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Training Engineers for Sustainability at the University of Bremen*

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Technical innovation is necessary but should not be overestimated on the way towards sustainability. Asking ourselves what kind of knowledge and skills engineers need for a more sustainable design of technologies, processes and products, we came to at least three answers: 1) Knowledge about targets and impacts: scientific knowledge about possible impacts on health, safety and the environment and on 'carrying capacities' of socio-ecological systems (sources and sinks); 2) Knowledge about technologies and interventions: methods to analyse and evaluate technologies, processes and products and to design more sustainable and robust solutions; 3) Knowledge about innovation processes, about the complexity of socio-economic systems (e.g. innovation systems) and knowledge about the options for engineers to influence processes within these systems, as well as skills that lend the ability to make optimal use of these options. The curriculum development in the Division of Technological Design and Development at the University of Bremen's Production Engineering Department can thus be summarized by the terms 'impacts', 'methods' and 'innovation processes', with a scope that is influenced strongly by the emerging field of industrial ecology. One of the strengths of our research and course programme is the full integration with the rest of the engineering department making both very practice orientated. We attach special importance to the taught knowledge being relevant in everyday engineering practice and implement this, among other things, by complementing our lectures and seminars with field trips, guest speakers from academia and industry, and interdisciplinary student projects in co-operation with other divisions and industry partners.

Keywords: sustainability; knowledge building; innovation systems; curriculum development; interdisciplinary education

ENGINEERS IN A COMPLEX WORLD

ENGINEERS are faced with growing complexity at their workplaces. In addition to their main engineering task of solving well-posed problems under well-defined boundary conditions and with a limited budget, they are increasingly challenged by the societal demands for solutions that are environmentally benign, socially balanced and appealing to the largest possible target group. A car that is to be designed is no longer just a vehicle for transporting people from A to B; it is at the same time an emitter of harmful substances, a consumer of non-renewable resources, a potential threat to the passengers, a building block of the corporate image, an object of political discussion, and so on. Engineers are increasingly asked to address these issues in the design of products and processes; they are forced to open up to the concerns and demands of society [1].

In their traditional role as problem-solvers, engineers are expected to find technological solutions to such pressing problems as diminishing resource supplies, global warming, toxic wastes and other environmental impacts. While engineers could feel 'at home' in this role, the situation is different from the traditional way of engineering, because now the problems to be solved are almost all interrelated and their mutual relations are not necessarily linear in nature. The famous example of CFCs shows the dilemma engineers are facing: solving the problem of toxicity and occupational risks from refrigerators in the 1930s created a problem of a very different kind and with a much larger impact: ozone depletion. The fact that CFCs are also potent greenhouse gases aggravates the problem and demonstrates that linear thinking in a narrow corridor of causes and effects is no longer adequate to deal with the problems arising from complex technology-nature interactions. On the one hand, technology is part of our sustainability problems (by sustainability we limit ourselves here to the definition of the Brundtland commission's view of it as the ability to satisfy today's needs without compromising the ability of future generations to satisfy their own needs, which is a matter of intergenerational justice); technological innovation, on the other hand, will be an important factor in solving these problems, yet it will not suffice to deal with the rising complexity. The traditional 'technology-push' innovation process is inherently non-systemic; it needs to be augmented by other approaches that make use of a system view.

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One could argue that the fundamental tasks for engineers have not changed: finding new solutions to technical problems or societal demands and optimizing existing solutions. While in essence this is still true, the scope and the nature of the systems that engineers are dealing with have changed. The effects of the engineers' developments and solutions on the environment, economy and society are also very often outside the core expertise of engineers and rather described by atmospheric chemistry and physics, biology, ecology, social science, medicine and others. When engineers are working on solutions to minimize these effects, they need to have a basic understanding of them and need to work across disciplines.

In our view it is thus especially important to train engineers in system thinking and make them aware of the complexity of sustainable development. This requires knowledge about the possible impacts of technology on nature, the economy and society and of methods to assess such impacts ('impact knowledge') and it requires knowledge of how it is possible to control these impacts at different levels by technological design and control measures ('design and control knowledge'). With increasing emergence of new insights into the relations and interdependencies of technosphere, society, nature and the economy, static knowledge becomes quickly obsolete. It is therefore of at least equal importance to strengthen the capabilities of engineers to assimilate the knowledge of other disciplines and to review their own decisions in the system context. In other words, the analytical and creative capabilities need to be complemented by communicative and reflexive capabilities [1]. We aim at strengthening the students' abilities to deal with incomplete knowledge and to make precautious decisions in complex situations.

Many of the new requirements faced by engineers are covered by a currently emerging field of science: industrial ecology, which is developing around the idea of designing industrial (socio-economic) systems using nature, or more precisely ecosystems, as a model (see [2] for an overview of the field of industrial ecology). Industrial ecology has its roots in the engineering sciences and draws heavily on the concepts of (biological) ecology, but has evolved (and still does) to include other natural sciences, social sciences and economics. Since its focus is on the socio-economic level (see [3] for a discussion), engineers in industrial ecology naturally have to look and think across their discipline's borders. It is in the spirit of this that we developed the curriculum in our division.

We believe that, equipped with some basic knowledge of impacts and methods, an understanding of the fragility of complex systems, the necessary abilities to communicate and reflect upon themselves, and the ability to make decisions based on complex and incomplete information engineers can develop an awareness for their role in the quest for sustainability.

Knowledge and methods for sustainable engineering

Now we want to focus on the curriculum, the qualifications and the knowledge needed to understand the interactions between anthroposphere and technosphere and some essential methods and tools to assess and shape these interactions.

We divide the knowledge required to develop sustainable solutions broadly into impact knowledge, knowledge for technological design, and knowledge about socio-economic processes. Impact knowledge is the knowledge of the possible environmental, social and economic impacts of socio-technological activities. It comprises knowledge from many fields of science, ranging from atmospheric chemistry and biology to social sciences. An important aspect of this is the knowledge of (direct and indirect) impacts on human health, safety and the environment. A number of tools help in assessing them: Life-Cycle Assessment, Ecological Footprint Analysis, Human/Eco-Toxicity Analysis, and Risk Analysis are prominent examples which are taught in our courses.

Knowledge for technological design and knowledge about socio-economic processes is about the directions of innovations and the capability to innovate. It is knowledge of how to influence the interactions of socio-technological activities with the environment, society and the economy to decrease negative impacts or to increase the resilience of affected systems. In the past, this knowledge was mainly technology orientated. However, in order to be successfully implemented, it must be accompanied by a systemic impact assessment; we come back to this later. There are different levels at which knowledge to design and process innovations can be developed and applied: the level of the immediate cause for environmental, social or economic impacts (e.g. a certain exhaust pipe); the level of the system directly surrounding this cause (e.g. the process or the producing factory); the level of the organizational unit this system is part of (e.g. an enterprise or industrial sector) and the overall socio-economic system level (e.g. a national economy) . The history of controlling environmental impacts from industrial processes serves as a good example. In the beginning, controlling environmental impacts was achieved by so-called 'end-of-the-pipe' technologies, i.e. by filtering out or diluting unwanted emissions. Later, this approach was accompanied and then substituted by the 'cleaner production' approach, where impacts were being avoided at the process level instead of being filtered out. In contrast to the end-of-the-pipe solutions, this step yielded generally lower environmental burdens with constant or even increasing production and thus increased the eco-efficiency of processes. Still, solutions were implemented on the process or plant level and not system wide.

The next step in this direction is the integration of control measures (by design) at the organizational system level. The relevant systems in this context are production-consumption systems (systems of provision) extending from the extraction of resources to the use phase and the final reuse, recycling or disposal of the products. To control the negative impacts and the resilience-strengthening parts of such systems, a holistic view across the traditional boundaries of companies or production sites is required. This approach even demands measures being implemented across industries (along the supply chains). It thus also requires engineers capable of comprehending the upstream and downstream consequences of their design and optimization strategies. We find that the basic training of engineers usually does not provide such knowledge and thus has to be taught from scratch in specialized courses. It should be obvious that optimizing systems with this very broad approach cannot be done via static rules or simple recipes. The design and optimization of systems is also not the task of only one engineer, not even of a single company. Decreasing the environmental burdens imposed by such systems demands some co-ordination of all actors, from resource extractors to consumers.

A possible implementation of this approach at a very early stage of systems development could, for example, be the development of products and technologies according to guiding principles (*Leitbilder*) like 'inherent safety', bionics (learning from nature) and 'closed loop production' [4]. If the actors within a given system of provision share the same guiding principles, a system-wide optimization seems possible. On a somewhat broader scale, namely at the level of industrial systems, Industrial Ecology might provide an interesting guiding principle. Its core philosophy calls for taking eco-systems as role models for designing industrial systems with closed material loops, cascading use of renewable resources and final emissions that are well embedded in the natural cycles [2]. On the engineering level, these principles need to be implemented in the design and optimization of technological solutions.

Inadequacy of some single methods

Even with system-wide approaches to design socio-technological systems and thus minimize environmental, economic and social burdens the effects might remain insufficient due to the complex nature of the affected systems (nature, economy and society). As we have seen, the required design and control knowledge tends to be even more complex and multidisciplinary than the impact knowledge. Impacts in highly coupled systems can never be completely assessed. For example, the impact of greenhouse gases is only partly described by their global warming potential (which can be calculated from physical properties and with the help of atmospheric chemistry). Since the climate system is inextricably coupled to other parts of the environment, to the economy and to social development, impacts on the climate will necessarily affect all the other systems as well. These secondary effects are not necessarily small, due to the non-linearity of couplings between the affected systems, and they might feed back to the climate system. Hence, a full assessment of the impacts of greenhouse gases would have to take these secondary effects into account.

Models covering the complete range of effects are not yet available. Those that include more than just the direct effects and that span the economic, the social and the environmental dimension are beginning to emerge, but are not yet widely used in the engineering world to assess the implications of technology. Examples are economic input-output life-cycle assessment models [5] and integrated assessment models (for global environmental change and policy making, see e.g. [6]).

Thus the knowledge about the impacts of socio-economic activities so far remains restricted to the direct effects. If the impact knowledge thus remains incomplete, it must be even more true for the design and control knowledge, since every attempt at controlling the impacts or redesigning the system necessarily comes with its own impacts, albeit maybe on a different scale and with a different scope. However, in complex and non-linear systems far from equilibrium, small disturbances might have large and sometimes unpredictable effects; thus attempts at improving such systems might just lead to the opposite. As a consequence, strategies for decreasing societal, economic and environmental burdens must be implemented carefully and their effects must be monitored thoroughly. A consequence for engineering education is that engineers need to understand the limitations of technological solutions and the limits of assessing the effects of such solutions. In other words, engineers at first need to know the 'islands of knowledge in the sea of the unknown', but they must even more acquaint themselves with the shoreline. Also, they should design socio-technological interventions in accordance with a 'trial and error' approach to the problems of uncertainty. This means in particular, that the steps of development and 'scaling up' are to be designed as 'small steps'. Then, an error will very likely be manageable and less likely turn out to be a long range catastrophe.

Curriculum in sustainable engineering

Some of the curriculum development is based on the discussion of teaching Technology Assessment at German universities summarized in a report from VDI (German Association of Engineers) [7]. In addition, we are developing our curriculum in accord with the production engineering department's overall agenda and programme requirements, and keep an open exchange with various professionals from industry and administration regarding the requirements for engineers. When, in the course of this exchange, we have identified a new development that we consider relevant to our curriculum, we update our courses (or their content) accordingly.

The faculty of Production Engineering at Bremen University has five programmes to offer students: Production Engineering (mechanical engineering and process engineering), Industrial Engineering and Management, Science of Trade and Technology, Systems Engineering (Bachelor and Masters programmes) and Master of Science in Production Engineering. The unique features of these programmes are their closeness to the real world of engineering and the incorporation of many practice-orientated labs, internships and projects. Our division's contribution to the curriculum shares this unique feature. We achieve this practice orientation by being fully integrated in the department. Thus the task of translating and transforming the knowledge of other disciplines into the approaches of engineers is our own task. We are convinced that this is more efficient and effective than inviting lecturers from other disciplines to give lectures in the engineering department. A beneficial precondition for this lies in our own training (and research) which was (is) multidisciplinary and includes biology, social sciences, philosophy of science and physics.

Sustainability-related issues are covered by courses from at least three of the twenty-two divisions within our department: Environmental Process Engineering, Process-integrated Waste Minimization, and Technological Design and Development. The authors are members of the latter division and the description of the curriculum will mainly focus on courses developed there. We will, however, shortly summarize the curriculum of the other divisions relevant to sustainability. All of our courses are targeted at students in mechanical and process engineering, systems engineering, industrial engineering and electrical engineering (from the Department of Physics and Electrical Engineering). In addition to our main target group, we are also seeing more and more students from other programmes in our courses (e.g. programmes in biology and geography). We welcome this development, since it helps the engineering students to get in touch with other disciplines: in their class papers and presentations they have to keep in mind that they are talking to students from other fields of science and the discussions in class bring forth aspects that a purely engineering audience would not have touched. Our courses also attract quite a number of students in the 'extension studies' programme (open to elderly citizens), which makes the diversity in class even greater. Our engineering students thus not only have to cross the borders of their discipline when presenting their ideas and analyses, but also have to communicate across borders induced by social status and age group. This leads to some refreshing debates like the one between the members of a 'salad oil motorists' group and our guest lecturer about the life-cycle impacts of rape seed oil compared to bio-diesel. Although we can only marginally influence the attendance of outside students, we are glad for our students to have the opportunity to argue their case in front of an audience with representatives from multiple societal groups.

The curriculum at the division of Technological Design and Development has been developed with three objectives:

- equipping the students with the relevant knowledge on impacts and methods pertaining to their field of study;
- enabling them to make decisions or design solutions based on the acquired knowledge and argue their case in an appropriate manner;
- demonstrating the relevance of engineering decisions in the framework of sustainability.

All three objectives must be approached from a systemic viewpoint as described above. Thus, as a general objective, the students should be trained to recognize the systemic character of the environment they are operating in.

Regarding the first objective, we are focusing on three dimensions of sustainability knowledge: impacts, methods and innovation processes. The methods dimension includes topics from two of the above-mentioned knowledge areas, impact knowledge and design knowledge (e.g. impact assessment methods and design-for-recycling guidelines). The impacts covered in our courses are primarily to do with the environment and human health, (see Table 1). The impacts and methods require the input of several disciplines, as outlined above. Our division covers expertise from biology, ecology, political sciences, physics, mathematics and computer sciences. Other disciplines feed into our courses via guest speakers from other faculties or universities and field trips to companies and research institutions.

Some impacts, however, are intentionally not covered by our courses since they are fed into the engineering education from other places: economic impacts are only covered marginally, since these are more broadly addressed in courses given by other divisions in the Department of Production Engineering and by the Department of Economics; impacts on society are also only marginally covered, since they are more deeply covered in courses offered by the Department of Social Sciences and *artec,* the Research Centre for Sustainability Studies at the University of Bremen. We do, however, integrate our expertise with other disciplines (including the two just mentioned) in the form of student projects, which are overseen by two different divisions (from within or outside the Production Engineering Department). With our own expertise and the help of experts from other disciplines we thus help our students to integrate the various aspects into a more holistic view of the complex interactions of technology, environment and society.

Courses

The most general course we offer is an Introduction to Technology Assessment. It starts out with the description of major technological risks and

Table 1: Overview of courses taught since 2003/4

Course	Impacts	Methods	Semester	Hrs/week
Introduction to Technology Assessment	toxicity, global warming, ozone depletion, eutrophication, acidification, summer smog, resource availability, noise	RA, LCA, AHS, CED,MIPS, ST, EA, DFE, DFI, BI	Winter	4
Early Detection, Assessment and Management of Risks	toxicity, radiation, accidents, noise	RA, RM, AHS, DFI, FMEA, FTA	Summer	2
Life-Cycle-Assessment in Practice	global warming, ozone depletion, eutrophication, acidification, summer smog, eco/human toxicity, land use, resource availability	LCA, CED, EA	Summer	2
Modelling and Life-Cycle Optimisation of Products and Processes	global warming, ozone depletion, eutrophication, acidification, summer smog, resource availability	MO, LCA, CED, EA	Winter	2
Ways Into the Future —Energy Supply Scenarios	global warming, ozone depletion, acidification, resource availability	ST, LCA, CED	Irregular	2
Nanotechnology—Success Stories, Future Chances and Risks	toxicity, accidents	AHS, ST, LCA, CED, MIPS, DFE, DFI, RM	Irregular	2
Material Flow Management	resource availability, toxicity	MIPS, CED, MFA, SFA, DFE	Summer	4
Bionics—Eco-Technology Guided by Nature?	resource availability, toxicity,	BI, LCA, DFE	Irregular	2
Introduction to Industrial Ecology—Design of Industrial Systems	resource availability, global warming, eutrophication, acidification, summer smog, ozone depletion, land use, eco-system quality, toxicity	LCA, DFE, MIPS, MFA, SFA, CED, MO, RA	Summer	4
International Lecture Series on Industrial Ecology	resource availability, global warming, eutrophication, acidification, summer smog, ozone depletion, land use, eco-system quality, toxicity	LCA, DFE, MIPS, MFA, SFA, CED, MO, RA, PA	Only once (Summer 05)	4

RA=Risk Assessment, RM= Risk Management, AHS= Assessment of Hazardous Substances, LCA=Life-Cycle Assessment, CED=Cumulative Energy Demand, MIPS=Material Input per Service Unit, ST=Scenario techniques, EA=Entropy Production Analysis, DFE=Design For Environment/Recycling, DFI Design For Intrinsic Safety, BI=Bionics, FMEA=Failure Mode and Effect Analysis, FTA=Fault Tree Analysis, MO=(Dynamic) Modelling, MFA=Material Flow Analysis, SFA= Substance Flow Analysis, PA=Policy Modelling and Assessment

the responsibilities of engineers. It then focuses on the possibilities of engineers influencing the design of processes and products within the innovation process. It explains the connection between innovation, quality management and competitiveness. Increased competition in dynamic and segmented markets and increased vulnerability of enterprises (in view of public scandals) are shown as drivers towards corporate social and environmental responsibility. Quality management in this context can be understood as an attempt to improve not only the economic performance of companies, but also their social and ecological performance. In a third section the course details the general objectives of technology assessment and the most relevant methods (risk assessment, cost-benefit analysis (including external costs), life-cycle assessment (supplemented by cumulative energy demand, material input per service unit, entropy production analysis), (eco)toxicological analysis and scenario techniques. All methods are presented using current case studies.

Direct from life examples

Case studies are important for the comprehension of the different methodologies and concepts, which is why they play a crucial role in the courses. Case studies are chosen because they are simple enough to be comprehended by beginners in the field, and yet show all of the aspects of the methodology they represent. Examples are ‘life-cycle assessment of fuel cells and cars’, ‘risk assessment of nano-particles’, ‘external costs of transportation systems’, ‘the assessed choice of materials in light-weight constructions’, and others. These case studies also serve as guiding examples for the students' own class papers, in which they are asked to apply one or several of the presented methods to an example of their own choice (or write a report of such an application). As the mentioned methods are methods for modelling and assessing impacts, the corresponding impact models are also explained and systematically grouped in the categories of toxicity, systems equilibrium (from homeostasis to climate change), resource availability, and biodiversity. Methods from the design and control knowledge domain are grouped into the categories end-of-the-pipe, integrated environmental protection and sustainability strategies. Examples for such methods are design for recycling, substitution of hazardous substances, ecologically optimized material selection, or bionics. This course is given every winter semester and extends over four hours per week.

As mentioned above, the knowledge required from other disciplines is provided by our own staff and by external experts during field trips. Since the methods mentioned above cannot be covered in detail in this basic lecture, we offer in-depth courses for selected methods: risk assessment, life-cycle assessment, scenario techniques, material flow management and modelling.

These courses are generally taught every other semester with two hours per week. In addition to these methodological courses we offer courses on nanotechnology, bionics/biomimetics, and industrial ecology as case studies for applying the knowledge and tools learned in the other courses (particularly designing technologies orientated towards guiding principles). Also these courses are accompanied by guest lectures and field trips. We chose nanotechnology as a course subject, because we believe some areas of nanotechnology pose well suited examples for the problems at hand. They represent emerging and highly enabling technologies expected to bring solutions to many environmental problems, but at the same time they are viewed with much apprehension for their possible (and yet mostly unknown) impacts. In this course we also profit very much from the expertise concentrated in our engineering department, which we tap into by inviting guest speakers and visiting laboratories.

A course that summarizes much of our philosophy regarding engineering education is industrial ecology. Our approach combines system thinking with the development of sustainability strategies at the national, regional and company level; methods include material flow analysis, substance flow analysis and physical input-output tables. As a one-time opportunity we offered an international lecture series on industrial ecology this summer semester with experts from many different disciplines. It brought together the knowledge required to develop sustainable solutions in the engineering context and it included literally all of the disciplines involved in the sustainability debate (www.industrial-ecology.de). Following this success, we will offer courses on industrial ecology every summer semester which includes guest lectures by local scientists, politicians, managers and stakeholders in order to integrate as much external knowledge as possible.

To achieve a thorough understanding of the course material we believe it necessary to apply the knowledge, or at least get a first-hand experience of its application. We therefore require every student to write a short paper on a topic of their own choice (usually some kind of technology, process or product) in which they apply one or several of the methods they learned in class. Also the field trips to local companies that have relevance with respect to the corresponding course increase the practical value of the courses.

Student projects

Another option for applying the knowledge gained in class is participating in one of the student projects that we offer. Currently these are 'Mobility in urban areas until the year 2020' (in co-operation with the Department of Economics) and 'Innovation management—technology trends and market opportunities' (in co-operation with the Institute for Ultra-precision Machining), 'Robust infrastructure systems for water and electricity in Bremen 2050' (in co-operation with the Institute for Environmental Process Engineering). Another recent project was 'Recycling of carbon fibres from airplane production into new applications within the plane' (in co-operation with the Fibre Institute Bremen).

Other divisions

Of course, we are not alone at the University of Bremen in teaching sustainability related courses to engineers. There are at least three other divisions which must be mentioned: the Division of Environmental Process Engineering (Prof. Räbiger) offers courses in, naturally, Environmental Process Engineering. The Division of Process-integrated Waste Minimization (Prof. Thöming) offers courses in Process Optimization, Process-integrated Recycling and Fuel Cell Technology. The Research Centre for Sustainability Studies at the University of Bremen, artec, (Prof. Weller, Prof. von Gleich, Prof. Lange, Dr Bogun, and Prof. Müller-Christ) offers a course module called Sustainability Studies, which consists of several courses open to all students (but especially directed at students from the Departments of Engineering, Economic Sciences and Social Sciences). Some of the courses offered are Sustainable Production and Consumption, Sustainable Management, Sustainability, Risk and Precaution and Political Sociology of the Environment. Our division contributes at least one course each year to this module.

Especially in artec courses, engineering students are brought into contact with students from other disciplines. The Sustainability Studies module should thus create a focal point for interdisciplinary course work. However, it is for these transdisciplinary courses, that we find it difficult to attract engineering students. We definitely need to improve this situation by increasing our motivational and informational efforts.

Evaluation

Most of the courses taught by our division are evaluated after completion. Some courses are evaluated by the students' organization (StuGa), some are evaluated by ourselves. We have recently begun to make use of the e-learning platform in place at the University of Bremen (elearning.uni-bremen.de) which allows easy implementation of surveys, polls and evaluations. The students are asked to fill out an anonymous evaluation form, which is then analysed by us. Questions concern the quality and quantity of the course material, the preparedness of the lecturer, the style of teaching, the skills acquired, and several other aspects. As our curriculum is new (we started our lectures at the University of Bremen only 2½ years ago), and the student numbers in our department are small, we have not enough data yet to analyse these evaluations statistically. However, we are able to use survey results to improve the content of course material as well as presentation.

Notwithstanding the usefulness of surveys and evaluations, we feel that the best evaluation tool is the students' direct feedback. When they call on us to help them find a thesis topic or for help with developing their project ideas, we know that we have hit a nerve with our teachings. If not, we have to seriously question our teaching methods and our course material. To steal a phrase from quality management, 'quality is when the student comes back, not only the questionnaire'. Another good evaluation tool would certainly be to interview alumni about the usefulness of what they learned in our classes, especially when they entered industry. We have not yet developed this idea any further. We do, however, get occasional feedback from the industry sector when engineers and other industrial professionals visit our public lectures, as, for example, in the lecture series on industrial ecology. So far the feedback has been encouraging and has made a contribution to curriculum development, e.g. in the form of new ideas for field trips and invited lectures.

Future development of the curriculum

As in the past, our curriculum will in the future develop along with our research projects (actually focusing on 'sustainable metals management including entropy analyses' [8], 'substitution of hazardous substances as an innovation process'[9], nanotechnologies and bionics/biomimetics). We will continue this work and proceed more towards the development of an integrated innovation and risk management and towards design of technologies orientated towards guiding principles with a focus on nanotechnologies and bionics.

In addition, we are hoping to better integrate sustainability issues in the general training of engineers, i.e. within the first one or two years of the programmes. Currently we are mainly teaching third and fourth year students and the courses are only optional. We believe that the material we are presenting is of a general interest to all engineering students and should therefore find its way into the compulsory curriculum. This need not be in the form of a dedicated course, but maybe as an extension to already existing classes. We see it as our challenge to demonstrate the necessity for sustainability related education in view of the growing economic pressure German universities are subjected to, and in view of the increasing competition on the engineers' job market.

REFERENCES

1. M. F. Jischa, Technikfolgenabschätzung in Lehre und Forschung (*Technology assessment in education and research*, in German), in: T. Petermann and R. Coenen (ed.), Technikfolgen-Abschätzung in Deutschland: Bilanz und Perspektiven, Campus, Frankfurt/Main (1999).
2. T. E. Graedel, Industrial ecology, Prentice Hall, Upper Saddle River, NJ (2003).
3. C. Bey, Quo Vadis Industrial Ecology? GMI, vol. 34, pp. 35–42 (2001).
4. A. v. Gleich, Towards sustainable nanotechnology? Guiding principles as a means of shaping this technology, in: M. Steinfeldt (ed.): *Nanotechnology as a means towards sustainability? Prospective assessment and design of a future key technology*. A publication by the Institute of Ecological Economic Research, Berlin (2003)
5. S. Joshi, Product Environmental Life-Cycle Assessment Using Input-Output Techniques. *Journal of Industrial Ecology*, **3 (2–3),** 1999, pp. 95–120.
6. E. A. Parson and K. Fisher-Vanden, Integrated Assessment Models of Global Climate Change. *Annual review of energy and the environment,* **22**, 1997, pp. S. 589–628.
7. E. Appel, C. Canavas, A. v. Gleich (eds.), Technikbewertung in der Lehre: Erfahrungen und Standortbestimmung (*Technology assessment in education. Experiences and progress assessment*, in German). VDI-Report 28, VDI Verlag, Düsseldorf (1998).
8. R. Ayres, A. v. Gleich, S. Gößling-Reisemann (eds.): Sustainable Metals Management, Kluwer Dordrecht (2006).
9. A. Ahrens; A. Braun; A. v. Gleich, K. Heitmann; L. Lißner: Hazardous Chemicals in Products and Processes—Substitution as an Innovative Process, Physica Verlag Heidelberg (2006).

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