted from limited natural resources such as by mining, which frequently comes with huge local environmental damage. The present mining of rare earth elements, required for materials in numerous high-tech applications, unequally distributes benefits and harms in both space and time. It favors consumers in rich countries at the expense of the local population at mining sites, and it favors the present generation at the expense of future generations who might have no more access to these resources. Abigail Martin and Alastair Iles discuss the complex ethical issues that arise if dealing with global and intergenerational justice at the same time, which all chemists should be aware of if they consider applied research projects involving rare earth elements (Chapter 12). The issues invite chemists to research both substitutes for rare earth elements in high-tech materials and effective recycling processes that would reduce the demand for mining.

The two remaining chapters both discuss famous cases of chemical involvement in atmospheric and climate science. The first one, by Joachim Schummer, is on researching possible hazards before they actually occur, of which the most prominent case of chemical hazard foresight is Molina and Rowland's 1974 prediction of stratospheric ozone depletion by human-made chlorofluorocarbons (CFCs), which would have threatened most terrestrial life (Chapter 13). In this story, a postdoc project would trigger a revolution in global environmental politics, culminating in the Montreal Protocol of 1987 that banned CFCs worldwide. While Molino and Rowland are undoubtedly moral role models, the chapter discusses if and to what extent scientists have a special moral duty of hazard foresight based on their particular intellectual capacities.

As scientific evidence for global warming through the large-scale emission of carbon dioxide, methane, CFCs, and other substances had grown and international politics appeared unable to cope with that, atmospheric chemist Paul Crutzen in 2006 first broke a taboo by suggesting chemical methods for engineering the climate. Crutzen's suggestion prompted a vivid, but largely isolated, debate by ethicists that failed to address chemists. Dane Scott provides a balanced assessment of the various pros and cons of climate engineering with a focus on chemical methods of atmospheric carbon dioxide removal and answers the questions if today's chemists ought to engage in climate engineering research and which ethical conditions should be considered (Chapter 14).

3.4 Challenging human culture

Not all ethical issues of chemistry are a matter of life and death, or directly concern physical harm. Some arise from the way science questions, undermines, or ignores traditional ways of thinking and valuing, thereby challenging human culture. These issues, which cannot be studied by toxicological or other scientific methods, because they concern values such as justice, liberty, quality of life, or human dignity, are frequently overlooked by scientists, although they can raise very heated debates and potentially radical aversion of science. Others are so subtle and enduring that they might develop a long-lasting negative attitude toward scientists because of their potential ignorance of these issues. The chapters of this section address various cultural and societal aspects each typical of chemistry.

Based on a three-step model for making ethical judgments, Klavs Birkholm discusses the recently tremendous rise of psychotropic drugs as chemical tools for human enhancement (Chapter 15). While the promise of 'enhancement' sounds good at first glance, it always comes with downsides. First one should recognize the risks posed by a chemical drug to individuals, then assess the possibility for misuse, and finally imagine the cultural consequences of widespread drug use. The author identifies three potential cultural/societal consequences of psychotropic drugs: a medicalized culture that suppresses individuality, the fading quest for social recognition as an important driver of societal developments, and chemical enhancement becoming a societal norm that undervalues natural qualities.

In the second chapter, Joachim Schummer investigates societal and ethical issues of creating artificial life, from premodern times to current Synthetic Biology (Chapter 16). His case in focus is Craig Venter's 2010 announcement of having produced the first self-replicating cell, echoed by a worldwide media accusation of Venter 'playing God', which chemists in various forms have faced ever since. While the scrutiny of ethical arguments behind that accusation reveals meager results, the author argues that Venter himself provoked the public reaction in order to attract media attention, which raises the question of how to responsibly interact with the public on ethical issues.

A third issue that has caused heated debates in society is whether one can have intellectual property rights on human gene sequences (Chapter 17). While this suggests to some the disturbing notion that one can own parts of the human body, for a chemist, DNA is just a molecule. Saurabh Vishnubhakat takes the lawsuit of Myriad Genetics (2010-2013) to discuss the underlying scientific, legal, and ethical issues of patenting DNA. Rather than providing a simple answer, he argues for a procedural approach that mediates between specialist and generalist views and interests.

3.5 Codes and regulations

The final part moves to a more general level by discussing cases of how to rule the behavior of chemists. As was mentioned before, there are two other normative realms besides ethics, customs and law, which ideally harmonize with ethics. The first one is established in the form codes of conduct of chemical societies, and the second one as chemical regulations.

While the regulation of (the production, trade, and use of) chemicals is legally binding for anyone in a country, here exemplified by the European regulation (Registration, Evaluation, Authorization and Restriction of Chemicals [REACH]), the codes of conduct (exemplified by that of the American Chemical Society [ACS]) are not, not even for chemists. However, chemistry students should be familiar with both the codes and legal regulation of chemicals in their country, and they should be aware of the differences by which normative framework come into force. Legal frameworks are (in democratic society) decided by parliaments and thus express the current majority will of the population. Codes of conduct, at best, express the majority view of members of a local professional society. In contrast, ethical guidelines are supposed to be based on generally accepted ethical principles regardless of locality, nation, profession, and personal moral preference. Ethics thus is the very basis on which both local legislation and professional codes can possibly be judged, and thus justified or criticized. In other words, if you do not like some parts of your professional code or regulations, you need to refer to a normative framework of ethics to justify your criticism There is nothing else beyond.

In the first chapter of that part, Jeffrey Kovac reviews the codes of conduct by the ACS, arguably the oldest chemical society to establish such a code, from the 1965 'The Chemist's Creed' to the current version of 'The Chemical Professional's Code of Conduct' and various supplementary guidelines including on publication ethics (Chapter 18). By looking at the underlying ethical values, he compares the ACS codes with those by the British and German chemical societies and the more recent international codes, the 'Hague Ethical Guidelines' and the 'Global Chemists' Code of Ethics'. He argues that a future revision of the ACS code should put more emphasis on research integrity and on societal and environmental issues.

Incidentally, none of these codes has been set up or revised with advice from an ethicist or ethically trained chemist, to the best of our knowledge, nor is there much known about democratic procedures for approval by members. More than anything else, the way that chemical societies have produced their 'ethics' codes of conduct reflects the actual distance between the disciplines of chemistry and ethics.

The final chapter takes REACH, the European regulation of marketing chemicals, as a case to illustrate how ethical ideas have actually influenced legislation (Chapter 19). Jean-Pierre Llored demonstrates that, after curative and preventive environmental policies of the past, REACH has been informed and guided by the precautionary principle. Rather than providing a fixed set of interdictions, the regulation tries to face the uncertainty of the future with precautionary measures to be regularly revised.

4. Cases of Chemistry According to the Cultural History of Chemistry

The cases of this volume are selected so as to ideally form a canonical set that we think all chemistry students should be familiar with. Although future research will certainly explore further cases, the present set arguably comprises the most important historical events and processes that have shaped the public view of chemistry ever since the early 20th century. Whereas public media every now and then provides documentaries on these issues, usually on anniversaries, these cases are nowhere part of the standard curriculum of chemistry. As a rule, chemistry students are informed about the cultural history of their own discipline at best by public media, which illustrates the poor state of chemistry education.

Hence, this volume can also be read as a cultural history of the 20th and early 21st century. If the cases are historically lined up, it becomes more obvious why public aversion of chemistry arose during the 20th century. There were earlier strong resentments immediately after WWI, based on the large-scale deployment of chemical weapons (Chapter 3), which triggered literary fantasies of a chemical apocalypse (Schummer 2021). Chemistry's engagement in warfare continued to be important, from the atomic bomb and napalm in WWII, to Agent Orange and napalm in Vietnam War (Chapters 4 and 7), each contributing to public unease and mistrust. However, the most forceful impact began in the early 1960s when concerns about the adverse global impact of insecticides on the biosphere, such as DDT (Chapter 9), largely triggered the environmentalist movement. At the same time, the worst-ever pharmaceutical tragedy by the drug thalidomide, promoted worldwide as a remedy against 'morning sickness' of pregnant women, resulted in thousands of miscarriages and deformed babies (Chapter 6). These and other cases carried the general message that chemical products have an all-devastating potential of mass poisoning, from warfare and industrialized agriculture to pharmaceuticals.

Further cases made people aware that not only the chemical products but also their impurities (Chapter 7) as well as side-products and waste carry a deadly threat for the environment if not carefully processed. Sea water had been polluted with mercury for much of the 20th century, which the chemical industry had used as catalyst for the production of acetaldehyde in Japan (Minamata) and elsewhere (Chapter 11). Soil and groundwater became spoiled by uncontrolled dumping places of chemicals around the globe, some of which later turned into ground for greedy land development, such as in Love Canal, New York State (Chapter 8). Air pollution, a regular companion of industrialization, reached a new dimension when CFCs moved from the lower atmosphere in the local area to the global stratosphere, threatening all life on the earth by ozone depletion (Chapter 13). Moreover, apart from the unintended adverse effects of the products and waste, also the chemical production process can be extremely hazardous, as the worst-ever industrial disaster of chemistry in Bhopal, India, made obvious in 1984 (Chapter 5), as well as many previous and later cases. To complete the picture, because chemical production ultimately depends on natural resources, it is worthwhile to look also at how these resources are originally gained and at what costs, as the environmental damage of mining rare earth elements has increasingly illustrated (Chapter 12).

The full life cycle of industrial chemicals thus reveals many different hazards that have shaped the bad public image of chemistry over the 20th century. However, that image is one-sidedly focused on the chemical industry of the past and neglects the numerous chemists who have contributed to minimizing environmental harm. They did so by developing instruments and models to measure and predict environmental pollution, frequently being the first ones to raise public awareness of these issues (Chapter 13). They have worked hard to develop alternative products and processes that could replace the harmful ones of the past, guided by ideas of Green Chemistry (Chapters 11 and 10). And they are the only ones who research and develop methods to clean up the mess, from decontaminating dumping places to the large-scale binding of CO_2 in climate engineering (Chapter 14).

In recent years, chemistry increasingly became involved in cases that do not fit the simple scheme of doing/preventing/undoing harm through chemicals, or at least the public awareness has shifted to a broader scope of ethical issues and values. Global environmental issues, such as climate change and the exploitation of limited resources, have taught us that every harm and its remedy affect different populations and different generation unequally, which raises the issues of global and intergenerational justice for which there is no technical fix (Chapters 14 and 12). Recent attempts to create life in the laboratory are not seen as threats to one's health but as ways to undermine received cultural values (Chapter 16). Similarly, the public debate on whether a sequence of human DNA can be protected by patent law or not does not refer to physical harm but to a possible erosion of values (Chapter 17). Moreover, as chemistry has the potential of changing the human mind through drugs, both temporarily and enduring, it undermines the notion of what a normal human being is if enhancement drugs become regularly available (Chapter 15).

The various ethical issues and scandals of the past had an impact on the norms and regulations of chemistry. Both chemists and governments responded. Chemical societies tried to counteract the growingly bad public image of chemistry by issuing and revising codes of conduct, starting with the ACS (Chapter 18). Governments increasingly regulated the production, commerce, and use of chemicals by developing ever more restrictive and, in view of uncertainty, more flexibly adjustable regulations based on the precautionary principle, as did the European Union (Chapter 19). Readers of this volume are invited to check for themselves whether these normative schemes by chemical societies and governments have sufficiently coped with the growing challenges at a given time, or if and when additional guidance would have been required by ethics proper.

5. Cases of Chemistry According to Fields of Chemistry

The most prominent ethical cases, summarized above, cover almost all fields of chemistry, although there have been different emphases at different times.

Chemical warfare research was initially dominated by *physical and inorganic chemistry* during WWI, before organic and biochemist took the lead with the research of nerve agents, napalm, and other weapons (Chapters 3 and 4). There is a strong link between organic warfare chemistry and *agricultural chemistry*, because the same substance classes that were investigated as potential nerve agents appeared to be also promising candidates for insecticides for pest control, and vice versa. While that indeed enabled, along with fertilizers, an agricultural revolution by fighting famines through strongly increased productivity, it also produced devastating environmental disasters, from bio-contamination by widespread use of DDT for pest control to the terrible accident of the Bhopal plant that was producing another insecticide (Chapters 9 and 5). Last but not least, the herbicide that the US army employed as a strategic weapon in the Vietnam War, named Agent Orange, and that poisoned thousands of civilians because it contained toxic impurities, was a severe failure of the organic synthesis and product control (Chapter 7).

Pharmaceutical chemistry had been suspect to many people ever since, if only because of religious reasons. However, its potentially disastrous effects by lack of careful advance studies became evident by the thalidomide scandal in the early 1960s (Chapter 6). Fortunately, strict standards of clinical studies have been established since then before the official approval, which some politicians and their submissive administrators are trying to undermine only in the current Covid-19 pandemic. Other issues have risen since then because of the efficacy and power of chemical drugs in modifying the human mind, because that also modifies our understanding of human normality (Chapter 15).

Geochemistry, particularly *atmospheric chemistry*, along with *instrumental chemistry*, has been a major player in recent environmental matters. It even established itself, out of a combination of *physical chemistry* and meteorology, to understand the human impact on the atmosphere (Chapter 13). Climate change poses an entirely new challenge in not only contributing to understanding the global phenomena, but in posing the ethical question whether climate change should be managed by chemically manipulating the atmosphere (Chapter 14).

Moreover, the classical field of *inorganic chemistry*, which was originally about studying which elemental combination has what property, beyond the realm of organic chemistry, has become of pivotal ethical importance. If we take it, in its applied orientation, as the study of the earth economy of the chemical elements, it explores the possibilities and problems of any elemental substance flow, which includes the mining, recycling, and dumping of chemical elements. Once that dimension becomes obvious, every research decision on which elemental composition to explore further and for whatever research project must take into account the combined issues of the mining, recycling, and dumping of the respective elements. That is particularly obvious in the case of rare earth elements (Chapter 12), where elemental resources tend to be scarce, the mining extremely harmful to the environment, and therefore recycling technologies are required. However, it would also cover every management of dumping places (Chapter 8), and, more general, the pollution of air, water, and soil by elemental compounds, including large-scale attempts at capturing carbon dioxide to reduce climate change (Chapter 14).

Polymer chemistry has only recently become under ethical scrutiny, beyond the unspecific public aversion of plastics that tend to neglect the great diversity of environmental properties of polymers, including biodegradability and ultraviolet (UV) instability. On the one hand, the industry seems to be locked in received manufacturing practice that ignore environmental and health standards, due to toxic additives and toxic combustion products as in PVC (Chapters 10 and 11). On the other hand, there are tremendous challenges for polymer chemists to develop new materials that comply with standards of green chemistry, if only these standards would become more widely accepted by chemists.

Because of its relation to medical ethics, *biochemistry* has frequently been a matter of moral disputes. However, there are several distinct ethical issues that chemists should be aware of. One is whether one ought to be allowed to file patents on human (and nonhuman) genes (Chapter 17), or if these genes are considered public good because they are part of (human) nature. Another one, more radically, asks if the potentially artificial creation of life from inanimate matter by way of chemically means would violate any ethical norm. In legal term, at least, researchers are free to explore their own field (Chapter 16).

Most of the ethical issues discussed in this volume are relevant to all of chemistry far beyond the specific case and field. For instance, issues of moral responsibility for unintended adverse consequences go across all fields of science and technologies. Thus, the historical cases are only a starting point to engage in ethical discussions. The two chapters on codes of conduct and chemical regulation (Chapters 18 and 19) as well as the chapter on scientific misconduct (Chapter 2) obviously have no thematic focus but refer to all fields of chemistry.

6. Conclusion: How to Use This Volume in Class

This volume has been composed as a reader to support ethics classes for undergraduate students of chemistry. Each chapter focuses on different ethical issues based on a particular case from chemistry; it can form the basis of a class session. Ideally, the volume covers a one-semester course that discusses the cases in the order of the chapters, thereby introducing students into the full range of both ethical issues and important events of the cultural history of chemistry. For a complementary reading, we point to the 'Recommended Reading' section of each chapter, including the one below.

However, each chapter can also be read independently from the other ones, which allows for selective reading according to different aspects and class needs. Because the field of ethics of chemistry is still in its infancy, we imagine teachers with different backgrounds at the beginning who want to, or are required to, give a mandatory course in ethics of chemistry, including ethicists, historians of chemistry, and chemists. This volume is flexibly composed so as to meet all their needs.

While an ethicist would probably select the cases according to the order of our chapters, a historian of chemistry might want to make a different choice. For that purpose, we recommend the order of reading from Section 4 that arranges the cases according to the cultural history of chemistry. In yet another form of teaching, historical-ethical aspects would directly be integrated into chemistry classes, so as to enrich the traditionally narrow focus of teaching, for example, in physical, inorganic, and organic chemistry. In that way, ethics of chemistry can be part of a regular study-program in chemistry throughout. To that end, we refer to the order sketched in Section 5 that arranges the cases according chemical fields, as well as to the subject index for identifying more specific topics.

This book can also be used by students in their project work. They can be inspired by the case studies when they choose the topic of their projects and when they formulate their problem statement. Moreover, they can draw parallels between their own work and the cases analyzed in the book.

Whatever the selection of chapters and order of reading might be, the lack of teaching material can no longer be an excuse for the lack of courses of ethics of chemistry, nor for inadequate ethics courses that miss what matters in chemistry. The discipline has an extraordinary record of historical events that made it, more than any other one, suspect in moral regard to the broader public. The appropriate response is not distancing oneself ever more from the humanities, but integrating ethics into chemistry curricula. This volume aims at a turnaround by eventually educating future generations of responsible chemists.

Further Reading

Kovac 2018 is a brief introduction to ethics with cases from chemistry. For a list of books, paper collections, case studies, and other materials related to ethics of chemistry, see Børsen & Schummer 2016. Beauchamp & Childress 2009 introduces and discusses moral principles like respect for autonomy, non-maleficence, beneficence, and justice. Good and brief introductions to philosophical ethics are Frankena 1988 and Rachels 2012.

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