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Mehlich, Jan

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RESEARCH ARTICLE

# Technology assessment in the STEM curriculum: Teaching responsible research and innovation skills to future innovators

Jan Mehlich\*<sup>1</sup> 

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**Abstract** • This article describes and evaluates a novel approach to incorporating technology assessment (TA), responsible research and innovation as well as science and technology ethics into STEM curricula (science, technology, engineering, and mathematics) by the example of the online course ‘Good Chemistry – Methodological, Ethical, and Social Dimensions.’ Based on the evaluation of extensive student feedback, this article answers positively to three major reservations (Is it possible? Is it necessary? Does it make a difference?) that often preclude such contents from STEM curricula: first, understanding the normative dimensions of chemists’ professional agency is a skill, like many others, that requires adequate teaching and training; second, engaging with TA issues not only teaches discourse and critical thinking skills, but increases students’ professional competences to collaborate in highly interdisciplinary settings; third, though this is less evidential and needs to proof in the future, it may enhance chemists’ responsibility as drivers of innovation.

## Technikfolgenabschätzung im MINT-Curriculum:

Kompetenzvermittlung aus Responsible Research and Innovation an zukünftige Innovator\*innen

**Zusammenfassung** • Dieser Bericht beschreibt und bewertet einen neuartigen Lehransatz für Wissenschafts- und Technikethik für Studierende der MINT-Fächer (Mathematik, Informatik, Naturwissenschaft, Technik) am Beispiel des Onlinekurses ‚Good Chemistry – Methodological, Ethical, and Social Dimensions‘. Auf Basis eines umfangreichen Feedbacks der Kursteilnehmer\*innen reagiert der Aufsatz auf drei wesentliche Vorbehalte (Ist es möglich? Ist es notwendig? Ändert es etwas?), die oft gegen

die Integration solcher Inhalte in MINT-Fächern angeführt werden: Erstens ist das Verständnis normativer Dimensionen des beruflichen Handelns von Chemiker\*innen eine Kompetenz, die, wie viele andere, in angemessener Weise vermittelt und trainiert werden muss; zweitens schult die Auseinandersetzung mit TA-Inhalten nicht nur Diskurskompetenz und kritisches Denken, sondern verbessert auch die Fähigkeit der Studierenden zur interdisziplinären Kooperation; drittens, wobei sich dies in der Zukunft noch erweisen muss, kann ein Kurs wie dieser dazu beitragen, Chemiker\*innen als treibende Kräfte von Innovation auf verantwortliches Handeln vorzubereiten.

**Keywords** • responsible research and innovation, STEM education, interdisciplinarity, discourse skills, innovation ethics

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## Introduction

Natural sciences, social sciences, and humanities form different cultures (Kagan 2009). For example, there is debate whether normative sciences, like ethics, have any business in the so-called hard sciences. While more and more science and engineering departments incorporate courses on good scientific practice and research integrity into their curricula, the competence to participate with normative judgment and discourse skills in innovation teams, interdisciplinary research consortia, or in the context of scientific policy advice is not taught formally at most STEM (science, technology, engineering, and mathematics) faculties. It is even questioned whether this skill is necessary for scientific experts, whether it is teachable at all, and whether curricular courses on societal and environmental impact of scientific agency can, indeed, lead to more sustainable and beneficial innovation and technological progress (Englehardt and Pritchard

\* Corresponding author: [jmehlich@uni-bonn.de](mailto:jmehlich@uni-bonn.de)

<sup>1</sup> Center for Life Ethics, Rheinische Friedrich-Wilhelms-Universität Bonn, Bonn, DE



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2018). This article argues that all three questions should be answered with a definite yes.

The approach of Responsible Research and Innovation (RRI) as conceptualized and methodologically explicated by the academic trans-discipline technology assessment (TA) offers a practical, pragmatic, and well-elaborated conceptual framework for the role of experts and their contributions in above-mentioned discourses that take place outside of their institutional and disciplinary boundaries (Koops et al. 2015). Based on at least two decades of experiences with interdisciplinarity research, ELSI research, constructive and parliamentary TA, and the sociological study of expert agency in the wider context of

credits, it consists of 16 classes, each featuring 50 minutes of video lectures that are accompanied by exercises, reading assignments, case study discussions, and quizzes, exploiting the technical possibilities of the e-learning platform Moodle. A related textbook provides additional in-depth information and exercises (Mehlich 2021).

The course intends to sharpen the attendees' proficiency in research methodology and its philosophical foundations as well as their ability to oversee, understand, evaluate, and engage in contemporary discourses on ethical and social issues arising in the context of scientific and technological (S & T) progress. The course is designed in particular for chemistry students and re-

*Being able to see the larger picture of their professional activities and to make sound and scrutiny-withstanding judgments are the key learning objectives.*

public communication, of testimony at courts and political panels, or of corporate innovation efforts, it is possible to define a standard of what normative discourse competence of scientific experts should consist of (Gianni et al. 2019). These standards are teachable in a mix of theoretical and practical classes.

The designated goal of occupying slots in the STEM curriculum with RRI courses is to increase the chance that innovative efforts, in which the students will be engaged at later stages of their career, will produce outcomes that are beneficial for society, environment, and economy (Mejlgaard et al. 2018). Thus, being able to see the larger picture of their professional activities and to make sound and scrutiny-withstanding norm and value judgments are the key learning objectives of such courses' syllabus. If the syllabus with its lecture, exercise, case study discussion, and practical discourse training components is well-designed, students can be well-prepared for their professional roles in academic science, corporate research and development (R & D), or public service jobs. In the following, it will be shown at the example of such a course that course components that are conceptually informed by methodologies and competences of TA can significantly increase the chance to reach that learning goal.

## Course description and objectives

Based on the syllabus and teaching experience of face-to-face courses on *science and technology ethics* at Tunghai University and Fengchia University in Taichung (Taiwan), the author developed and compiled the online course 'Good Chemistry – Methodological, Ethical, and Social Dimensions' for the European Chemical Society (EuChemS), which is accessible since fall 2018 to all chemistry students in countries whose national chemical societies are EuChemS members. Worth 2 ECTS

related fields and requires no background knowledge in ethics, sociology, philosophy, or history of science. The featured content such as logic and theory of science, scientific reasoning and the rationale of scientific methodology, scientific misconduct, academic writing, operating in multi-stakeholder teams with various interests, dealing with uncertainty and risk, arguing in terms of sustainability, etc., is strongly linked to the participants daily research activities. Thus, the course is recommended to second year Master's students or PhD students at the beginning of their research projects. This recommendation is based on the perception that students with lab experience and their own research projects will be able to better understand the practical significance of S & T ethics for their own work than younger students, who usually operate on a more theoretical level. It is important to keep in mind that the course aims at skills that are applied in all kinds of chemical professions and not just in academic environments at the student level. The course content, thus, covers three important domains of chemical expertise and activity: academic science, private-sector industrial R & D and innovation, and public service.

As its title suggests, the course is divided into three main parts: Science is good—or: done well—on the *methodological level* when the scientist understands and correctly applies the practical and theoretical competences of scientific agency (Pruzan 2016). A scientist is good in terms of *research ethics* (internal responsibility) when he or she complies with the guidelines of good professional conduct (Iphofen 2020). On the level of external responsibility, science is good when its outcome is beneficial for *society and the environment* (Develaki 2008). While the first part of the course is mostly informed by science theory, epistemology, the philosophy of science, and the respective practical methodologies of scientific agency, and the second part is a matter of compliance with moral common-sense commit-

Class #	Class/Part title	Content and key themes
1	Introduction	What is professionalism? When is chemistry (a) good? Interplay of facts and norms; discourse skills; rationale and structure of the course.
2–4	Part 1: Methodology	Science theory; epistemology; scientific method(s); scientific reasoning.
5–9	Part 2: Research Ethics	Good scientific practice; misconduct; publishing issues; conflicts of interest; academic freedom; animal experiments.
10	Science and Values	Chemistry as social sphere; chemistry as science and/or technology driver; neutrality theses; dual use; social constructivist views.
11	Sustainability	Concept and definition of sustainability; sustainability as a normative framework for S & T discourse; sustainability as value co-creation.
12	Responsibility	Four dimensions of responsibility (who is held responsible, by whom, for what, in view of what rules or knowledge?); types of responsibility (legal, social, organizational, moral).
13	Risk, uncertainty, precaution	Definitions of risk and uncertainty; risk assessment; risk management; risk discourse types; precautionary principles.
14	Science and technology Governance	The role of scientific expertise in S & T policy and governance; technology assessment; EU frameworks (ELSI, RRI, 30); knowledge reporting.
15	Public communication of science	Science and mass media; scientists and science journalism; public participation in S & T discourse.
16	Course summary	Taking responsibility = taking the right action; good chemistry as a discourse skill.

**Tab. 1:** Content overview of the course “Good Chemistry – Methodological, Ethical, and Social Dimensions” (classes irrelevant for this article grayed and summarized, classes 10–15 = Part 3: “Societal and Environmental Impact”).

Source: author's own compilation

ments, the third part requires ethical reasoning and argumentation skills and an awareness of the societally embedded and legitimized role of scientific expertise. This paper focuses on this latter part (see Tab. 1). On a side note, the combination of these three topics in one course also follows a strategic rationale: promoters of such courses usually face reluctance of STEM faculties to provide space in their tightly organized curricula. A comprehensive syllabus addressing all three obviously relevant fields of responsible research in one course increases the acceptance significantly.

Classes 10 to 15 contain exercises and case explorations that require students to make value- and norm-related judgments. The strategies for inferring and validating these judgments are informed by principles of applied ethics (Hansson 2017), discourse conduct (Zeidler 2003), history of science (Bensaude-Vincent and Simon 2012), and sociology (Felt et al. 2017). It proved useful to let students engage in a warm-up example case, test their state-of-the-art knowledge and skills, proceed to knowledge and practical approaches for solving comparable issues, and finally test their progress with a comprehensive case that, by comparison with their performance in the introductory case, illustrates the acquired skill. This problem-based learning concept is in line with an inductive teaching approach. It should be noted that the goal of the lectures and course activities is the development of a practical skill and the creation of an aware mindset of the scientific expert. In terms of Bloom's (1956) taxonomy, this requires reaching at least level five (creation). Both theoretical foundations of the course content, RRI

and applied S & T ethics, are not taught theoretically as such, but are manifested in concrete exercises and real-world situations of scientific agency.

## Technology assessment in the course content

The third part of the course – discussing sustainability, dual use, risk, precaution, S & T governance, and public communication – features content and exercises from TA and related disciplines (Dusseldorp and Beecroft 2012). It aims at preparing STEM students for a professional life that is embedded in a multi-stakeholder network of interests and frequently requires normative discourses on S & T-related issues. Settings such as academic research groups, corporate innovation teams, or scientific testimony in public committees benefit from S & T experts with RRI competences such that normative aspects of the issues at hand are effectively scrutinized and assessed in the perspective of the state-of-the-art of factual knowledge. Examples range from narrow and highly specific contexts such as writing grant proposals, designing an innovative solution for the detection of a chemical substance, assessing the malfunction risks of a component of a system, or defining the threshold of the concentration of a pollutant in an environmental protection regulation, to large and overarching endeavors such as work packages on ethical, legal, and social implications (ELSI) of EU-funded research consortia, scientific policy-advice on tackling climate change or en-

Class #	Learning objective	TA/RRI-informed content and exercises
10	Understand normative dimension of science	Social construction of science and technology; Actor-Network-Theory; refutation of neutrality theses; case discussions: Manhattan Project, Agent Orange
11	Make plausible sustainability assessments and decisions	Chemical leasing as sustainable innovation; REACH* as sustainability through regulation; value co-creation
12	Defend and accept responsibility attributions	Responsibility definition with cross-disciplinary acceptance; vase discussions: chemical weapons, POPs* assessment
13	Assess and communicate risks from a larger perspective	IRGC* concepts of risk management and risk discourse ('risk escalator'); workable precautionary principles; case discussions: nano sunscreens, chemometrics
14	Contribute meaningfully to innovation discourses	Scientific policy-advice, ELSI, multi-stakeholder comm.; interdisciplinarity; case discussions: speculative nanoethics, UN panel on marine plastic pollution
15	Communicate effectively with non-experts and the public	Expert-layman communication; public participation in science and innovation; case discussions: crosstalk at a public information event on nanomedicine, misrepresentation of chemistry in science journalism

**Tab. 2:** Course content and exercises informed by TA (\*abbreviations: REACH = Registration, Evaluation, Authorization and Restriction of Chemicals, POPs = Persistent Organic Pollutants, IRGC = Intl. Risk Governance Council). Source: author's own compilation

ergy supply, or open innovation projects with participating public stakeholders. In all these situations, the S & T expert is making—more or less consciously—normative judgments concerning one or more values and their prioritization. Since many of these cases are complex and beyond a common-sense ethical evaluation, this judgment-ability or *normative literacy* requires training at least, and curricular education at best.

In view of these objectives, TA—here understood as an academic trans-discipline that emancipated itself from both sociology (of technology) and engineering (technical risk assessment)—is best suited to inform the course content with its long experience in interdisciplinarity, methodologies of normative S & T discourse, models of techno-scientific agency, etc. (Simonis 2013; Grunwald 2019). All its contemporary formats—parliamentary, participative, constructive, rational, real-time, and so forth (Ely et al. 2014)—share the commitment to the bridge-building function between those who know what *is* (or will be)—scientists, engineers, experts—and those who have the competence and task to assess, choose, and enact what *ought* (Mehlich 2017). This theme of combining factual and normative discourse under participation of various stakeholders in constructive and real-world-relevant fashions is found in many practical and well-established concepts that were endorsed and methodologically elaborated with TA expertise, such as ELSI research (Parker et al. 2019), RRI (European Commission 2013), 3O (Open Science, Open Innovation, Open to the World, see European Commission 2016), innovation research, and scientific policy-advice as practiced in many European countries (Bauer and Kastenhofer 2019).

Table 2 presents an overview of concepts, cases, and exercises that are course elements with necessary link to and input from TA. Most of these topics could be discussed from a “chemical” perspective, for example green/sustainable chemistry approaches to chemical synthesis, or life cycle assessment as the

chemical contribution to risk assessments. Yet, that would miss the core objective of this course, the formation of a normative discourse competence in interdisciplinary or multi-stakeholder settings. The disciplinary comfort zone within which chemistry students feel familiar regarding modes of thinking and of problem-solving is broken up and substituted by simulations of discourses with a large variety of views and interests that TA deals with all the time (Barry and Born 2013). These simulations are facilitated and guided either by the course instructor or the design of the exercise (for example, the case discussion or the scenario of the task) so that the chemistry students cannot satisfactorily solve the issue with a mere “chemical” reply. At the same time, the expectations and demands on chemical expert input in such topical discourses can be clearly defined without blurring the differences to other contributions (for example, an applied ethics or social science input) and risking a confusion of the students (for example, the false impression that chemists need to know moral philosophy to engage in ethical discourses). Rather, the operation at the *inter-space*—between disciplines, between competences, between modes of problem-solving—can be illustrated effectively with the experiences, tools, and methods of TA.

## Course assessment and evaluation

Attendees completing the course are requested to evaluate the course with a questionnaire that leaves a lot of space for free-text comments. Besides an assessment of technical and procedural aspects of the course, the main part of the survey focuses on the learning experience (12 questions) and the effectiveness of the course elements (9 questions). Over the three years that this course has been offered, completed questionnaires have been received from 138 students.



The *societal and environmental impact* section of the course has been rated outstandingly positive. While the methodological part is sometimes perceived as dry or boring (“All that philosophy ...”) and the research ethics part as trivial (“We already know that cheating is wrong!”), the external responsibility part seems to be more astounding, eye-opening, and practically orientational for the students. At that early stage of their career, most are not aware of the requirements on innovation discourse in academia, industry, and S & T governance. Those who have experiences with interdisciplinary collaboration, for example in EU-funded research consortia with attached ELSI work packages, report that the competences taught in this course significantly helped them understand the approaches of such efforts and gain the confidence to contribute actively to them. Class 11 on sustainability received the highest score for popularity (Question: “The class I liked the most is class No.\_\_\_\_”). A student commented aptly, “I finally know how to argue with my Sustainable Chemistry professor that sustainability is more than environmental friendliness”. The provided exercises, case studies, and discussion opportunities found widespread appreciation. Students feel comfortable with the strategy to look at chemical cases from the non-chemical perspectives that the TA-inspired approaches facilitate. This result indicates the teachability of RRI skills in STEM contexts.

Empirical research indicates that classes on scientific integrity cannot decrease the scientists’ susceptibility for scientific misconduct (Mumford 2017). On the other side, learning dis-

*A synergetic collaboration of education efforts beyond disciplinary boundaries can greatly contribute to a societally and environmentally sustainable development.*

course skills and interdisciplinary competences in the context of scientific and technological innovation—elements of RRI—does, according to the students’ feedback, induce a change in their attitude and professional mentality. Of course, it is difficult if not impossible to measure long-term effects of this course’s efforts, for example whether S & T-related innovations that are instantiated with the contribution from scientific and technical experts that attended RRI courses, indeed, are more sustainable or shift dual use potentials to the benefit side (a method that may be employed to this aim is described in Heras and Ruiz-Mallén 2017). Yet, it is plausible that innovation discourse participants with an understanding of the logic connection between factual and normative premises direct argumentative forces in innovation-related decision-making towards scrutiny-withstanding normative validity. According to student feedback, this mission—increasing awareness of normative implications of scientific expertise and improving practical argumentation and discourse skills in interdisciplinary innovation discourses—is accomplished.

## Conclusion

The claim of a necessity of TA and RRI skills for scientific-technical experts is substantiated by students’ course experiences as described above and their considerable improvements of normative assessment and argumentation skills as well as their confidence and courage to engage in such discourses across hierarchies. The initial question of this article, whether such skills are teachable, is thus answered positively by the successful combination and implementation of cross-disciplinary course content. Joining scientific-technical competence and its empirical-analytic mode of problem-solving with ethical-normative judgment-ability concerning societal and environmental impacts shapes STEM students’ attitude towards value and norm assessments sustainably. Sensitizing future innovators to the ELSI dimensions of their work effectively targets the early phases of technology development and, thus, makes a viable difference for the trajectories and impacts of that development.

STEM faculties are often reluctant to open curricular for courses that go beyond the respective disciplinary core contents. While the acceptance of research and engineering ethics classes or courses on scientific integrity is slowly growing in science departments of universities, teaching interdisciplinarity and RRI skills is still underestimated and neglected. The experiences discussed here support the idea of widening the scope of such ethics classes for science students towards the societal and environmental impact dimension of scientific expertise:

1. Normative discourse skills in the context of RRI increase the chance for innovation efforts to have *beneficial* outcomes (however defined).
2. These skills do not depend on personality or character traits, but on practical competences of a specific expertise, namely the normative sciences including practical ethics, interdisciplinarity research, innovation research, and the sociology of science and technology, all of these represented and applicably conceptualized by contemporary approaches to TA.
3. If it is of interest for science faculties (representing a public interest) that their graduates occupy responsible positions in academia, industry, and public service (including policy-making or policy-advise) with a positive impact (for example, sustainable, risk-reducing, or supporting quality of life), they should open up for interdisciplinary educative engagements.

The concrete contributions of TA range from theoretical foundations such as social constructivism, the methodology of inter-

disciplinarity, or the real-world relevance of scientific policy-advice, to science-external professional expertise such as innovation management and S & T governance, to practical skills such as normative reasoning strategies, critical thinking, discourse performance, and argumentative logic. A synergetic collaboration of education efforts beyond disciplinary boundaries, thus, can greatly contribute to a societally and environmentally sustainable scientific and technological development.

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### DR. JAN MEHLICH

studied chemistry and applied ethics at Münster University. He worked at Europäische Akademie Bad Neuenahr-Ahrweiler GmbH (2011–13) and was Alexander-von-Humboldt fellow at National Chung Hsing University, Taichung, Taiwan. After an assistant professorship at Fengchia University, Taichung, he recently joined Prof. Christiane Woopen's Center for Life Ethics at Bonn University.