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Biotechnology Education in Schools

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When students deal with Biotechnology in Science or Biology courses at school they get to know a technology that is on the one hand very old – if we think of techniques of making bread or wine – but that on the other hand - when we think of genetic engineering for example - comprises very new aspects. This "modern" part of biotechnology shows a high potential for solving various problems of our modern world but at the same time it is accompanied by new and especially ethical questions and problems. From the high relevance as well as from the ambivalence of the topic biotechnology a particular responsibility of the science subjects at school concludes. This is the responsibility to – on the one hand - inform the students in a sound way of the scientific and technical aspects of biotechnology and – on the other hand - to qualify them as the decision makers of the future to cope in a reasoned way with the chances and the risks of biotechnology.

From a pedagogical and from a didactical point of view school education must deal with the basic knowledge as well as with the effects of Biotechnology. In addition its aim should be to improve the students ability of reasoned decision making in respect to this technological field. Education should lead the students to a basic understanding of the methods, the achievements and the effects of biotechnology on the one hand. On the other hand on the basis of this knowledge it should help the students to find own, justified decisions in respect to this topic and to act in a corresponding way.

As the knowledge in the life - sciences has exploded during the last two decades, for science teachers it is necessary to restrict to the main fields of biotechnology for teaching. However, the central application fields of biotechnology (pharmaceutical industry, medicine, farming, nutrition and environmental technology) as well as the procedures (*i.e.* genetic engineering, cell culture techniques, cultivation of microorganisms) should be taken into account. Out of the variety of all the procedures that are summarized under the term biotechnology genetic engineering is still one of the most discussed. Especially because of its potential significance for the future in the following the examples for teaching biotechnology will focus on this technique.

In this article first examples for teaching (traditional) biotechnology topics and examples for experiments are described for school education on different levels. For many biotechnological methods microorganisms are used. As microorganisms and especially bacteria play such an important role in biotechnology they are central for the understanding of this technique. As many research studies in biology-, chemistry- and physics - didactics show, pre-educational students' conceptions have an important influence of the learning outcome of students. As an example the results of an empirical study on students' preconceptions of bacteria and consequences for teaching – in this context especially of teaching biotechnological topics – will be shown. Beside this cognitive aspect of learning the motivational aspect of learning processes must be considered. Especially the interest in the particular topic that must be learned is very important for the learning outcome. To give an insight into this aspect of learning biotechnological issues the results of an empirical study on students' interest in gene technology are described. In the following hints for teaching materials on biotechnology are given. One important characteristic of the topic biotechnology in school education is the fact that it is such a complex issue that it should be taught in an interdisciplinary way. Ethical questions can not be excluded when teaching gene technology for example. Therefore finally a tool for discussing ethical problems in a structured way – an ethical analysis – is described and illustrated in a specific example.

Examples for Biotechnology experiments and topics in the classroom

Already in elementary school traditional biotechnical methods can be dealt with, given that there is a relationship to the everyday life of the students, *i.e.* the application of biotechnology in food production (Table 1). By carrying out experiments with microorganisms students make the experience that these creatures play an important role in food production, and they learn to look onto microorganisms in a differentiated way. In addition the meaning of fungi, bacteria and of other small organisms for decomposition can be shown by investigations of compost.

On middle school level biotechnological processes can be integrated into the topics "ecology" and the education in environmental problems, *i.e.* in the meaning of microorganisms as reducers in the nitrogen cycle. In the context of health education bacteria, funghi and viruses are dealt with as pathogens that cause infections.

When talking about human physiology with about 15 year-old students, enzymes and enzyme technology can be picked out as a central theme. By easy experiments, *i.e.* the degradation of pectin in the context of juice production, a connection can be made to economically important fields of Biotechnology. On this school level also the topic breeding - especially modern ways of cultivation - can be a linked to Biotechnology.

On high school level the students ought to deal not only with applications of biotechnology but as well with the historical development of biotechnological knowledge. They are to know the main methods used in biotechnology and they must learn to judge in a reasoned way the (very often) ambivalent application possibilities of this technique. This means that ethical and social aspects of the complex topic biotechnology must be integrated in the science classes.

Research on preconceptions of bacteria and consequences for teaching

Microorganisms are indispensable for biotechnology. As we know pre-educational students conceptions of the topic to learn are very much influencing the learning process in the way that they hinder the acquisition of the scientific conceptions. Therefore it is necessary to find out students' preconceptions on microorganisms and to integrate them in teaching programmes about microorganisms and biotechnology.

Students' preconceptions of microorganisms in general and on bacteria in particular are hardly considered in literature. Williams and Gillen, 1991 as well as Gillen and Williams, 1993 report that in general microorganisms are regarded as pathogens, and Corner, 1992 writes that in respect to bacteria the term mutation and mutant are being confused. Considering the important role bacteria have, regarding the education in the upper secondary level about biotechnology – including genetic engineering – we investigated preinstructional conceptions of 17-years-old-students about bacteria in detail (Bayrhuber et al. 1997). The investigation was carried out by interviews following the method of White and Gunstone, 1992 for "interviews about concepts". This interview form was developed by the authors in order to sum up all the knowledge entities a person has concerning a certain term. For White and Gunstone it is decisive that the knowledge of a person concerning one term does not consist only of propositional parts but that it is determined by attitudes, opinions, own experiences and mental images. For being able to take these aspects also into consideration in interviews the authors use a categorizing system of different types of knowledge in respect to the common cognitive-psychological presumptions about knowledge representation and thinking processes. This includes mainly propositions, images and episodes, and in addition intellectual and motor skills. Following White and Gunstone, 1992 already the knowledge about a single term is a function of the multitude of the different types of knowledge that a person relates to it. In conclusion the sum of these elements constitutes the understanding of this term. Because of the subdivision into different categories of knowledge the 'interview about terms' suits also (and especially) for the analysis of preinstructional students' conceptions, *i.e.* for the pre-instructional knowledge the students have about a certain issue when they come to school; since students' conceptions include besides propositional knowledge about facts especially everyday experiences (like episodical knowledge) and mental images. Conclusively White and Gunstone use this technique for the investigation of the pre-instructional knowledge of students.

The interview guideline we used in the main study was developed on the basis of ten interviews with students of the 11th grade. In the main study interviews were carried out with fifteen students of the 11th grade about their knowledge on bacteria. The answers the students gave during the interviews can be categorized as follows: taxonomy of bacteria, comparison with other organisms, features of bacteria, occurrence of bacteria, fighting bacteria and the meaning of bacteria for biotechnology. In this context we will only outline the results concerning the occurrence of bacteria and the meaning of bacteria for biotechnology.

The students' ideas where bacteria occur in the human body are very diverse. The students let bacteria play a role in several organs of the human body. First of all there is their role in the intestine. 4 students make remarks about a role of bacteria in digestion. One student mentioned the idea

that bacteria absorb noxious agents. A similar remark was made about the role of bacteria in the liver ('Bacteria in the liver process "unwanted" molecules'). Another student expresses the idea that bacteria in the liver play a role in the purification of the body. The general as well as the detailed ideas about bacteria in the liver are incorrect. Bacteria only play a role during digestion by the production of vitamin K. Students not only made remarks about the role of bacteria as 'purification assistants' in the liver but about the role of bacteria to purify blood as well. These remarks show the lack of understanding about the human immune system. According to the students' ideas bacteria also play a role in the production of bile. They think bacteria enhance the effectiveness of bile. A great number of remarks applies to the meaning of bacteria for the activity of the human stomach. 3 students give bacteria a role in the digestive process. In relation to gastric juice one student states that bacteria use it for nutrition. Other students think that bacteria can survive the gastric juice by the use of their own immune system. Furthermore one student remarks that bacteria survive the acidity of the gastric juice by using the mucous membrane of the stomach. This is correct for Helicobacter pylori but it is not sure that Helicobacter pylori is meant.

Altogether, according to the students interviewed, bacteria are present on the skin, in the eyes, blood, intestine, bile, liver, stomach, kidneys and 'organs in general' (Table 2).

Beside the human body students mention the soil as a place where bacteria live. This general idea is correct. Besides soil the following excorporal places are named: dirty places, swimming pools, glass, living creatures and air. The students name food that is prepared with the use of bacteria like yoghurt but as well they mention food that is not prepared with the use of bacteria like wine or beer. This finding suggests a partially correct general idea of the use of bacteria in the production of food.

Concerning bacteria and their relation to diseases, 2 students mentioned that bacteria secrete toxic substances. 2 students relate bacteria to diarrhoea. Another student makes bacteria responsible for the weakening of the immune system. The following diseases including corresponding toxic agents are mentioned: cholera – contaminated water, malaria fever – stablefly. Besides these illnesses the following are named: cold, flu, pneumonia, ulcer and tonsil inflammation. These remarks indicate detailed ideas about bacteria and their relation to illnesses.

As mentioned above students connect the production of particular food with bacteria. The first biotechnological process students connect to bacteria is the purification of water. They state, that bacteria purify water by decomposition of chemicals. This is a scientifically correct idea. Besides chemical purification one student mentions mechanical purification. This is correct as well since water is enriched with oxygen in a mechanical way. 2 students mention chemical purification of water explaining that bacteria are killed by added chemicals. The remarks relating to molecular genetics are very diverse. One students names resistance, another one the restoration of races as a result of molecular genetics. The statements are very general and only roughly correct. More detailed and correct is the statement that races are restored by the fusion of genetic factors. 4 students name manipulation of genes as a description for molecular genetics. 2 of these name the incorporation of resistance against a disease as characteristic. One student names the testing of medicines as characteristic for molecular genetics. One student makes detailed remarks about genetics talking about the extraction and modification of chromatine. Two remarks are made about methods for the transfer of DNA namely via bacteria and via viruses. These results indicate a partly deeper idea about molecular genetics.

Concerning molecular genetics the students were asked as well for their opinions toward this technique and its applications. Negative opinions and positive opinions were given equally. Anyhow, the results indicate that students with negative remarks about molecular genetics took ethical aspects into their consideration rather than the ones that showed positive opinions concerning the issue.

Students' interest in Biotechnology topics

Interest in and attitudes towards the topics to be learned have a clear cut effect on the learning outcome of students. Todt and Götz, 1998 conducted an empirical study in which they captured students interest in and attitudes towards biotechnology and gene technology in particular. In this quantitative study they used questionnaires. The results showed that the interest of students in genetic engineering develops at an age of about 16. Girls of this age are more interested in social and ethical aspects of the topic, boys' interest, however, is directed towards economical and technical aspects. This interest is little knowledge-based. It is more a kind of curiosity and a general openness towards a new technology. The interest in genetic engineering develops parallel to the interest in other general social issues. Media seem to have more impact on the development of interest in this technique than science education at school. The students show a particular interest in advantages and disadvantages of gene technology, in its risks, in application possibilities in medical care, in the maintenance of world nutrition as well as in ethical questions. The youth shows a less interest in the application of gene technology in animal and plant production.

Between the interest and the negative attitudes towards gene technology there are more or less no meaningful (negative) correlations. In respect to the use of genetic

engineering in environmental protection and for the diagnosis of hereditary diseases hopes prevail; in respect to the use of gene technology for plant and animal production as well as in connection with the release of genetically modified organisms students' fears are higher than their hopes. Students see risks in connection with the abuse of gene technological knowledge and in the possibility that gene technology could get out of control in research as well as in its different application fields. The acceptance of genetic engineering is very differentiated. Most of the students interviewed ask for a sound public information about risks, about control mechanisms, and about ethical aspects before a decision on the genetically modification of an organism or species, respectively, is taken. Students show a serious interest in a sound informing on the topic gene technology. Todt and Götz, 1997 give a detailed overview on the hopes and fears of students concerning the various applications of this modern kind of biotechnology.

Material for teaching Biotechnology in schools – The European Initiative for Biotechnology Education (EIBE) as an example

Several investigations in Europe show that citizens are very critic whether their governments and other public committees can cope with the risks of biotechnological applications (Eurobarometer, 1993; Bauer et al. 1997). As a reason for this findings a lack of sound information of the public is seen. As a reaction to this results in several countries of the European Union the topic "Biotechnology" has been integrated into the school curricula. This fact led – among others – to a project called EIBE (European Initiative for Biotechnology Education) that was financed by the European Commission. The aim of EIBE is the information of the public – and of school students in particular - on Biotechnology (Grainger, 1996). About 25 teaching units on different biotechnology topics were developed by international groups of scientists and educators. They are published in the internet under the address http://www.rdg.ac.uk/EIBE/ENGLISH/INTRO.HTM. In these materials information for teachers, student activities and materials for students as well as hints for literature etc. are combined. One characteristic of the units is their multidisciplinary approach. Not only the science aspects but as well ethical, social, legal and economic questions related to the topic in question are integrated in the materials. Examples of the materials that are dealing with a wide range of biotechnological issues are shown in Table 4.

Ethical aspects of biotechnology – how to teach them in biology classes?

As has been mentioned before when teaching biotechnology at school the topic can not be restricted to pure science aspects. Especially social and ethical questions related to the topic are the aspects students are mostly interested in and occupied with. When teaching a biotechnological issue in school we therefore must differentiate two dimensions: the descriptive-explicative dimension, that deals with scientific facts and methods on the one hand and that can be judged as right or wrong; and on the other hand the normative dimension that deals with the moral judgement of human actions that can be judged as morally good or bad. With this second dimension the teaching aim is connected, to improve students' ability of moral judgement. This term means in this context the ability to decide in a dilemma situation between two values – *i.e.* the health of a human being versus the health of an animal - in a sound way. To give the students a structure for their argumentations we define to higher categories: the category of welfare of man and/or nature on the one hand and the category of human dignity on the other.

The question, however, is, how to deal with these two dimensions in the classroom with the students in a reasoned way. For this purpose we developed an ethical analysis to help teachers to structure their teaching on ethically ambivalent topics like biotechnology. By using the ethical analysis we try to help the students to develop a reasoned opinion towards a particular topic of biotechnology. In addition the students shall get a pattern at hand how he or she can develop a sound opinion in normative questions.

The ethical analysis can be structured in the following steps:

1. Formulation of the dilemma;
2. Finding out the possible options of action in this situation;
3. Assignment of the optional actions to values that are touched by the action and reflection of the consequences;
4. Taking a justified decision for one of the options of action in respect to the reflections in step 3;
5. Assignment of the decision taken to one of the two higher categories of argumentation;
6. Description and discussion of the consequences of the decision taken in step 4 for the individual and for the society.

A question that could be dealt with in the classroom – after teaching the students knowledge on DNA and basic molecular biological methods - by ethical analysis is for example the question whether human DNA should be made patentable or not. When using the ethical analysis it is indispensable that at first the students get information on the topic; this means the descriptive-explicative dimension must be considered as the basis for the ethical reflection. In this case the students must for example get information on patents.

The three options of action that are possible in this case are:

1. All human DNA-sequences must be patentable, no matter whether their function is known already or not;
2. Only DNA-sequences can be made patentable, which function is known;
3. DNA-sequences may not be made patentable at all

In the next step the students assign values to these three options that are touched by the particular action respectively. In this example this could be the right of self-determination, economic profit or individual health. In the following the students take a decision for one of the options of action and assign it to one of the higher categories of argumentation. The point of reference in this example for self- determination would be the dignity of man; the welfare of man would be the point of reference for the economical profit or for the right of individual health. Finally the students describe the consequences of their decision (see step 6). In conclusion the different opinions that have normally been developed by different student groups in the classroom and their way of argumentation are discussed in a comparative way. A various number of biotechnological issues and the application of the ethical analysis on these are described by Bayrhuber et al. 2001 in detail.

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APPENDIX

Tables

Table 1. Examples for biotechnological experiments in the classroom (Bayrhuber and Lucius, 1992).

School level	Example
Elementary school	Production of yoghurt and sauerkraut.
Middle school	Experiments with and microscopical investigations of yeast and yeast dough. Gradual formation of lactic acid in sour dough. From juice to wine, from wine to acid.
High school	Enzyme-Linked-Immunosorbent Assay detection of the Pelargoium Flower Break Virus in Pelargonium leaves. Hydrolysis of l-DNA by restriction enzymes and separation of the DNA-fragments by gel electrophoresis. Production of citric acid. Comparative protein analysis.

Table 2. Overview of the students' remarks about the occurrence of bacteria in the human body and the role they play in different organs. (n=15).

Occurrence of bacteria in/on the human body	Total number of remarks	Number of students
Occurence of bacteria on the human body	**49**	**10**
Role in the human body	**7**	**3**
Role in the blood	**6**	**5**
Role in the intestine	**34**	**10**
Role in the liver	**6**	**3**
Role in the bile	**2**	**1**
Role in the stomach	**13**	**8**
Role in the spittle	**3**	**3**

Table 3. Students' ideas about the occurrence of bacteria in the body, outside the body, and in food.

Bacteria in the body	Bacteria outside the body	Bacteria in food
Bile, bladder, blood, eyes, hands, intestine, kidneys, liver, lungs, mouth, neck, organs, skin, stomach, tonsils	Air, animals, dirty places, everywhere, fluids, organisms, plants, soil, swimming pool, tables	Apple-cider, apple-juice, apple-sauce, beer, biscuits, butter, buttermilk, cheese, dirt, faeces, leftovers, milk, yoghurt, wine

Table 4. Examples for units developed by the European Initiative for Biotechnology Education (EIBE). Each unit is available in English and in several other languages as well.

Microbes and Molecules	Transgenic Plants I + II
DNA Fingerprinting	Transgenic Animals
Biscuits and Biotechnology	A Model European Council
Issues in Human Genetics	Novel Food
Fermentation Technology	Human Genome Project
DNA Model	Biotechnology and the 3rd World
Debate of a Personal Dilemma	Environmental Biotechnology
Practical Immunology	The EIBE-Family