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# Initiatives, experiences and best practices for teaching social and ecological responsibility in ethics education for science and engineering students

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## ABSTRACT

For the past 14 years the Social Ecological Responsibility in Science and Engineering Education (SERSEE) Network has discussed the challenging but necessary task of teaching social and ecological responsibility to science and engineering students. Identifying, sharing and developing best practices, pedagogical materials and tools as well as a strategy for promoting it at universities can aid and promote this endeavour. This paper presents the central concepts and pedagogical methods that have emerged during the informal network's meetings, and compares these concepts and methods to trends in the research literature.

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Ethics; social responsibility; sustainability; science education; engineering education

## Introduction

### *Teaching social and ecological responsibility to science and engineering students*

Science, Engineering, and Technology (SET) are incarnations of efficiency, control, and instrumental reasoning. Thus, policy documents and public debate often frame SET as solutions to environmental and societal problems. Indeed, SET possesses potential for solving societal and environmental problems as well as for co-constructing peace. However, one can also argue that SET has historically been the cause of conflict and environmental and societal problems when misused or when unexpected or undesired (side) effects have materialised. Despite the power of SET for both good and ill however, a democratic society is not a technocracy. Therefore, citizens, not experts alone, must also be involved in policy development.

If one accepts this entanglement of SET, environment, and culture, it leads to the understanding that individuals and institutions involved in SET have socio-ecological responsibilities. SET impacts society, culture, and the environment. As in other spheres of life, SET should assume responsibility over those it influences. Practitioners of science, engineering, and technology, and their institutions, must resume this responsibility – to involve the public in problem solving, avoid the misuse of SET for unethical purposes, be mindful of unexpected long-term effects, and train students and professionals to consider ethical aspects in decision-making processes.

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This perception of SET and its entanglement in society is not entirely mainstream however. While the prevailing view may not go to the opposite extreme – of science as a privileged activity, conducted in isolation by genius technical experts – what is reproduced in university science and engineering education is the false belief that things like codes of conduct can fully avoid, or keep within bounds, the negative consequences arising from abuse and unintended side effects. University science and engineering education often does not include discussion of the responsibilities of SET, or such discussion is present as a small fraction of the curriculum.

In 2005, an informal network of educators teaching topics related to ethical, social, and environmental responsibility to scientists, engineers, and technical experts was established with the goals of mainstreaming a contextual perception of SET and promoting the inclusion of courses addressing socio-ecological responsibilities of science, engineering, and technology. The network promotes the inclusion of competencies for socio-ecological responsibility in SET university study programmes and develops and evaluates courses that promote the development of such qualifications. It also serves as a platform between teachers and for involving potential partners such as accreditation agencies. In October 2016, the network, reduced to a group of seven university teachers from five countries and two continents, who gathered in Berlin for the fifth meeting of the network.

In May 2019, the sixth network meeting was held at UN Environment's Russian office in Moscow. That meeting was entitled 'Sustainable development and socio-ecological standards in science and engineering education' and focussed on the inclusion of UN's sustainability goals in science and engineering education. More than 50 people participated in the meeting, mostly Russians, but also representatives from Denmark, France and India attended the meeting. This paper was presented at the Moscow meeting with the purpose of updating the meeting participants to the discussions that so far had taken place in the network.

Hence, the objective of this paper is to identify what were the central concepts and pedagogical methods that have been addressed during years of network activities: What were the topics, questions and answers, which were deliberated? What concepts can we derive from the network activities that others involved in ethics teaching in science and engineering can learn from? This article presents these points to contribute to sustainable development and ethics teaching of science and engineering students at a time where these matters find more and more interest and needs. It also analyses these concepts and methods by comparing them to trends in the research literature.

### **Research design**

The research approach employed by the SERSEE Network in general and in this paper in particular is inspired by Action Learning, which is a branch of Action Research (Kemmis and McTaggart 2005, 561).

The fundamental idea of action learning is to bring people together to learn from each other's experiences. There is emphasis on studying one's own situation, clarifying what the organisation [here: the people brought together at network meetings] is trying to achieve, and working to remove obstacles. (Kemmis and McTaggart 2005, 561)

The SERSEE network has all along tried to bring people together at workshops and meetings who either were teaching or had ambitions to begin teaching ethics to science and / or engineering students. The reason for doing so was – in line with the fundamental idea of action learning – to make learning from participant to participant, and from peer to peer, possible. Two tools have been applied to facilitate per learning: (1) At workshops participants have presented their experiences with teaching ethics to science and engineering students followed by thorough and facilitated rounds of discussions. (2) Preparation of texts summing up trends appearing across the presented experiences. The preparation of texts has been a collective endeavour involving several workshop attendees. The focus of the prepared texts has typically been on identifying obstacles for teaching ethics to science and engineering students, and means to overcome those obstacles.

In this paper, we aim to identify key concepts of the teaching ethics activities (Pastré 2011) and to link them to research findings about ethics teaching. In other words, we have also employed a third tool to facilitate learning from experiences with teaching ethics to science and engineering students – namely to link to the collective learning originating from network workshops to the experiences reflected in research literature.

We sum up the content of the texts originating from the first five workshops organised in auspices of the SERSEE network. We will give special attention to the experiences present at the fifth meeting held in Berlin in 2015 because these experiences have not previously been published. Then we link the collected experiences from the different workshops together and draw parallels to insights found in the research literature.

### *First meeting – 2005 – Copenhagen*

The SERSEE network was formed in 2005 at a workshop held at the Niels Bohr Institute in Copenhagen, Denmark. The meeting had approximately 15 participants. The first meeting discussed both the justification for and methods of teaching ethics. According to the workshop report, discussions between the attendees of the foundational network meeting revealed a shared belief that universities should not only teach individual-level ethical (micro-ethics) to science and engineering students, but should also introduce a critical, systems-level approach (macro-ethics).

The report from the meeting delivered the articulated teaching goals as well as pedagogical methods, including two case studies for the classroom (Børsen Hansen 2005). The four major questions debated at the meeting are presented in Table 1 alongside the consensus answers.

### *Second meeting – 2008 – Hamburg*

The second network meeting took place in 2008 at the Carl Friedrich von Weizsäcker-Centre for Science and Peace Research in Hamburg, Germany. More than 50 people attended the meeting. It developed 12 conclusions and recommendation for how to promote teaching social responsibility initiatives.<sup>1</sup> The conclusions and recommendations centre around four central themes: the obligation of universities to prepare all students to address issues inherent in their future professions, the external influences that can support ethics education, the internal and institutional support necessary for successful ethics education, and the opportunities and challenges presented by ethics education. These themes and conclusions are presented in Table 2.

### *Third meeting – 2010 – Delft*

A third network meeting was organised in 2010 at the Delft University of Technology, the Netherlands. The meeting had more than 50 attendees. This meeting resulted in the publication of a

**Table 1.** Four major questions concerning justification for and methods of teaching ethics discussed at the 2005 Copenhagen meeting.

Debated question	Consensus answer
Why should ethics be taught to science and engineering students?	To contribute to forming a feeling of right and wrong among students, maintain professional integrity, interact responsibly with stakeholders, and contribute to sustainable development and making of just and effective policy and legislation.
What kinds of problems can be dealt with in the ethics teaching?	The workshop developed and discussed two illustrative cases studies that can be used in social responsibility teaching: Chemical pollutants in the environment and military research at universities.
What ethical norms and principles are to be taught?	The central concepts in teaching social responsibility to students of SET should not merely be applying conventional anthropocentric ethical theories. Normative approaches must be included that address global issues as well as insight into and reflections on how science and technology is regulated.
How should the individual student relate to these norms and principles?	Students should appreciate existing ethical anthropocentric and global norms and legal regimes without uncritically internalising them. This approach maintains the analytical spirit and method of the sciences.

**Table 2.** Conclusions and/or recommendations from the 2008 Hamburg meeting.

Theme	Conclusions and/or recommendations
Universities have an obligation to prepare all students for issues inherent in their future professions.	<ul style="list-style-type: none"> <li>Responsible use of science and engineering is essential and must begin in training.</li> <li>All students must be reached, so a compulsory model is needed.</li> <li>Natural and engineering faculties lag behind medical faculties in teaching ethics.</li> <li>The predominant individualistic approach to teaching ethics is insufficient; a larger systems-approach must be pursued.</li> </ul>
External influences can support ethics education.	<ul style="list-style-type: none"> <li>The criteria from accreditation bodies support teaching responsibility.</li> <li>Funding decisions and guidelines from governing bodies have triggered introduction of some successful ethics education efforts.</li> </ul>
Both internal and institutional support are necessary for successful ethics education.	<ul style="list-style-type: none"> <li>A nucleus of motivated and competent staff is essential.</li> <li>Staff nuclei must often be augmented with adequate funding support.</li> </ul>
Implementation of ethics education creates opportunities, but challenges remain.	<ul style="list-style-type: none"> <li>Meeting attendees highlighted ethics teaching programmes of considerable diversity in both scope and character.</li> <li>The Bologna Process<sup>10</sup> offers an opportunity to introduce new educational elements.</li> <li>Active learning forms – relating the learning process to real-life situations – are important.</li> <li>Teaching material needs to be developed and disseminated.</li> </ul>

special issue of the journal *Science and Engineering Ethics* on European perspectives on teaching social responsibility to students of science and engineering. The special issue contained 16 examples of – or comments on – teaching social responsibility to science and engineering students at different universities.<sup>2</sup> From that body of case studies, the main conclusions shown in [Table 3](#) – relevant to teaching social responsibility in science and engineering – were identified and discussed. See also Zandvoort et al. (2013).

**Table 3.** Four major questions concerning the definition and methods of teaching social responsibility as discussed at the 2010 Delft meeting.

Debated question	Consensus answer
What is social responsibility?	Teaching social responsibility should include ethics, peace studies, sustainability, and law. <sup>11</sup> It has both an individual and a collective structural component, and involves three elements: knowledge, judgment, and action.
How ought we teach social responsibility in science, engineering, and technology?	The teaching must be connected to or embedded in the study programme in which the students are enrolled and should not be attached as an isolated appendix. It can use student-involving activities such as role plays, analyses of case studies, and active discussions.
Who should teach?	Individuals with double competences in SET and ethics / sustainability / peace studies / law can teach, or interdisciplinary teams of teachers can be engaged.
What are the barriers to implementing social responsibility teaching in SET?	Many points were identified and include: Scientific communities often think they are isolated from society; Ethical issues are complex and cannot be solved by conventional science and technology tools; Interdisciplinarity is difficult, often reduces to rivalry between involved disciplines, and often does not fit well into existing academic structures including funding and career mechanisms.
What are the requirements for integrating social responsibility aspects in science and engineering education?	Many points were identified and include: Bottom-up teaching activities that are developed by local teachers but supported top-down by allocating needed resources and curriculum changes.
What are some next steps?	Form alliances with external partners to clarify how social responsibility competencies are mandated by society and/or may be used by future employers; Develop teaching material.

#### Fourth meeting – 2012 – Bradford

In 2012, the fourth network meeting was organised at the Bradford Disarmament Research Centre in the United Kingdom. Approximately 30 people attended this meeting. The network event was a twin meeting with members from both the informal network of social responsibility teachers in science, engineering and technology, and the biosecurity education community. The goal of the meeting was to allow members of the communities to meet and exchange experiences. During the first part of the twin meeting, papers on social responsibility teaching in science, engineering and technology were presented. In the second part, papers on biosecurity education were introduced. The output of the twin meeting was published in the proceedings of the meeting<sup>3</sup> and contains 15 presented papers (Sture 2012a). One joint conclusion was that engineers have knowledge and skills to make non-violent contributions to peace (Bowen 2012). Other conclusions and recommendations are outlined in Table 4.

#### Fifth meeting – 2016 – Berlin

To assist in the teaching of social and ecological responsibility in the context of science, engineering, and technology, a workshop was convened at the Technical University of Berlin in 2016. The programmatic goal was to provide a forum for practitioners to describe and share pedagogical tools and best practices.

Teachers, as well as many other stakeholders of higher education such as accreditors and labour union officials<sup>4</sup>, were invited to present their engagement in this field. Seven participants from six different countries (Denmark, France, Germany, the Netherlands, Russia, and the United States) accepted the invitation to participate and presented information on six distinct initiatives. The primary goal of the workshop was to be a showcase of different projects in the field and to unveil the commonalities and differences between these practices. Therefore, the organisers

**Table 4.** Conclusions and/or recommendations from the 2012 Bradford Meeting.

Theme	Conclusions and/or Recommendations	
	From the informal network of social responsibility teaching in science, engineering, and technology:	From the biosecurity education community:
Conceptual framing in ethics education efforts can vary.	<ul style="list-style-type: none"> <li>Two approaches to engineering education were presented: a 'holistic engineering education' approach with a hybrid focus on technical competencies and social perspectives; and a second approach perceiving the world through a single lens (Ocone 2012).</li> </ul>	<ul style="list-style-type: none"> <li>Broader concepts of 'responsible conduct of research' and 'research integrity' can be more useful teaching constructs in biosecurity education than the narrowly-defined 'dual-use' construct (Husbands 2012).</li> </ul>
Ethics education can be deployed in different ways, with varying outcomes.	<ul style="list-style-type: none"> <li>Ethics can be taught to engineers as part of an English course (Griffin 2012).</li> </ul>	<ul style="list-style-type: none"> <li>Different experiences with teaching biosecurity and dual-use issues to life science professionals have been analysed (Mancini and Fasani 2012; Rhodes 2012; Novossiolova and Whitby 2012)</li> </ul>
Tools for teaching and evaluation are being developed and disseminated.	<ul style="list-style-type: none"> <li>Social responsibility competencies in engineering education are linked to interactional expertise (Børsen 2012), leadership (Alpay 2012), and collective decision-making (Zandvoort 2012).</li> <li>An array of case material for use in social responsibility teaching in science, engineering and technology has been developed (Coates 2012).</li> <li>A tool to analyse engineering ethics education is available that consists of a two by two matrix: macro/micro and objective/subjective (Conlon 2012).</li> </ul>	<ul style="list-style-type: none"> <li>A toolkit is available to promote ethical decision-making by life scientists as well as a website to support awareness rising in that group (Sture 2012b and Minehata 2012).</li> <li>A proposed International Biosecurity Education Network would support developing and sharing best practices (Dando 2012).</li> </ul>

consciously refrained from setting up an exact timetable so that every participant had ample time to present their experiences and ideas to others. However, the subsequent discussions were always given more time than the actual presentations. This fostered thorough discussions where the participants worked together to identify the goals/objectives of all the projects as well as their implementation. Additionally, the drivers as well as the barriers and opportunities were identified. After the workshop, common themes were identified, and a menu of initiative components was constructed.

While a broad array of higher education stakeholders was invited to participate in the workshop, all eventual participants were instructors, and as such represent only one viewpoint from within a larger ecosystem. That said, all participants reported deliberately engaging with multiple stakeholders as a key part of their initiatives.

Six different initiatives were presented at the Berlin workshop. Appendix presents a summary of the descriptions, goals and objectives, drivers, barriers and opportunities, and outcomes of each experience. More detail on each experience follows.

### ***Science Outside the Lab: changing perceptions of social responsibility***

#### ***Description***

Science Outside the Lab is a 2-week science policy immersion programme in Washington, D.C., the centre of federal science policy in the United States.

#### ***Goals and objectives***

Science Outside the Lab focuses on changing perceptions of social responsibility by introducing science and engineering graduate students to the complex ecosystem of federal science policy in the United States. After programme participation, the goal is that students can (1) describe and appreciate the complex web of people, institutions, and processes involved in shaping science policy; and (2) understand how those complexities – including the role of competing values – impact relationships among science, engineering, and society.

#### ***Driver(s) behind activity***

Conventional science and engineering training often fails to prepare students to engage with ambiguities and social dimensions associated with science and engineering issues in society. Scientists and engineers who do have a strong appreciation of societal context are better positioned to successfully navigate through policy issues and work constructively with policymakers.

#### ***Implementation***

Science Outside the Lab aims to ‘show, not tell’ how science and technology interplay with democracy, ethics, and values, and how those values and their proponents compete for prominence. It is a supplemental mode of education that allows scientists and engineers to grapple with their technical work and social context. The programme is place-based, discussion-based, and includes deliberate exposure to conflicting views from competent individuals.

The physical separation of students from their traditional laboratory context and pressures can encourage critical reflection. The discussion-based structure of the programme engages two dozen guest speakers over ten days. It is an active learning pedagogy with students driving the discussion and the direction of the 90-minute sessions. Discussants are professionals – analysts, lobbyists, industry executives, lawyers, regulators, and scientists (from the government and NGOs) – who either use science in their decision making, or who make decisions that will impact science and technology fields. We deliberately bring in speakers with diverse, and sometimes contrasting perspectives.

### ***Barriers and opportunities***

Replicating the programme at scale is an issue, as is accessibility. To increase the reach of this, or a similar programme, the Science Outside the Lab model could be attempted at more modest, local scales such as with municipal governments or in university ecosystems.

### ***Outcomes***

The Science Outside the Lab programme has been running for over a decade. In assessments of the initiative – including pre-, post-, and one-year later follow-up instruments for the 2015 cohort – participants left the programme with greater humility about the role of scientific expertise in science and engineering policy, increased scepticism of a linear relationship between scientific advances and social benefits, and a deeper and more nuanced understanding of the actors involved in shaping science policy (Bernstein et al. 2017). In addition, many student participants reported an increased interest in policy issues and governance that may enhance their insight and involvement during their career. The results of this formal assessment were in line with 10 years of informal observations.

### ***InnovENT-E: using competencies and accreditation to build trainings and evaluate learned social responsibility<sup>5</sup>***

#### ***Description***

InnovENT-E is a project through several French groups of engineering schools and universities that aims to develop French subject matter experts' skills in the fields of innovation and export, including a competence for 'managing ethical issues'. InnovENT-E was initiated by the Insa group, the 'Universities of Technology' network, Lorraine University, and the Cesi Group. The trainings are based on pedagogical innovation and the pooling of knowledge from InnovENT-E's network of professors.

#### ***Goals and objectives***

The ethical skills competency was added within the innovation and export skills framework to counterbalance the students' production of innovation without critical reflection, specifically from an ethical point of view. Several goals were pursued. The network wanted to awaken students to ethical problem-solving approaches; to provide students with a few keys and landmarks to enable them to manage an ethical issue; to make them responsible for and able to give their recommendations about a societal and technological issue; to spread interest in ethics and related trainings into universities as a function of the visibility and quality of the certification framework; and to valorise ethics as a competence and a qualification.

#### ***Driver(s) behind activity***

The InnovENT-E network believes that higher education has a social responsibility to provide students awareness and tools to face ethical issues.

#### ***Design and implementation***

Designing the ethics component of the framework followed four steps: First, managing an ethical issue had to be framed as a competence. Secondly, a competence was built that described how to approach an ethical issue, and how to work on it responsibly. Thirdly, a collective focus was emphasised by involving impacted persons: an ethical issue cannot be satisfactorily addressed on an individual level alone. Fourthly, in the face of very difficult ethical issues, subject matter experts' were strongly encouraged to remain engaged with the collective problem-solving process, and by so doing to develop their confidence.

The implementation followed a typical process. First, a team with ethics and pedagogic experts was built that represented each school. Then, the guidelines of the project were defined, including

a common representation of ethics. Finally, 'Manage an ethical issue' was formally registered as the 17th competence in the InnovENT-E repository. After this, the course was designed, and the competence was registered as a certification in the RNCP (national skills certification repository) which required an evaluation process, recommendations from firms, and other conditions.

### ***Barriers and opportunities***

A major difficulty facing InnovENT-E is the availability of experts. They often have other fields in which the institutions prefer them to work and the scheduled time in the curricula is also often marginal. Even though we argue that a subject matter expert should be interested in ethics, there is a global lack of desire to develop competence in the ethics field. As a positive offset, the professors who have contributed to this skills framework are highly involved, and so facilitate a lot the work and goal attainment.

### ***Outcomes***

As a result of InnovENT-E, the management of ethical issues can now be considered to require a specific competence, which can be described in a skills framework. The skills framework offers guidelines and learning outcomes to design ethics courses. It also offers a means to certify ethics competence. It places ethics as a major competence for innovation and export, as the same level as demonstrating creativeness or constructing a business plan.

## ***Sustainable development activities: project-driven teaching in an environmental management course***

### ***Description***

The course of International Environmental Activity at Udmurt State University in Russia includes both structured instruction as well as a creative workshop, case study, and practical activities.

### ***Goals and objectives***

Sustainable development teaching activities at Udmurt State University aim to spread sustainable development knowledge, involve students in sustainable environmental activity, study environmental management principles, and use the best sustainable international practices for national implementation. Specific topics of interest include green building, green public procurement<sup>6</sup>, and the best available techniques for worldwide waste problems.

### ***Driver(s) behind activity***

The initiative was driven by a lack of public knowledge about sustainable development, and by a perceived strong need for such knowledge in industry, government, and society alike. While national economies must comply with international standards and rules, a legislative and management knowledge gap currently exists for national environmental activity and may be compounded in the future by the absence of integrated, interdisciplinary, and multi-level environmental management courses in most training programmes.

### ***Implementation***

The work is organised in interactive forms to involve students in real creative activity. Firstly, students contribute to both the formal instruction on theoretical questions, as well as practical activities. This contribution occurs via staged individual tasks where the student must investigate and deliver questions for whole group to discuss, consider feedback, and frame an opinion around the issue. Secondly, students are encouraged to apply their theoretical knowledge to practical work. A project must include a theoretical base (to confirm its necessity), use the main points of environmental law (to defend the right action), describe the funding possibilities for the project (including interaction with international organisations, etc. for training), confirm the working directions through the

international standards and best available techniques (named and explained), and consider the solution as part of a suit of environmental management tools. For example, one student group used waste treatment as a topic. They considered the best available technology and legal aspects (theoretical questions), created their own scheme of waste treatment stakeholders, considered logistical points, determined current conditions and prices, and combined this information to create a proposal to improve the waste treatment situation (practical activity).

One very effective way to create sincere interest in sustainable development activity has been to have students role-play work in different groups with different management levels: from personal responsibility, to city sustainable management, to the president, to the UN and other international organisations. This method results in strong solutions and students enjoy feeling responsible for decision making. Helping students envision themselves in positions of power may also be motivating and influential along the longer career arc.

### ***Barriers and opportunities***

Barriers encountered in the course implementation include limited course time, the absence of connected faculty and courses to expand the knowledge base, and the absence of an interdisciplinary department to manage sustainable development work, including educational efforts. In addition, limited recognition of the importance of sustainable development at the administrative level compounds organisational and resource challenges.

### ***Outcomes***

After participating in sustainable development teaching activities at Udmurt State University, the students have knowledge of Green Paradigm questions (Knill 1991) and sustainable development concepts. They understand the priority and meaning of environmental law (at the international level) and are able to use environmental standards, licenses, and certifications in their work. Students become acquainted with the goals, operations, funding, problems, and advantages of international environmental and social organisations. Students have basic structural understanding of the world economy, environmental problems, and global needs, and the environmental management tools at the micro and macro levels suitable for tackling specific problems. Perhaps most importantly, students can work collectively on a project to develop solutions to practical and often local issues.

## ***Blue engineering: student-driven teaching of social and ecological responsibility***

### ***Description***

Blue Engineering is a student initiative that was founded in 2009 at the Technical University of Berlin to teach social and ecological responsibility in a highly-modularised course format. Since 2012, the president of the university has recognised the initiative as a study reform project and has granted a lecturer position and three student tutor positions to ensure further development.

### ***Goals and objectives***

The primary goal of the Blue Engineering course is to raise awareness among prospective engineers of their social and ecological responsibilities and to encourage them to act accordingly on both individual and collective levels. The course has two central learning outcomes which address both the individual and collective scopes of action of prospective engineers:

- 1 The prospective engineers analyse and evaluate the present reciprocal relationships between technology, individuals, nature, and society by taking different perspectives. Based on this analysis and evaluation, they can explain both their personal perspective and values held by others, understand the interaction of those perspectives, and act accordingly.

- 2 The prospective engineers cooperate with each other to analyse and evaluate – in a democratic process – the present reciprocal relationships between technology, individuals, nature, and society. Based on their analysis and evaluation, they can work out a collective understanding regarding their collective values and democratise the reciprocal relations.

### ***Driver(s) behind activity***

Blue Engineering was founded on the belief that students should have an opportunity to question technology and society, and if they disagree with current forms and relationships, they are encouraged to develop different relationships, beginning with themselves and their university context.

### ***Implementation***

The original Blue Engineering student group designed the course over five semesters and first conducted it – using student tutors alone – in the winter semester 2011. To ensure the further development of the course, the student group successfully applied for university funding for one lecturer position and three student tutor positions. However, Blue Engineering remains a student-driven initiative due to the involvement of many student volunteers and the special course design.

The two learning outcomes are further specified based on the concept of *Gestaltungskompetenz*<sup>7</sup> which identifies twelve competences necessary to participate in sustainable development (De Haan 2006). In addition, the learning outcomes are used at the lesson level where they are constructively aligned with activities and a respective assessment. The key element of the Blue Engineering Course are the building blocks. These units of 10–90 min each cover a wide range of topics and didactic methods which mostly transfer the responsibility of teaching and learning to the group of participants. Therefore, any person with a little time for preparation may easily conduct a building block since they comprise all necessary information to ensure a demanding, interactive teaching and learning unit.

The tutors conduct a set of basic building blocks during the first six weeks of the semester to give the participants an idea of what is expected of them. After that, the participants can freely choose already-existing building blocks and conduct them for and with their fellow students. In addition, over the course of the semester, students work in small groups to develop a new building block on a topic of their choice. These newly-constructed building blocks are conducted during the remaining weeks of the semester and go through a rigorous feedback and review process by the tutors and fellow students. These new building blocks are then added to the collection of existing building blocks.

### ***Barriers and opportunities***

Time is the only fundamental barrier that influences the development of the Blue Engineering Course. First, it takes time to develop such a highly-demanding course. The original student group took almost five semesters to fully develop the course design and the first building blocks required to initially conduct the course. Second, tutors alone did not have enough time to conduct the course and to develop it at the same time. As a result, the student group applied for funding for one lecturer position through which the capacity of the course could be expanded from 25 to 100 students while arranging it in such a way that in the future, tutors alone may conduct the course. Since summer semester 2016, tutors alone have conducted the course, and as a result, there is not one single person that is essential for the course.

### ***Outcomes***

By now, over 140 building blocks exist and are regularly used within the Blue Engineering Course and in various educational settings. An initiative has been taken to make every existing building block available online under a Creative Commons license. The Blue Engineering course has been conducted each semester since winter semester 2011/2012 (12 times in total), with an average of 70 students per offering. The students have come from various study programmes and find this interdisciplinary

working atmosphere very pleasant. The quantitative and qualitative evaluations of the course are highly positive and show not only that the students appreciate such an interactive course but that they acquire competences in sustainable development.

### **Ethical case studies in chemistry: case-driven teaching of social responsibility**

#### **Description**

This initiative aimed to publish approximately 20 case studies analysing ethical dilemmas in chemistry. The case studies were published in four special-issue volumes of the scientific journal HYLE: International Journal of the Philosophy of Chemistry (Børsen and Schummer 2016, 2017, 2018).

#### **Goals and objectives**

The case studies had to be more complex than mere examples. They had to address real life issues and each case study needed to illustrate a certain ethical dilemma and include several perspectives (such as values and actors). The context and location of the dilemmas needed to be specified. All case-studies had to include an ethical analysis that linked the concrete and the abstract. In a longer time perspective, it is believed that the collection of ethical case studies in chemistry will boost ethics teaching to chemistry and chemical engineering students. The case studies can both be used in stand-alone courses in ethics of chemistry and integrated in the curriculum of traditional chemistry courses.

#### **Driver(s) behind activity**

Ethical issues are rarely addressed in chemistry textbooks and teaching material addressing chemistry and chemical engineering students is limited. Ethical literature is often perceived to be abstract and difficult for chemists to apply. This makes it difficult to initiate teaching activities on socio-ecological responsibility and ethics related to chemistry. A special issue of the journal HYLE: International Journal for the Philosophy of Chemistry could provide accessible and relevant case studies while engaging the chemical scientific community in ethical deliberations – to put social responsibility and ethics on the scientific agenda.

#### **Implementation**

The call for papers requested case studies that addressed one or more of the following four issue groups described in Table 5. Specifically, the call for papers requested case studies that were:

- Accessible to undergraduate students of chemistry
- Between 7000 and 9000 words long

**Table 5.** The fifteen published case studies for teaching social responsibility in four issue areas (based on <http://www.hyle.org/journal/issues/special/ethical-cases.html>).

Issue area	Case studies
Misuse and misconduct	Misconduct in chemistry (example: 1. fabrication of data) Weapons research (examples: 2. Poison gas and 3. Napalm)
Local unforeseen consequences	Industrial disasters (example: 4. Bhopal) Unforeseen consequences of drugs (example: 5. Thalidomide) Chemical waste disposal (example: 6. Love Canal)
Global and long-term influences and challenges	Global environmental pollution (examples: 7. Bisphenol-A and 8. DDT) Green chemistry (examples: 9. PVC and 10. Chemists' responsibility) Chemical climate prediction and engineering (example: 11. Capture of CO <sub>2</sub> )
Impact on human culture	Creating artificial life (example: 12. Craig Venter) Human enhancement (example: 13. psychotropics)
Codes and regulations	Codes of conduct (example: 14. American Chemical Society) Chemical regulation (example: 15. REACH)

- Both historically and chemically informed
- Situated in their organisational, institutional, broader societal or/and global context

They were also requested to contain the following specific components:

- An introduction that points out why today's chemistry students should be familiar with the case and what general lessons are to be learned
- A detailed ethical analysis that links the concrete to the abstract. Thus, the case should be linked to appropriate ethical concepts and principles and highlights, if possible, dilemmas and conflicts of interests rather than clear-cut moral judgments
- A brief discussion of comparable cases
- A list of accessible literature for further reading

### ***Barriers and opportunities***

Language was a barrier for some contributors. Many are not native English speakers, and accordingly, many submitted case studies are not submitted in fluent English. At present, no grant supports the production of the special issue, and therefore it has not been possible to hire a professional proof-reader to edit the contributions. To address this challenge an Irish student was hired to proof read the papers written by non-native English speakers.

Academic jargon was another barrier. All case-studies were sent to two anonymous reviewers – typically a chemist and an ethicist – and assessed according to interdisciplinary criteria. It was not easy for all contributors to honour these criteria since not all authors hold double competences in chemistry and ethics. In addition, not all contributors are academics, and the academic jargon was an obstacle.

By using a peer-reviewed research journal as a vector for this project, university researchers and teachers may consider the publication an incentive to develop potential teaching material.

### ***Outcomes***

So far, 15 case studies have been submitted toward the final goal of approximately 20 ethical case studies in the form of teaching material that has been quality assured through peer review. When the four volumes of the special issues are launched, a Ph.D. workshop will be organised where the case studies will be used.

## ***Introduction to German engineering: interdisciplinary and intercultural teaching***

### ***Description***

The Introduction to German Engineering (IGE) project course is a one-week intensive, immersive project course that introduces students at a German technical university to the design process coupled with the development of professional and social skills through active learning.<sup>8</sup>

### ***Goals and objectives***

The main aims of IGE are to teach technical expertise in German engineering design and professional and social skills, e.g. group working techniques, communication, etc.; develop skills for interdisciplinary and intercultural team work; provide a future perspective including a sense of an industrial group project and how coursework is related and relevant; develop confidence as competent representatives of their discipline; and motivate students.

### ***Driver(s) behind activity***

The IGE project course was developed in response to industrial demands for graduates with strong professional and teamwork skills alongside technical skills, an interdepartmental evaluation, and the incorporation of interdisciplinary project courses in the engineering training programme.

### ***Implementation***

For the one-week duration of the design project course, groups are advised by a tandem of a team and a technical adviser. The team adviser focuses on team development, discussion, and team working methods whereas the technical adviser focuses on the task, the discipline itself, and problem analysis and solving. The task itself must be challenging, complex, socially-relevant with no standard solution, require specialisation and division of labour within the group, have multiple possible concepts and solutions, and have conflicts between time, available resources, and completion in given timeframe (Dirsch-Weigand et al. 2015; Dirsch-Weigand et al. 2018; Koch et al. 2017; Möller-Holtkamp 2017; Pinkelman, Awolin, and Hampe 2016). In 2016, IGE was both interdisciplinary and intercultural with students from Germany, the United States, and Hong Kong from engineering (mechanical, chemical, and industrial/logistics), materials science, and political science backgrounds. The task was to develop a 'fair' car to solve the VW emission problem. This included defining the meaning of 'fair', and the social, political, environmental, and economic impact of the technical design including material source, production, etc. Groups had to consider the impact of ethics and sustainability on technical design and technical design on ethics and sustainability and justify their choices.

### ***Barriers and opportunities***

In preparation for this course, the resources needed are large including labour (advisers for each group and experts) and time to design an appropriate task that includes enough quantity and quality for each discipline along with an interdependence among the disciplines. The diversity of groups is also challenging under the aspects of integrating all disciplines within the working groups and, especially for engineering students, recognising and valuing the importance of humanities and political science in technical problems and their impact on their solution(s).

### ***Outcomes***

Assessment has shown that students are aware of the significance and value of interdisciplinary and intercultural team work, that they acquired teamwork and communication competences, and that they see themselves as competent representatives of their respective fields (Dirsch-Weigand et al. 2018; Koch et al. 2017; Steinheider et al. 2009). Anecdotal evidence also shows that the students recognise the value of interdisciplinary teams and the global impact of solution, i.e. relating the problem back to the larger social implications. In addition, students recognise the challenges and benefits of conflicting opinions and different perspectives.

### ***Central concepts, methods and trends***

Three trends are identified in the output from the first four network workshops: One regards the content of ethics and socio-ecological responsibility teaching, another identifies possible forms of teaching ethics and socio-ecological responsibility. The third trend regards changing science and engineering education as to include ethical elements.

### ***Content of ethics for science students and engineers***

The purpose of teaching ethics to science and engineering students is to create a feeling of right and wrong, maintain professional integrity, interact responsibly with stakeholders, contribute to sustainable development and to the making of just and effective policy and legislation.

The corresponding teaching content covers an array of normative approaches, including ethical values, sustainability, global issues, peace studies, science and technology regulation, and law. It has both an individual and a collective structural component, and involves three elements: knowledge, judgment, and action. Teaching ethics and responsibility to students of science and engineering is an interdisciplinary affair, and can be linked to the development of other student competences such as leadership, collective decision-making and collaboration skills. These elements must connect to core content of the science and engineering study programmes – not attached as an isolated appendix. Ethics can be included in different topics, and not necessarily in an ethics course.

Network deliberations on content of ethics and responsibility education sum up to suggesting that it includes both aspects on the micro (development of personal skills) and the macro (e.g. legislation and sustainable development).

This is in line with the work of Joseph R. Herkert (2001, 2003, 2005). Drawing on ethicist John Ladd he divides engineering ethics into micro and macro ethics. '[I]f the focus is on relationships between individual engineers and their clients, colleagues and employers' (Herkert 2005, 374) an ethical issue perceives as micro ethics. If an ethical issue regards collective responsibilities of the engineering profession it is labelled as macro ethics. Herkert segments this dichotomy into three, and distinguish between individual ethics (micro level analysis), professional ethics (professional responsibilities) and social ethics (legislation and macro level analysis of technology as such). Li Bocong supports this conceptualisation when he distinguish between micro, meso and macro ethics (2011, 2012).

A recurring theme in the Berlin workshop discussions was the relationship between individual and collective responsibility and how the two are addressed through the respective projects. This is not a new theme, and has been raised in previous meetings, but we re-emphasised here that we cannot address ethics only at the individual level, but must strongly stress the collective elements of social-ecological responsibility and encourage systems perspective. Each initiative incorporates this common theme and can be compared in Table 6.

### **Active learning forms**

As science and engineering students should appreciate an array of different approaches without uncritically internalising them network participants recommend the use of both case studies and student activating teaching methods. According to both Yin (2017) and Stake (2005) the trademark of case studies is a synthesis of different approaches and input to address a single issue. Active learning forms support judgment and adaptation to real-life situations. Presented student-involving activities covers methods such as role plays and active discussions.

Network participants have suggested that individuals with double competences or interdisciplinary teams could take responsibility for the teaching activities. This question has also been examined by John Ozolius (2005), and his conclusions are similar: it is advantageous to combine the field experience of engineering educators with the theories ethics. The ethical values added by philosophers are perceived better by engineering students, and their capacity to address complexity and to be careful with evidences improve as well.

Many of the initiatives rely on some form of 'problem-based learning' (PBL). Problem-based is a pedagogical methodology that is based on students learn while they in groups and under supervision address or try to solve real life problems (Kolmos, Fink, and Krogh 2004). There is both a process and a product element reflected in PBL: Students both learn how to collaborate with fellow students and their supervisor (process) and they have to describe and formulate suggestions for solutions to the addressed problem in a project report. A PBL approach can help students to identify and tackle relevant and meaningful problems. Hence, a PBL approach integrates the real world into teaching ethics and responsibility into the class room, or vice versa.

For example, Science Outside the Lab explicitly brings students out from their laboratory contexts to observe and interact with the real world of science policy. The sustainable environmental activities at Udmurt State University bring students to interact with their local communities. In the

**Table 6.** Comparison of how all six initiatives address the individual and collective relationship.

Addressing the relationship between micro and macro levels	
<b>Science Outside the Lab</b> Changing perceptions of social responsibility	<ul style="list-style-type: none"> <li>• Science policy is depicted as a complex network of people, institutions, and processes, with interactions between them</li> <li>• Effective intervention requires understanding of context</li> <li>• People confront their own point of view while making the ethical decision</li> </ul>
<b>InnovENT-E</b> Using competencies and accreditation to build trainings and evaluate learned social responsibility	<ul style="list-style-type: none"> <li>• Collective approach to ethical problem solving – judged highly important and impactful – is also used</li> </ul>
<b>Sustainable Development Activities</b> Project-driven teaching in an environmental management course	<ul style="list-style-type: none"> <li>• Students role-play different management levels: from personal responsibility, to city-level sustainable management, to presidential concerns, to the UN and other international organisations</li> </ul>
<b>Blue Engineering</b> Student-driven teaching of social and ecological responsibility	<ul style="list-style-type: none"> <li>• Sustainable development solutions are discussed across all levels</li> <li>• Engineering students are encouraged to get to know their personal values and the values of one's own group.</li> <li>• They are then encouraged to collaborate with others to recognise other values, and act accordingly on an individual and collective level</li> </ul>
<b>Ethical Case Studies in Chemistry</b> Case-driven teaching of social responsibility	<ul style="list-style-type: none"> <li>• All case studies present an ethical dilemma addressed in its organisational, institutional, broader societal, and/or global context</li> </ul>
<b>Introduction to German Engineering</b> Interdisciplinary and intercultural teaching	<ul style="list-style-type: none"> <li>• Students are diverse in nationality and technical or educational background</li> <li>• Solutions require specialisation, division of labour, and pose conflicts between time, available resources, and completion in given timeframe</li> <li>• Students are encouraged to look at the problem and solution from alternative perspectives, e.g. an engineer from a political science viewpoint and vice versa</li> <li>• Groups must justify all decisions (technical, social, ethical, sustainability).</li> </ul>

same courses, role-playing at different levels of decision makers (e.g. local, presidential, or UN) encourages students to reframe problems in different outside contexts, often in wide global frameworks. The modular design of Blue Engineering is intended to be transferrable, distributed, and inspiring to different contexts. Some Blue Engineering modules invite speakers from outside university to interact with the engineering students. In the Introduction to German Engineering programme, multicultural and multidisciplinary groups act in teams, but bring and contend with their own group identities. Case studies present an ethical problem, already enmeshed in its broader, outside contexts.

In addition, InnovENT-E proposes a broad understanding of competencies. Here, competencies are not only narrow or abstract competencies (as in solving maths problems) but consider the ability to skilfully work with enmeshed real life problems to be a valuable competency.

Some teaching methods focus on 'what?' (for example, a specific ethical concept or problem), while others focus on 'how?' (for example, the process of solving such a problem). These approaches are complimentary and could be stronger when offered together. For example, case studies present real-life problems in a rigorous and systematic way. A case study gives a thoughtful introduction to a topic with meticulous mapping of actors and values. However, case studies remain neutral, and do not propose an ideal solution. The academic methodologies of case studies can help provide a nuanced understanding of 'what' a problem is, before the 'how' of generating a solution is pursued by PBL or similar methods utilised in the described initiatives.

### *Changing science and engineering education*

The third line of deliberations regards formulating a strategy for changing the science and engineering education to include ethics and social responsibility elements. There is a need for bottom-up

teaching activities that are developed by local teachers, supported top-down by allocating needed resources and curriculum changes.

Relations to both internal and external stakeholders should be established and course material developed. If science and engineering faculty and university management supports the transformation of education as to include ethics it will make it easier to realise such transformation. Externally support from accreditation authorities, governmental bodies, funding agencies, business and future employers of scientists and engineers. The InnovENT-E initiative, carefully addressed above, was involved in the network as a result of outreach initiatives.

Several network meetings have issued calls for the development of teaching materials. The lack of discipline specific teaching material may be a barrier for including ethics in a programme. Examples of existing material have been presented and discussed at network meetings. The development of case studies for chemistry and chemistry engineering students was fuelled by an assumption that the presence of adequate teaching materials will make teaching in the ethics of chemical engineering more widespread.

While some work has been done toward mainstreaming a contextual perception of SET and promoting the inclusion of courses and competencies addressing socio-ecological responsibilities of science, engineering, and technology in university study programmes, much remains to be done. This has for example been pointed out by Mitcham and Englehardt (2016) who calls for 'accountability and pedagogical research into what works in teaching and learning offers special opportunities.'

Accreditation criteria have effects in e.g. the US, but in other countries accreditation do not require ethics in engineering curriculum. Well-funded groups of engineering researchers and teachers at universities are more the exception than the rule. As a result, the goals of teaching initiatives such as the ones presented here are realised only in some cases (Colby and Sullivan 2008). While some teaching materials are available, sufficiently critical accounts of structural, collective ('macro') issues such as law and policy are still largely lacking. Significant research and curriculum development are needed to better support educators teaching topics related to ethical, social, and environmental responsibility to scientists, engineers, and technical experts.

## Discussion

These SERSEE network findings mostly corroborate those of other publications. They give a strong basis to think about new challenges for ethics teaching.

It is not easy to teach socio-ecological responsibility to science and engineering students. Members of the SERSEE network have faced difficulties in setting up and initiating such teaching activities. Especially in the beginning of the existence of SERSEE attendees experienced a need to justify their socio-ecological responsibility teaching. Such experiences seems to be shared by teachers at engineering schools in France (Didier and Derouet 2013).

SERSEE teachers argue that there are good reasons for integrating socio-ecological responsibility issues in engineering education. They call for the duty of institutions of higher education to prepare their students for their future jobs where socio-ecological responsibility is needed. They try to motivate their colleagues making reference to the pedagogical challenge it is to teach such a topic. They find help in their endeavour from small groups of involved teachers or external stakeholders. The need for ethics teaching is illustrated in the existence of a CDIO workshop on teaching ethics.<sup>9</sup> CDIO is an abbreviation for 'Conceive Design Implement Operate' and denotes a particular active learning pedagogy. SERSEE teachers use such pedagogical methods.

A trend seen at the latest SERSEE meeting in Moscow, which also appears in other networks in the world, is to liaise SET teaching to the 17 UN goals for sustainable development (Wack, Roussel, and Fayolle 2019). A continuation of this trend could be to help students to link their vocational projects with these goals. How can a supervisor to coach such approaches?

The European Union has similarly made ethics, social responsibility and sustainable development a focus in their Responsible Research and Innovation tool (Horizon2020 2014), in the European ethics

guidelines for AI (European Commission 2019) and in their ‘whistleblowers’ protection mechanism (European Union, the European Parliament and the Council 2019). It seems topical for SERSEE to discuss how these elements are taken into account in ethics teaching of science and engineering students.

AI and robots are drawing new frontiers of the relationship between humans and machines and in-between humans. They bring with them questions about who is a human being. How can we teach ethics when the definition of what it means to be human is under revision? How to prepare students for ethical decision-making about the use of robots and AI? How can we prepare them to take decision in a way that preserve the blossoming of men and women?

E-learning is becoming a major way to learn. How to design e-learning curricula in order to transmit ethical skills in SET? Are there any learning outcomes that specifically need to be learned in a classroom? What learning outcomes can be learned virtually or in flipped classrooms?

There are several items that the SERSEE network can embrace in their future work. In this period where persons have to face new questioning that have never been faced before and new teaching methods, it seems fundamental that everybody has a proper understanding of his or her values, and those of others he or she is living with. Scientists and engineers must be prepared to practice ethical decision-making in a time of uncertainty. The sustainable development, user involvement, public engagement in science, robots, A.I., and e-learning, etc. require scientists, engineers and others with a SET awareness to exert their full responsibility.

## Conclusion

In the previous pages, we have pointed out good practices and important aspects to consider if one gets involved in teaching ethics and socio-ecological responsibility to science or engineering students. They count the following advice:

*Be close to real life. Involve students in learning ethics.*

If the ethics teaching of science and engineering students is brought closer to the real life of the scientist or engineer the students become more involved. That may be not enough for ethical reflections to become meaningful for science and engineering students. The curriculum should be designed to make every student experience in real life settings the need to get competencies to manage ethical dilemmas. It should lead and help them towards involvement in ethical topics in which SET has stakes.

*Use active pedagogy. Project work makes students build resources, lead group work and make collective decisions.*

Active pedagogy is a beneficial way to engage students. As teaching ethics has a social purpose, all means to train to collective work and to learn to conciliate different points of view contribute to building social skills and competences. Ethics needs active reflection, and active pedagogy stimulates that.

*Embed social responsibility courses into the curricula. Do not isolate ethics.*

Ethical dilemmas are found in any field. They cannot be addressed without collective and professional reflections. This is a reason for embedding socio-ecological responsibility into the curricula and not to isolate it. Another benefit of this is that, as part of the curricula, social responsibility learning could get support and resources on equal terms as other science and engineering topics. Embedded social responsibility courses provide a better recognition of these. Students may identify them as an important part of their studies.

*Link ethics teaching to both critical thinking and scientific methods as well as to contextual elements.*

Science and engineering often face issues in which ethical dilemmas could emerge. Critical thinking and scientific methods are needed tools to define problems and design solutions as well as critically approach information. The societal context and public debate are full of issues deriving from scientific applications and engineering solutions. Embedding science and engineering in their social context and linking these endeavours to the public debates are ways to bring science and engineering ethics closer to real life.

*Establish links with external partners and ask for their support to promote socio-ecological responsibility teaching.*

To broaden the representations of a problem or dilemma is one major step into ethical decision-making. When university students and teachers establish relations with external partners, they learn how to manage different interests and perspectives, discover other values and new ways of reasoning. External partners, as future employers, legitimate the importance to integrate ethics and SET.

Furthermore, internship experiences with organisations facing ethical issues can train ethical decision-making. It is often difficult to use such experiences because of the confidentiality often attached to them. A good relationship with the organisation can help to design fair ways to collect and to use these experiences, and to give, as much as possible, constructive feedback to them.

*Promote different perspectives. Teach to collect and take into account different points of views.*

Corresponding to the previous point, this one is an inescapable point of attention for teaching ethics in a SET context. The goal is to contribute to living together and collective problem solving. This can only be done when paying attention to who are others.

In this paper, we have presented and reflected on output from SERSEE network experiences generated over 14 years. Even though the interest for ethical issues related to SET is increasing, teaching such matters require more support from university management, staff and external stakeholders. Teaching ethics of science and engineering must be in tune with appropriate pedagogical approaches.

The outcomes of the SERSEE network underline key points that figure above: Teaching ethics to science and engineering students is recommended to be close to real life, involve students in learning ethics by using active pedagogy, embed social responsibility courses into the curricula, link ethics teaching to both critical thinking and scientific methods as well as to contextual elements, establish links with external partners, and promote different perspectives.

Society is facing huge challenges with emerging technical possibilities, such as A.I., or achieving the sustainable development goals of the United Nations. To manage these challenges each citizen should be able to make responsible decisions. That is specifically true for graduates of higher education. To develop knowledge about what has to be learnt and how to massively train citizens to assume these responsibilities is a current duty and aim of SET researchers and teachers as those of SERSEE network.

## Notes

1. The conclusions and recommendations were published in a folder aimed at university educators: <http://www.dirk-rathje.de/brochure-teaching-responsible-use-2008.pdf>.
2. The 16 papers in the special issue of Science and Engineering Ethics address the following cases / topics: undergraduate courses from Bilkent University, Ankara (Ozaktas 2013), University of Hamburg (Spitzer 2013), Imperial College, London (Alpay 2013), Technical University of Berlin (Baier 2013), Leuphana University Lüneburg (Michelsen 2013), University of Darmstadt (Liebert 2013), and Technical University of Catalonia (Fabregat 2013); experiences with role plays at Delft University of Technology (Doorn and Kroesen 2013) and in Germany (Hunger 2013); biosecurity education for life science professionals from around the world (Minehata et al. 2013; Nixdorff 2013); PhD course for climate scientists at the University of Kiel (Børsen, Antia, and Glessmer 2013); and reflections on reforms of engineering education (Takala and Korhonen-Yrjänheikki 2013; Geerts 2013; Didier and Derouet 2013; Conlon 2013).
3. The proceedings are no longer available on the internet, but an electronic copy can be obtained by contacting the corresponding author of the paper.
4. A complete teaching and learning ecosystem involves many practitioners. Accreditation organisations can secure the requirements that must be imposed upon education and interact with employers and society as a whole. Labour unions can be engaged with the ethical issues that employees experience in view of social/ecological responsibility, and hence could or should have a special interest in this teaching.
5. This work has been carried out within the frame of the InnovENT-E project which is partly funded by the ANR (French National Research Agency).
6. Green public procurement is 'a process whereby public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life cycle when compared to goods, services and works with the

same primary function that would otherwise be procured' (Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 2008).

7. Gestaltungskompetenz is a German design competence that, in mastery of its 12 component competencies, should enable students to use their knowledge of sustainable development to analyse cases; to understand the interactions between ecological, economic, and social elements; to identify problems in unsustainable development; and to design and implement sustainable processes.
8. The terms 'German engineering' and 'German engineering design' refer to engineering and engineering design in Germany. It does not refer to special kinds of German engineering practice or engineering design.
9. CDIO workshop; Aarhus 2019 June 24th <http://conferences.au.dk/cdio2019/working-groups/working-group-teaching-ethics/>.
10. The Bologna Process allows for countries, institutions and stakeholders in the European area to continuously adapt their higher education systems making them more compatible and strengthening their quality assurance mechanisms (European Higher Education Area 1999).
11. We desire a critical approach to law guided by the question of which laws and regulations are needed to help secure responsible development and application of science and technology.

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## Appendix

Matrix of six educational initiatives useful for teaching social and ecological responsibility in science and engineering education. Interested educators are invited to match their own goals and objectives with the projects described here, consider the barriers and opportunities, and either choose one project packet to emulate, or select several elements and construct their own tailor-made system.

	Description and implementation	Goals and objectives	Driver(s) behind activity	Barriers and opportunities	Outcomes
<b>Science Outside the Lab</b> Changing perceptions of social responsibility	<ul style="list-style-type: none"> <li>Two-week immersive, place-based workshop on U.S. science policy in Washington, D.C.</li> <li>Programme fosters student discussions with invited speakers who use science in their decision-making, or who make decisions that will impact science and technology</li> </ul>	<ul style="list-style-type: none"> <li>Demonstrate the complex interaction of science and technology with democracy, ethics, and values</li> <li>Highlight how those values and their proponents compete for prominence</li> </ul>	<ul style="list-style-type: none"> <li>Exploring contrasting viewpoints may increase empathy and lead to more successful interactions between scientists and policymakers</li> <li>Students should be provided with an opportunity to grapple with their technical work in a social context</li> </ul>	<ul style="list-style-type: none"> <li>Challenge of scale</li> <li>However, programme type could be applied to more modest local environments: larger than the lab, but smaller than U.S. federal government</li> </ul>	<ul style="list-style-type: none"> <li>Programme run as a supplemental mode of education for over 10 years</li> <li>Students leave with deeper understanding of science policy complexity, and greater humility about technical expertise in policy debates, yet still appreciate technical contributions to society</li> </ul>
<b>InnovENT-E</b> Using competencies and accreditation to build trainings and evaluate learned social responsibility	<ul style="list-style-type: none"> <li>Collective project of several French engineering schools and universities to develop a specific competence for managing ethical issues</li> <li>Held within a programme designed to develop students' skills in innovation and export</li> </ul>	<ul style="list-style-type: none"> <li>Introduce a formal ethics competence in the educational programme</li> <li>By certification make it visible and provide legitimacy to those who want to implement it in courses or curricula</li> </ul>	<ul style="list-style-type: none"> <li>Higher education has a social responsibility to give students awareness and tools to face ethical issues</li> </ul>	<ul style="list-style-type: none"> <li>Non-availability of ethics and pedagogic experts</li> <li>Marginal available time in curricula</li> <li>Global lack of desire to become competent in the ethics field</li> <li>However, highly-involved contributing professors sustain project</li> </ul>	<ul style="list-style-type: none"> <li>Developed a skills framework to describe the management of ethical issues</li> <li>Resulting guidelines and learning outcomes can help design and certify ethics courses and competences.</li> <li>Ethics is elevated to the level of 'creativity' or 'business plan' competences</li> </ul>
<b>Sustainable Development Activities</b> Project-driven teaching in an environmental management course	<ul style="list-style-type: none"> <li>Course in international environmental activity that emphasises sustainable development knowledge</li> <li>Students apply theoretical knowledge in practical work</li> </ul>	<ul style="list-style-type: none"> <li>Involve students in sustainable environmental activity</li> <li>Project work should include theoretical base, legal justification, funding possibilities, and consideration of international standards</li> </ul>	<ul style="list-style-type: none"> <li>Public sustainable development knowledge is a necessity for industry, business, government, and society</li> <li>Integrated, interdisciplinary and multi-level environmental management courses are not available</li> </ul>	<ul style="list-style-type: none"> <li>Limited course time</li> <li>Absence of connected faculty courses or an interdisciplinary network to manage sustainable development work at the university level</li> <li>However, the course gives to students the principal general view of multi-level Environmental Management, that could be spread and applied practically</li> </ul>	<ul style="list-style-type: none"> <li>Students can identify the basic structure of the world economy, environmental problems, and global needs</li> <li>Demonstrated understanding of environmental laws, standards, organisations, and social institutions</li> <li>Developed collaborative projects that apply to practical (often local) issues</li> </ul>

(Continued)

Continued.

	Description and implementation	Goals and objectives	Driver(s) behind activity	Barriers and opportunities	Outcomes
<b>Blue Engineering</b> Student-driven teaching of social and ecological responsibility	<ul style="list-style-type: none"> <li>Highly modularised, student-driven course</li> <li>Students analyse and evaluate the relationships between technology, nature, individuals, and society, from different perspectives and learn to democratise the relations</li> </ul>	<ul style="list-style-type: none"> <li>Raise student awareness of their personal and collective values and learn to act accordingly</li> <li>Students create new activity modules in the process of course completion</li> </ul>	<ul style="list-style-type: none"> <li>Students should have an opportunity to question technology and society, and to shape it differently</li> <li>This includes one's own university if so desired</li> </ul>	<ul style="list-style-type: none"> <li>Time for initial development of course building blocks</li> <li>However, developed course building blocks are self-contained and may be used by any course leader with minimal preparation</li> </ul>	<ul style="list-style-type: none"> <li>Over 140 course building blocks are completed and regularly used</li> <li>Current initiative ongoing to make existing building blocks available online under Creative Commons license</li> </ul>
<b>Ethical Case Studies in Chemistry</b> Case-driven teaching of social responsibility	<ul style="list-style-type: none"> <li>20 case-studies that analyse ethical dilemmas in chemistry for use in university teaching</li> </ul>	<ul style="list-style-type: none"> <li>Publish a four-part special issue of HYLE: International Journal for the Philosophy of Chemistry</li> </ul>	<ul style="list-style-type: none"> <li>Little teaching material is available on ethical issues in chemistry</li> </ul>	<ul style="list-style-type: none"> <li>Language barriers</li> <li>Interdisciplinary writing</li> <li>No external funding</li> <li>However, contributors benefit because their work is published in a scientific journal</li> </ul>	<ul style="list-style-type: none"> <li>Will publish teaching material for university students in a scientific journal</li> <li>Will disseminate cases as teaching tools to a broad audience</li> </ul>
<b>Introduction to German Engineering</b> Interdisciplinary and intercultural teaching	<ul style="list-style-type: none"> <li>One-week intensive, immersive project course</li> <li>Focused on one specific design task that is challenging, complex, socially relevant, and has no standard solution</li> </ul>	<ul style="list-style-type: none"> <li>Teach technical expertise in German engineering design</li> <li>Teach skills for interdisciplinary and intercultural team work</li> <li>Highlight relevance of coursework to future industrial projects</li> <li>Develop confidence as competent representatives of their respective discipline</li> </ul>	<ul style="list-style-type: none"> <li>Industry demands students with strong professional and teamwork skills alongside technical skills</li> <li>Inter-departmental evaluation of curriculum</li> </ul>	<ul style="list-style-type: none"> <li>Large resource needs</li> <li>Integrating all disciplines within the working groups</li> <li>Engineering students recognising and valuing input from the humanities and political science and vice versa</li> <li>However, students recognise the challenges and benefits of conflicting opinions and different perspectives</li> </ul>	<ul style="list-style-type: none"> <li>Students propose a technical solution to a task that considers social, political, environmental, and economic impacts</li> <li>Students are aware of the significance and value of interdisciplinary and intercultural team work</li> <li>Students recognise global impact of their technical solution</li> </ul>