Integrating sustainable development in engineering education
The case for chemistry and chemical engineering

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1. Introduction

The CIRRUS project that runs on the faculty Technology and Natural Sciences of the Brabant University of Professional Education (Hogeschool Brabant) has as goal the introduction of sustainable development as much as possible completely integrated in all studies. Sustainability is not to be treated 'only' in a separate course or as an optional subject or additional specialisation, during or after a study. The approach is discussed in a separate paper during this conference [1].

Essential components for integration as we intent, are:

1. Each course, project and other activity in the 'normal' curriculum takes care of the issues relevant for sustainability connected with its own subjects such as materials use, energy, design approaches, economics, business operation methods, etc.
2. An introductory course on an early moment elucidates the concept; sets out the 'line of approach' needed for sustainable development, supplies a general framework and 'integrates' the separate issues and details treated in the various courses and projects.
3. Attitude, lateral thinking, interdisciplinary ability aimed at sustainability will get much attention throughout all activities in the study and increasingly so towards the end. Learning by doing through various tasks, practical work and the final project in the study offer the best opportunities for this.

The goal must be: students will still become experts in their respective fields, but with basic knowledge, understanding and a 'frame of mind' necessary to have in their future jobs the competences and attitude for 'sustainable thinking and doing'. That is achieved not by extensive knowledge of specific (so-called sustainable) technology, but by knowing the conditions that are to be met when designing, developing and operating processes and products when caring for people, the planet and economic development, now and in the future.

Bearing this in mind we have adapted the existing curricula based on a set of 'minimum learning goals and criteria' with the intention to integrate sustainability in the 'normal subjects' [1].
All lecturers of the departments involved have had an introductory course on sustainable development. Some have also followed more specialist courses in the field, e.g. on sustainable use of energy. Discussed is also the options they have within their subjects and activities to introduce specific aspects and issues for sustainability. Introductory and 'integrative' courses on sustainable development have been being developed for chemistry and chemical engineering curricula and have run for two years now.

This paper describes our vision, approach and experiences with it.

2. Role of chemistry and chemical engineering

It is widely accepted that a truly sustainable society will use only renewable and recyclable resources and processes, which use resources extremely efficient, causing minimal pollution and disturbance. The contribution of chemistry and chemical technology is essential to achieve that.

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The practical issues in which chemists and chemical engineers have to play a major role are: making available raw materials, renewable and non-renewable and the efficient use of resources. Therefore is needed knowledge regarding recycling, development of high performance materials and of course the development of the required extremely efficient processes, products with minimal environmental impact and easy to recycle, and the production routes for sustainable energy sources, raw materials, food, etc.

Resources, production processes and product use are linked and influence one-another. The total chains of material flows and product use have to be taken into account when developing products: their application, the processes to produce them, the available resources, and reducing their possible negative effects on the environment, nature and human health and welfare. Attention for the whole chain is the only way to attain real and practical sustainable solutions. That includes also attention for the cultural and socio-economic aspects and the broader consequences of the use of technology. At the same time they must satisfy actual needs. Only such solutions really lead to a substantial improvement of the eco-efficiency of the economy and lead to products people are interested in and therefore industry can make in a profitable way. That is the challenge we have when integrating sustainable development in training the future professionals, who have to achieve that.

This requires attention for development in specific areas and at the same time a 'systems approach' that does not look at problems and solutions in isolation. Figure 1 gives the different areas of development we see as essential. This is the model we use as framework when introducing sustainable development to the students.

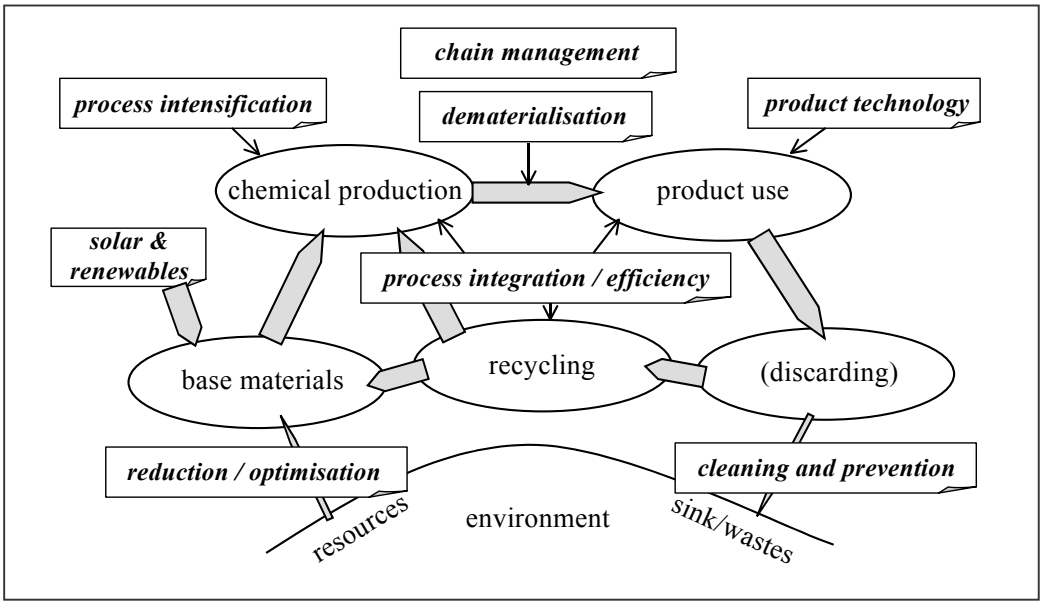

Figure 1. Focal areas of chemistry and chemical engineering for sustainable development

3. Sustainable structure for the chemistry and chemical engineering curricula

On the Brabant University of Professional Education chemistry and chemical technology are presently separate studies given by different departments and in different clusters of studies. It is the intention however to bring both together in a cluster 'Chemistry and Life Sciences' in the near future, together with environmental and biomedical laboratory sciences.
From the start on there has always been close cooperation between both and information, modules and project cases have been exchanged and used mutually. The approach taken is for both therefore more or less the same, in structure and to a large extent also content. In the sense

that chemistry is more product oriented and chemical technology more process and (sustainable) technology oriented.

The departments of chemistry and chemical engineering educate students to become employees in a wide variety of fields. The majority of them become research assistants in food, polymer, pharmaceutical and petrochemical industry. Many students end up in jobs like experts in process automation in process industry, environmental specialist, and head of an analytical laboratory, safety engineer, sales manager or teacher.

Employers expect our students to be acquainted with state of the art technology, next to being good team workers, communicators and independent, self confident and open-minded individuals. Sustainable development and the competences to handle issues in connexion with that, is becoming part of that expectation.
In order to achieve these qualities we apply a wide range of educational concepts, from simple lectures to challenging projects with real life problems. In those we have integrated all relevant aspects of sustainability we think are important for chemist and chemical engineer.

The main lines of the approaches for both studies fit the three components as described above
- Introduction of concepts and broader issues, integration of all aspects treated;
- Treatment in the 'normal' subjects and projects;
- Attention for attitude and a systems approach that asks for multidisciplinary and lateral thinking
Minimum time explicitly spend on specific sustainability issues has to be 5% of the total study hours.

A parallel development, to some extent stimulated by the discussion how to introduce sustainable development issues, is that for the curricula in general the way of teaching has shifted from 'old fashioned class wise teaching' to more interactive and problem oriented learning. That fits very good with the aims we have with learning 'sustainable thinking and doing'. The various projects serve to create a sustainability-oriented attitude in the students. It must become self-evident to use these insights and methods. Projects are intended to show students that a systems approach, multidisciplinary and lateral thinking offers better solutions and are more rewarding also through the fact that they offer professionals a new challenge.

In particular continuous attention is given in learning the ability to rise from a technical oriented pollution control approach to a more systems oriented approach including cultural and socio-economic aspects, commercial opportunities etc. That is: the step from environmental care to sustainable development.

Much information and inspiration we took from the various approaches that have been described in literature, but mostly are intended for dealing with sustainable development in isolated courses [4]. That has been adapted for use in the introductory courses and projects and for integration in the various courses for chemistry and chemical engineering, such as organic synthesis, materials technology, thermodynamics, separation technology, process control and instrumentation etc.

4. Chemistry

In general terms in chemistry sciences the focus is strongly on products and 'green chemistry'. Besides attention is paid to the role chemistry plays in environmental analysis and assessment of sustainability. The use of the learning-by-distance Internet tool (Blackboard) has become important.

4.1 Profile of sustainability in the study.

Starting with the 'learning goals and criteria' which have to be satisfied for the whole four years of the study an outline was made what had to be the major areas of attention. As is discussed elsewhere [1] we formed three groups of sustainable development criteria and learning goals:

1. Background information concerning environmental, ecological, economic and social issues involved.
2. System oriented issues concerning the methods and technologies to assess problems and come to real solutions
3. The human and society oriented issues, which give the conditions that have to be taken into account

All lecturers involved have been made responsible to take up the relevant issues in their own subjects. An evaluation has now to be made if all aspects and issues are indeed covered to a sufficient extent and with sufficient level.

To create coherence and to prevent that sustainability ends up as a set of somewhat isolated issues, specific themes and focal areas of specific interest have been defined and small projects set-up in which the different issues are dealt with in a more integrated way.
So the outline for introducing stainable (technological) development in chemistry is as follows.

Schematic outline of STD in the department Chemical Sciences at the Brabant University of Professional Education				
Phase	**Learning goals**	**Themes Focal areas**	**Subject(s)**	**Time (study hours)**
1st year	Background Human and society	Introduction of STD	• General introduction (backgrounds, incentives) • Simple LCA tools	40
	Background System	Project Flavours	• Inventory of environmental effects of a 1-step synthesis	40
2nd year 2.1	Background	Environmental Chemistry	• Sources and ways of emission, dispersion of pollutants • Environmental Laws • Toxicology	20
2.2	Background	Project Environmental analysis	• Legal rules on water, soil and pollutants • Standard Procedures for environmental analysis • Aspects on sampling	20
2.3	System	Chain Management and LCA for chemistry	• Chain management • Life cycle analysis • Pollution prevention • Green Chemistry	40
2.4	System Human and society	Project Vanillin	• Inventory of environmental effects of all aspects of the production process (resource, product, use, disposal) • Choosing the environmentally most benign process on the basis of this inventory	40
3rd year 3.1	System	Polymers	• Renewables (biopolymers) • The (im)possibilities of recycling • Effects of polymer additives • Biochemical production methods for polymers • Catalysis	40

3.2	System	Capita Selecta	• Retro synthesis in organic chemistry • Role of chemical analysis in process control	20
In-company traineeship and examination project 3.3 – 4.4	System Human and society		• Description of the activities of the company concerning STD • Inventory of aspects of sustainability in own research projects in relation to company's interests and social interests	80
total				320

As can be seen in later years learning focuses strongly on the production chain, pollution prevention and life cycle aspects of chemical products, using as framework the approach as is shown in figure 1. Eventually all students are obliged to perform moderate life cycle assessment during practical projects.

4.2 Illustration

Early in the first year an introduction lecture is given on sustainability.
Much attention is paid to the principles of 'Green Chemistry' [5] because that gives the students a direct feel for the role chemistry can play. And it offers challenges students like to respond to.
Specific examples worked out in the lecture, and later on used in projects, are:

- the various options to use biomass for energy and feedstock for chemical processes such as
  - products from carbohydrates (C6 chemistry),
  - biomass based polymers (e.g. poly-lactic-acid and cellulose derivates)
  - through syngas production (as example a route to styrene)
- hemp fibres to make high strength composite materials
- organic photovoltaic cells, cheap and easy to produce and use
- novel catalysts for high selectivity for instance enantio-selective catalysis
- lightweight and super strong materials for construction
- new dying technologies and ways to create colours in polymers and textile fibers
- new analytic tools and methods for in line and direct process control, with attention on the fact that to remain competitive, analyses need to be smaller, cleaner, cheaper and faster.

Such examples will to be used through the curriculum for cases and in projects.

An example how a subject is used in the successive years is the vanillin project.
It concerns the production of a synthetic flavour 'vanillin'.
In the first year the students are asked to make an inventory of the environmental effects of the synthesis and production. Students learn to look at environmental (and safety) aspects in relation to the actions and choices made for a specific synthesis and production.
In the second year two possible syntheses are compared taking into account the total chain, starting with the choice of raw materials, wastes generated and effects of the side products. Their capability to look at the total chain, and use of an LCA methodology is tested.
A look at the natural production of vanillin flavour could be included, taking into account socio-economic conditions in developing countries and the influence our 'logic and simple choices' have on those.
In the third year the subject is used in a business-oriented project. As annex the main outline of this case is given. The case serves here in particular to make clear that the view that various actors have on sustainability issues can and quite likely will differ. It offers opportunities to discuss cultural views, business ethics and the fact that communication is often as important as technical expertise in evaluating and solving problems. It is a simple case with role-play but works quite well.

By using the same case again to illustrate different issues, it shows that all those issues are connected, because the information from one project in which the case was used, is needed and influences the issue in another.
Several other cases are used to deal with specific other issues

5. Chemical technology

In chemical engineering the set up is to a large extent the same as for chemistry. More focus is of course on process system integration to reduce the use of energy and reuse materials and water and optimised process control. The specific role chemical engineering has regarding recycling, making renewable resources practically available and to optimise pollution prevention gets specific attention in cases and small 'integration projects'.
Due to present rearrangement of the departments a definite outline for the whole study is not yet available.
Nevertheless much work has been done on the introduction in the first year. That has developed from a text-guided course to a workshop approach.

5.1 Introduction in first year.

We will shortly describe the three approaches that have been used.
All were done early in the first year already.

a. Introduction of general concepts followed by several short projects

Introduction of concepts is done using the 'general introduction module' written as part of the CIRRUS project.
The students are given several cases they have to work out and which are discussed and evaluated with the whole group. The cases are 'simple' issues from day to day life so the students have (mostly) sufficient own basic information and commonly have a personal view.
The following cases were used up till now:
- Shopping bags from paper or PE
- Sustainability at home
- Cleaner fuels for transport

The general outline is that a first inventory is made of opinions and visions of the students. That is afterwards compared their possibly changed view due to the outcome of the project.
The case is split in several separate activities that have to be done in parallel and which results have to be communicated, directly or at the end to get a total picture. The total course is spread over 8 weeks. Some multidisciplinarity, 'system view' and communicative skills are involved already.

The shopping bag case involves a LCA approach, which the students have no knowledge on in this phase, but which they have to work out in a basic form of course for themselves and by literature research. They directly are confronted with a broad range of aspects, which many quite capably and creatively are able to cope with. This personal experience is a good base to work on when they are formally introduced to chain management and LCA.

Sustainability at home case requires them to evaluate such common things as the consumption of energy and materials and the household emissions and wastes that are generated.
Besides they are asked to relate that consumption to 'available environmental space' and ecological footprint. Here aspects as 'rights' and ethics, equity, economic development and technical challenges surface in a first and simple form.

The 'Cleaner fuels for transport' case is more complex. It is based on programs that have run in the Netherlands. In particular the aspect of the 'systems approach' is relevant here.
Aspects the students have to consider are:

- why is traffic becoming jammed, structural and cultural aspects
- what is the total structure around a 'fuel system', eg when changing to a hydrogen economy
- which are the real problems concerning sustainability here, and are they solved by 'just a cleaner fuel'?
etc.
They are now asked to try to look at it as engineers, as policymakers and business people.
This is done later in the first year so they know already to grapple with technical issues, although not so complex is this one. Her too sustainability case can lay the groundwork for further learning in chemical engineering as such.

b. Introduction followed by short tasks and regular presentations by the students
Basis is again the 'general introduction module' of which same parts are treated in successive weeks. The students get small tasks based on the subjects treated after which they have to give a short presentation. The results are discussed.
In this way all major subjects related to sustainable development are being dealt with in an introductory manner.
The cases are the same or comparable as those described above. This approach takes 8 weeks.

c. Introductory lecture eg by expert in the field for outside the university and a workshop
This set up was done with a group of students from different studies. That offered the possibility for more multidisciplinarity in the cases.
Actually the concentrated workshop approach, involving only a few days, is the only (or at least logical) possibility because the structure and timing of the studies. Matching shared hours over a longer period is difficult.

The advantage of an outside expert is that the impact of the information can be larger: "it is not just academic but in companies people are working on these issues".

The workshop had as subject the LCA of a 'simple' household apparatus eg a coffee machine.
It is quite possible to address a multitude of sustainability issues in this way, form energy, choice of materials, production process but also business ethics, equity and global economics. So it is integrates the different issues into a 'systems approach'.
It further can show that broader sustainability is not just an issue for large multinational companies.

Conclusion
In view of the results obtained and the reactions by the students all three approaches seem to have their advantages.
The relevant issues are treated to their fullest extent in the second one. The first and the third one had the most appeal for the students. The plan for the future curriculum is now to combine the last two in particular.

For the coming year a program is therefore containing the following components:
- Introduction, when possible with a role for an outside guest-lecturer
- Workshop
- Short tasks to be done in a week followed by a presentation

The subjects of those tasks are parts of the 'daily life' cases as described in the first approach.

<u>5.2 Implementation in the main phases of the study.</u>
The curriculum Chemical engineering is presently being adapted. Problem oriented learning and self-study based on projects in small groups will become major components.

As discussed that is a perfect environment to integrate sustainability issues. Several projects and cases will be made around specific sustainable technology developments.
In all projects students have to make explicit in what way they have involved the 'People, Planet, Profit' triangle in assessing the problems and defining the solutions.
In that way sustainability becomes an integrated and 'normal' part of the design process.

Furthermore, as said already in all modules involving energy, materials, resources etc. the relation with sustainability will be made and the specific knowledge and tools required are treated specifically there.
Specific modules on safety, environment and regulations, and on business operation do exist. These will be adapted such that they cover sustainable issues that fall in their area, in particular also the 'non-technical' part of sustainable development.

6. Results, discussion and suggestions

Sustainable development is easily introduced in chemistry and chemical engineering. Actually in our opinion they have a strong connection, not only because C&CE is involved in much of the issues but also because of 'history'. Chemistry and chemical industry are strongly linked to the environmental issues that form one of the 'pillars' of sustainable development. There is therefore much affinity for it. It is one reason more why sustainable development must be integrated in C&CE studies.

Students proved to be in general quite interested, curious for new developments and co-operative. They were open minded to the concepts of sustainability and acknowledged in informal discussions its importance. They take part in the workshops and in the projects, which are done as introduction, commonly with much zeal and quite motivated.

Nevertheless it appears to be difficult to translate the broad, global, and therefore sometimes abstract features of sustainability to a more practical and operational level. A lot of students seem to have difficulties with this. The question whether sustainability has really been internalised in their 'thinking and doing' still remains.

A repeatedly occurring discussion is the apparent problem of 'introducing new subjects' in studies too crammed with subjects. Based on our experience and the proper arguments are:
- priority setting when selecting subjects and the extent they are dealt with is a normal situation: the outside world changes, so must the study.
- the major change that is needed concerns the 'mind-set' and attitude of students and the new conditions that are to be observed when developing and designing products and processes.
- many aspects and items relevant for the sustainable issues are already part of the normal subjects dealt with. It is more a change of scope then of subjects.

Based on our experience the conclusion can be that the impact in time is not too large and crowding out of subjects does not really need to be large. Much background information has to be gathered anyhow by the students themselves when doing projects and cases.
The shift in focus towards a 'systems approach' and multidisciplinarity can be achieved to a large extent by selecting suitable cases for projects and problem oriented learning. There is no need for time consuming extra courses.

Further information
Specific and detailed information on set-up of courses, learning materials and experiences is available through the project website ' www.projectcirrus.net ' (however only in Dutch language)

A final remark and contribution to the discussion on the future of chemistry:

As you have seen, the integration of sustainable development studies chemistry and chemical engineering is still unfinished. Progress is intermittently, partly due also to the restructuring of departments and studies that takes place on the same moment. Certainly that restructuring at the other hand offers opportunities for integration too
Notwithstanding the obstacles, we see much profit in the route for integration we chose against a route with separate and 'outside the ordinary' courses, which of course because of their 'isolation' could be set up much more easily and more appeal to outside parties.
The interest shown by the students, and the lecturers, confirms however that sustainability is seen as an essential part, although form and content are under discussion, and always will be.

Secondly, our experience, confirmed by reactions from other universities and industries, indicates that sustainable development and the innovation oriented role in it for chemistry and chemical engineering can provide the study and the profession again with a challenging character that it seemed to have lost. Specific courses and lectures on sustainable chemical development do appeal to many students and others. That could be used more explicitly to increase the attractiveness for the study, which is still rapidly dwindling.
In view of the necessary role chemistry and chemical engineering have to play in sustainable development, that will serve both.

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Annex

An Example: The outline of a Role Play for the Introduction of Sustainability in Chemistry

The case: ***Vanilla from the company Taste***

Its synthetical vanilla flavour contains a substance that is carcinogenic due to the specific production process and the substance is also in the air and water emitted. (specific information is given in a separte leaflet)

Method: discussion by means of roles with specific background information

5 Roles: general manager, research chemist, commercial manager, employee consumers organisation, journalist local newspaper.
Product: press conference organised by general manager and commercial manager for a large group of journalists and representatives of consumers organisations, in which a solution will be presented for the problems facing the company in order to safe the company's image.

Time schedule:

- 5 min handing out en explaining roles *to the entire group*

role play:

- 20 min discussion on the problem *in own small team*
- 10 min preparation of the press conference *in own small team*

press conference:

- 30 min performing the press conferences *to the entire group*
- 5 min final discussion on the case *with the entire group*

role 1: Research Chemist

***Characteristics*:**

- Performs research on preparation and extraction of vanilla
- Is the only one with substantial expertise on vanilla production
- Looks for solutions for technical problems (trouble shooter)

Tasks:

- During the role play the researcher tries to inform the manager and the commercial manager as good as possible with the information below;
- During the press conference the researcher remains at the background as a consultant for the commercial manager.

role 2: General Manager

***Characteristics*:**

- Supervises the division Flavours
- Stimulates people to solve problems
- Knows some things about chemistry, but relies mainly on his/her expert.

Tasks:

- During the role play the manager will lead the discussion.
- During the press conference the manager leads the discussion between the journalists and the marketeer.

role 3: Commercial manager

Characteristics:

- Develops new applications for flavours
- Takes care of the advertisement
- Is the spokes man/woman of the company, takes care of PR

Tasks:

- During the role play the commercial manager must prepare the press conference for the company. It is his/her duty to avoid as much damage as possible to the image of the company. In order to explain the solutions the company has come up with he/she puts a few key notes on a overhead sheet.
- During the press conference the commercial manager performs a short presentation and answers questions from journalists.

Role 4: representative consumer organisation

***Characteristics*:**

- Performs control tests to food products, e.g. from Taste.
- Rapports irregularities to society, including journalists.

Tasks:

- The role-play starts when the representative of the consumer organisation reveals the discovery below to the public. After that the discussion in the small team can begin.
- During the press conference the employee consumer organisation can assist the journalist in putting questions when another team performs their press conference. During the press conference of his/her own small team, the employee does not play a part.

Role 5: The Journalist

***Characteristics*:**

- Is seen as troublemaker by the company and is very critical;
- Suspects the Consumer organisation to have found something and puts sharp questions

Tasks:

- During the role play the journalist should follow the discussion closely and formulate critical questions with regard to public health and environment, etc
- During the press conference the journalist puts sharp questions to the other teams, when they perform their press conference.