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Broadening the Aims of Physics Education

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Introduction

In December 1970 the annual conference for Dutch physics teachers was devoted to Harvard Project Physics. A few draft copies had circulated in the Netherlands and the lucky ones who could get hold of the materials reported to the conference about its flavor. The audience was excited about this approach to physics education, especially about its cultural and historic context, the readers and the practicals. It was felt that we needed such materials for our students to make physics as attractive as it could be in our view as teachers.

Following this conference a proposal was sent to the government for funds to finance a project in which the good ideas from the new physics curriculum waves (PSSC, PP, Nuffield) could be made available to Dutch physics teachers through materials.

Funds became available for curriculum development with, however, the condition that work should start for junior general secondary education in which physics is a compulsory subject. The project started in 1972 and was named PLON (a Dutch acronym for Physics Curriculum Development Project). Its main task was to modernize and update the existing physics curricula. Its field was limited to physics as in the Netherlands the sciences were (and are) usually taught as separate subjects, both in junior and senior secondary schools. In the first years the PLON team consisted of three curriculum writers (physics teachers), one evaluator (psychologist), a technician and a secretary. In later years the team was more than doubled according to the same ratio.

Some more changes took place in the course of the project (1972-86). In the first years a lot of inspiration was found in American, British, Australian and German projects and work was limited to junior physics. In the second half of the project's lifetime the materials got their own distinct style and conceptualization and most attention went to senior physics materials. At first the materials were strongly related to the local environment of the pupils and to the technology surrounding them. Later, in both junior and senior curricula more attention was paid to the interaction between physics, technology and society (STS).

A chapter is not appropriate to describe all of the curriculum materials, teachers' guides, evaluation results, implementation, classroom experiences, etc. We have decided to limit ourselves to *the broadening of the aims of physics education towards STS*, to those products which have a clear STS label, to some of the problems faced by the team to write and rewrite materials and to some of the evaluation results. Finally we will draw some conclusions about our experiences in the PLON project and indicate along which lines we expect to be able to increase the quality of the materials in future.

A Broadening of Aims

A Shift of Emphasis towards STS

In general, physics education for students aged 12-18 in the Netherlands (but not only there) emphasizes the development of some scientific skills and an adequate mastering of scientific concepts, in order to lay down a solid foundation on which students can rely when entering those forms of tertiary education in which physics knowledge and skills are considered essential. Teaching physics in secondary schools therefore is aimed at preparing students for further education at tertiary level.

As a consequence most physics courses – also for the lower ability levels within secondary education – can be characterized as having a rather *academic*, theoretical nature based on the structure of physics as an academic discipline; little or no attention is paid to technological applications and to social implications of science and technology, and possibilities for adapting (parts of) the course to the different needs of individual students are lacking.

However, only a few students are, in due course, going to become scientists themselves. For the majority of the students physics is a difficult and alienated subject, having little or no practical use after they have left secondary school.

During the 1970s this type of physics education (but also other school subjects) started to be questioned, not only – or primarily – by teachers, but also by different pressure groups in society.

A growing number of teachers adopted the idea that *relating physics to everyday life phenomena* (be they technological or natural) would make physics teaching more interesting for their students, thus countering the decreasing motivation among students (related to a number of social changes, one of these being the increasing percentage of students entering some kind of general secondary education as opposed to vocational training). Another possibility for countering decreasing motivation was seen by the teachers: providing more opportunities for *individualized learning of students*, for accommodating differences in interest and abilities among students. At about the same time different pressure groups in society started asking for attention to technology within the existing school curricula. Some groups argued for this change in order to make the students (more) aware of the *importance of science and technology for maintaining a sound economy*, thus countering the increasingly negative image of industry due to its detrimental impact on the environment. Other groups used this impact on our environment to argue for attention to be paid to *alternative technologies and an ecological lifestyle necessary for survival in the long run*.

The tension between economic and environmental considerations led to a growing intensity of public debate, at first focusing on our energy future but very soon extending to more general discussion of the impact of scientific and technological developments on society in fields like (nuclear) armament, information technology, genetic engineering, etc. At the beginning of the 1970s some optional STS education started to develop at university level: STS courses were developed and taught, research started to deal with questions put forward by trade unions, environmental pressure groups and the like. The increasing societal debate on (the impacts of) science and technology and the emergence of STS at university level led to a growing pressure, both from within and from outside the secondary educational system, to *prepare students for a better understanding of the public debate and to provide them with the ability to take part in it in an informed and balanced way*. Education had to broaden the students' vision and had to present a framework for structuring the muddle of unbalanced, biased and fragmentary topic-of-the-day information on these complex socioscientific issues, had to provide some tools to help to make decisions on a (preliminary) point of view or course of action.

Internal and external pressures on the content of science education have led to a debate whether science education should broaden its aims and no longer concentrate mainly on the few students who will study science at university level. This debate not only takes place in the Netherlands, as can be seen from policy documents[1] of the Association for Science Education in the UK and the National Science Teachers Association in the USA, reports of the Science Council of Canada and English Examination Boards as well as numerous proceedings of conferences during the last decade.[2] The PLON project has been influenced by this debate, and the aims of physics education as stated within the project team have evolved over a number of years into a balance between:

- *preparing students for coping with their (future) life-roles as a consumer and as a citizen in a technologically developing, democratic society* (emphasizing the use of physics as one of the tools for decision making at a personal and at a societal level and contributing to (more) thoughtful decision making);
- *preparing students for further education and/or (future) employment* (emphasizing an adequate mastering of scientific concepts and skills and providing an orientation on the use of scientific knowledge in different societal sectors and types of further education).

Development of Teaching Materials

The broadening and balancing of aims in a number of cases has led to the development of STS courses, to be taken by students in parallel with (or instead of) academic science courses.[3] Although the PLON project recognized the importance of these separate STS courses, we felt they might not be sufficient to solve some of the problems students experienced with the academic courses. This feeling has led to the development of physics curricula in which a specific integration of physics, technology and society was striven for: curricula based on both the good features of an academic course in physics and of STS courses about the impact of science and technology on society.

The PLON project intended to construct teaching materials which:

- contain physics (basic concepts and skills) which in useful in everyday life regarding decision making situations on a personal and societal level, *and – at the same time –* which is essential for those who continue studying physics in tertiary education;
- present an authentic view of physics, by paying attention to the history, the nature and the methods of physics;
- recognize the differences among students in interests, abilities and plans for the future;
- stimulate students to be actively involved in experiments, literature investigations, data retrieval and analysis, etc.

So far, we do not claim to be very original: others have argued in rather similar terms. However, we have had the opportunity to put our ideas into practice on a scale which is rather unusual in the 1980s. Some forty teaching units were developed and used (and are still being used) in the classroom (see Table 1). And in a number of these units physics is dealt with in a *personal, social and scientific context*, in order to make students aware of the relevance but also the limitations of physics as a scientific discipline, in order to make physics socially relevant.

Table 1: PLON teaching units for secondary education

	All ability streams		
Grade 8	A First Exploration in Physics Men and Metals Working with Water Living in Air Ice, Water, Steam		
Grade 9	Bridges Seeing Movements Colour and Light Electrical Circuits Reproducing Sound Water for Tanzania Energy in our Homes Energy in the Future		
	Lower ability stream	Average ability stream	Pre-university stream
Grade 10	Forces Traffic and Safety Stop or Keep Moving Heating and Insulating Switching and Controlling Machines and Energy Nuclear Arms and/or Security Review for Final Exam	Comparing Weather Changes Music Traffic Electrical Machines Energy and Quality	The Human Body Music Traffic The Weather Energy
Grade 11		Matter Light Sources Ionizing Radiation Electronics Review for Final Exam	Sports Electric Motors Work and Energy* Physics around 1900 Automation Particles in Fields* Ionizing Radiation * systematic units
Grade 12			Satellites** ** remainder of units for grade 12 still in the course of development

All units consist of a student's book, a teacher's guide and a technician's manual. All course material is written in Dutch. So far only two units have been translated in English: *Bridges* and *Water for Tanzania*. At the moment more work is being done in this field: a grade 9 physics course based on a number of PLON units is being developed in the UK and the units *Light Sources* and *Ionizing Radiation* are being translated/adapted in Canada and Australia.

The examples in the following section will provide some idea of how we tried to translate the above mentioned broadening of aims into teaching units for classroom use.

Examples of Teaching Materials

It is not possible to present a detailed description of each of the units with an STS label. To illustrate the general format of these units we will describe one of them in more detail: the unit *Ionizing Radiation* (grade 11, average ability and pre-university streams). After that we will give a shorter description of several other units. (Other units have been described elswwhere.[4])

General Format of a Teaching Unit

The general format of a unit is pictured in Figure 1. The central theme in the unit, *Ionizing Radiation*, is the acceptability of the risk of applications of ionizing radiation.

The unit starts off with an *orientation*, introducing a number of everyday life situations in which the use of ionizing radiation might be an issue, and giving an idea of the nature of the risk concept (a combination, but not a straightforward one of probability and effects).

The next part contains *basic information and skills* about the nature, effects and sources of X-rays and radioactivity. Concepts important in risk assessment are introduced, such as half-life, activity, dose, somatic and genetic effects.

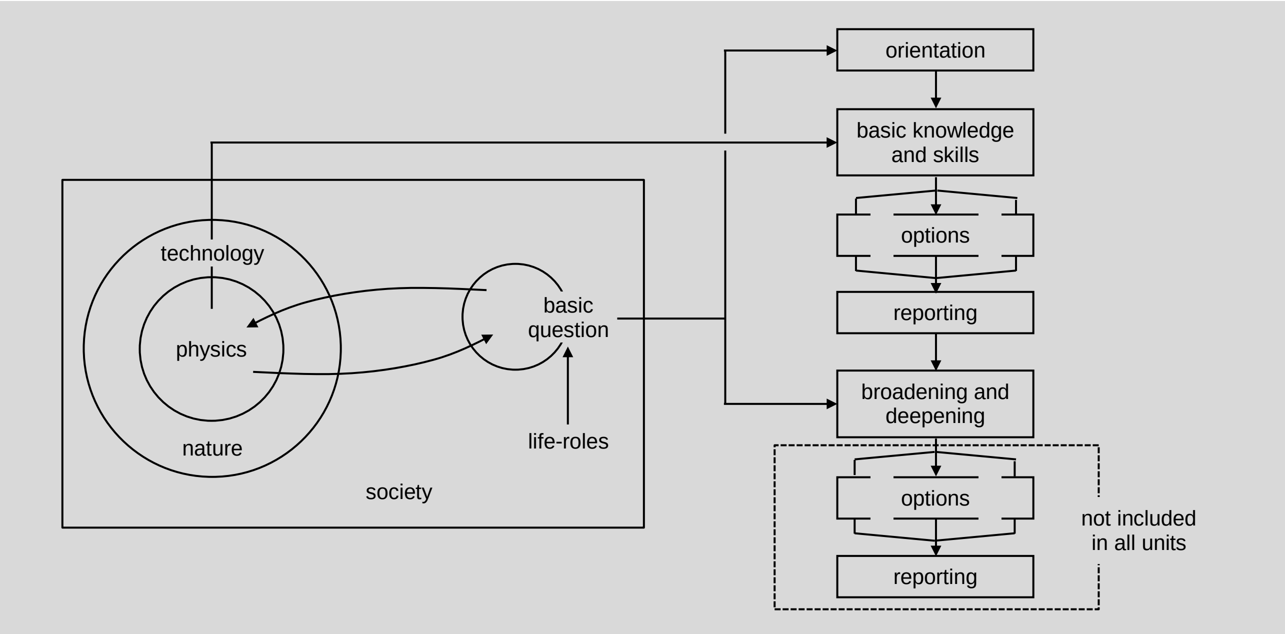
After dealing with the basic information, groups of students start to work independently on either one of the three *options*: nuclear energy, nuclear arms and the use of radiation for medical purposes. Background information on risk and safety aspects of each of these areas of application is given or collected by the students. In several subsequent lessons, students *report* their findings to other groups in class.

In the final part of the unit (*broadening and deepening*) procedures are dealt with to analyze and evaluate personal and societal risks, like being prescribed a brain scan or like the dumping of radioactive wastes into the ocean. A framework for evaluating risks is presented through a series of questions on advantages, on short and long-term risks with and without the specific application and on possibilities for risk reduction.

In addition to the general format as described above, the role of physics (concepts, laws, models, etc.) in a unit is identified. A *basic question* – taken from the society students live in, and regarded as relevant to them with respect to their (future) life-roles as a consumer and citizen in society – is stated in the orientation of a unit (in the case of *Ionizing Radiation*: *How acceptable are applications of ionizing radiation to you?*). This basic question acts as an organizer for the series of physics lessons and determines the physics knowledge and skills to be taught in order to be able to find some (preliminary) answers to the basic question. (In this way the basic question also acts as a selection criterion for the physics content.) After that, the basic question turns up again in the last part of the unit, in which the physics concepts and skills are broadened and/or deepened by applying them to situations in which the basic question is prominent: does the physics taught help in finding answers, help in being able to cope with a technological device, a consumer decision, a socioscientific issue? This turning back to the basic question – to society – is essential because it reflects the relevance of our physics teaching.[5]

Some units have an optional part at the end, meant to acquire a certain skill (for example, using external sources of information, writing reports). Reporting on these learning experiences might be more informal.

Figure 1: General format of a teaching unit



Basic Questions and Concepts

Three units chosen to further illustrate the broadening of aims outlined in that section are dealing with basic questions related to:

- the (future) life-role of the student as a *consumer* (with the ability to cope with and make decisions about products of science and technology in everyday life on aspects like quality, safety, costs, health and environmental hazards, sensible use);
- the (future) life-role of the student as a *citizen* (with the ability to interpret public debates and to make (more) thoughtful judgments on controversial socioscientific issues);

- aspects of *further studies* or *(future) employment* (of a scientific, technological, or social nature), relevant for the specific group of students (mainly in senior secondary education).

Consumer Physics

Focusing on the use of physics knowledge and skills in situations dealing with the (future) life-role of the student as a consumer, examples can be found in a number of units or parts of units. Most of these situations concentrate on making the best buy or using products in a sensible way.

- Which buy could be best: a filament bulb, a strip light or an (energy saving) SL-lamp? (*basic question* for part of the unit *Light Sources*, grade 11, average ability stream). Strip lights and SL-lamps cost more, but use less energy giving off the same amount of light. Which type of lamp is most economical in the long run? The relation between energy, power and time (physics concepts and laws) and the ability to draw and interpret diagrams (physics skills) are useful to arrive at an answer. Knowledge about the mechanisms of converting electrical energy into light (energy) in the different types of lamp provide a background for an understanding of the differences in light efficiency and colour of the light, and point at possible environmental implications (for example, mercury pollution).
- How might legal measures enforcing the use of seat belts and crash helmets improve traffic safety? (*basic question* for the unit *Traffic and Safety*, grade 10, lower ability stream). Concepts and laws from mechanics are useful for getting an idea of the magnitude of the force acting on a car driver during a collision (as compared to the force the human body can exert), of the way traffic safety devices like seat belts and crash helmets help to prevent injuries by diminishing the force on the driver through lengthening the ‘braking distance’, of the relationship between speed and breaking distance (selecting a safe speed), etc.

Other units deal with topics like fuel economy in traffic (unit *Traffic*), choosing between different means of transport like bike or car, private or public transport (unit *Stop or Keep Moving*), influencing room acoustics in order to improve the quality of (reproduced) sound (unit *Music*) and checking electrical motors in order to be (more) able to carry out small repairs on household appliances (unit *Electrical Machines*).

From the teaching materials dealing with the basic questions related to the consumers’ life-roles it follows that making fair comparisons is not easy at all. Even in what at first seem to be situations involving relatively simple decisions, the number of aspects requiring consideration turns out to be more than expected, for example, not only costs and safety aspects (prominent in most reports on consumer research), but also environmental implications. In clarifying these questions, the teaching materials aim to enable students to avoid naive and misleading choices.

Citizen Physics

From the examples given above on consumer physics it might be clear the distinction between consumer and citizen physics isn’t too sharp. The knowledge about fuel economy can also be used to analyze and discuss the recent (Dutch) debate on increasing maximum speed on motorways (focusing on traffic safety aspects, whereas environmental considerations are not very prominent in the public debate); connected to the individual’s choice of wearing seat belts is the question of enforcing the use of seat belts by law or promoting this use on a voluntary basis at a more societal level, etc. An important aspect of consumer physics is the possibility to translate a (more) informed, thoughtful judgment into direct personal action. (However, whether the student makes a choice, when he/she will do that and which way the choice turns out is his/her own responsibility.)

When dealing with citizen physics the aims are limited to making students aware of the public debate and to provide them with the means to interpret this debate in order to be able to reach a (more) informed, thoughtful point of view on the issue. The possibilities for personal action are more indirect: discussing the issue with others, voting behavior.

In addition to the examples already mentioned under the heading of consumer physics a number of other examples can be found in the units that relate to citizen physics.

- Which type of water pump is most suitable for pumping up drinking water in a Tanzanian village? (*basic question* in the unit *Water for Tanzania*, grade 9, all ability streams). The basic question reflects the Dutch debate on the character of Third World aid programs, in which alternative viewpoints come up: should ready-made industrial products be sent over or should Western countries provide the means for Third World countries to set up their own local industries. In the unit students assess different types of water pump, on criteria having to do with the operating principle (physics knowledge concerning the effects of pressure differences), different technologies (related to the construction and maintenance of the pumps) and social conditions in a typical Third World rural area.

- Can one survive a nuclear war? (*basic question* in the unit *Nuclear Arms and/or Security*, grade 10, lower ability stream). The unit concentrates on the effects of nuclear explosions in the short term (destruction by blast and heat) and in the long term (somatic and genetic effects of ionizing radiation due to fallout), and the (im)possibilities of protection against these effects. The knowledge base consists of the nature and properties of ionizing radiation and concepts like activity, half-life, dose and their units of measurement.

Other units deal with lively debated issues like energy scenarios (units *Energy in the Future* and *Energy and Quality*) and the pros and cons of the micro-electronics revolution (unit *Electronics*), but also with a debate which does not get too much attention: spending money on applied or fundamental scientific research (unit *Matter*).

An Authentic View on Physics

Using physics as a tool to get a more firm grip on everyday life requires knowledge of the *limitations* of this tool. Physics (and science in general) does not give all the answers, not only because there are more factors besides physics influencing decisions (like economic, cultural, political factors), but also because of the nature of scientific knowledge.[6]

The importance of modelling, but also the limitations of the models constructed, is most prominent in the unit *Matter*. However, the matter of the nature of scientific knowledge also turns up in other units: the controversy on the effects of low dose ionizing radiation on the human body (unit *Ionizing Radiation*), the uncertainties in the predicted rise of the sea level due to the greenhouse effect (unit *Weather Changes*). Models describing complex systems like the human body and the global carbon cycle are in no way adequate (yet). Uncertainties give way to different interpretations, also by experts.

The nature of scientific knowledge is explicitly dealt with in the unit *Matter* (grade 11, average ability stream), the *basic question* for this unit being: What is the difference between applied and fundamental research, for example, into the structure of matter – and what about the bill? In order to get an idea of what fundamental research is and for what it might be useful, the unit *Matter* starts with the ideas of the ancient Greek on the structure of matter and going through the centuries finishes off with the quark model and the attempts at unifying the four fundamental forces. The unit gives an idea of the development of physics as a discipline (such as working with models and making order out of chaos), the part technology plays in the progress made in research (from vacuum pumps to super colliders) and of the way in which some physicists left their mark on the development of their discipline. To be able to assess the value of fundamental research into the nature of matter, an idea of what these huge-sums-of-money spending, high-energy physicists are up to is necessary.

Presenting an authentic image of physics – physics as a developing product of human activity, in which objectivity and subjectivity are less separated domains than might be perceived by the general public – is a prerequisite for an adequate assessment of the role physics might play in dealing with consumer decisions and (debates on) socioscientific issues.

Teaching Methods

Next to the questions of ‘why teach physics’ and ‘what physics to teach’ comes the question of ‘how to teach it’. What do we expect students to do during the lessons? Just reading long texts doesn’t very much appeal to quite a lot of the students. In order to hold students’ attention, a variety of student activities stimulating active involvement in physics lessons appears to be necessary. But not only for that reason. The (future) lif-roles of students have a passive and an active component: not only knowledge is required, but also certain skills such as being able to read, watch and listen critically, to discuss, to work independently and to cooperate with fellow students, to communicate learning experiences, to perform experiments and set up investigations, to retrieve and structure relevant information and compare information from different sources critically.

Student activities have to be chosen carefully in order to give students a chance of acquiring these skills: skills necessary on the one hand for being able to do something with the acquired knowledge in practical situations in everyday life, and on the other hand for being able to tackle independently issues that couldn't be dealt with in the curriculum (time constraints) or issues that might come up in society in the time ahead.

So not only contents will have to change, also – and equally important – the teaching methods: less 'talk-and-chalk' by the teacher and more classroom discussion, literature research, interviewing, practicals, etc. The role of the teacher in the classroom changes into stimulating and facilitating independent work of (groups of) students.

Some Problems and Solutions

It took us about thirteen years to develop some forty teaching units. Each of the units has been rewritten at least once or twice, and some three or even more times if that seemed to be necessary. One might say we have been working on a trial and error basis, and what was described in the section on teaching materials, to a large extent, reflects the final product of the last four years of curriculum development aimed at an integration between academic physics and STS.

In this section we will point out some – in our view most prominent – problems during this curriculum development work and some solutions we think we have found for these.

Choice of Contexts

The choice of contexts to be incorporated in the curricula ideally would be influenced by the differences in interests, abilities and plans for the future among students, and by long-term developments in society.

At the level of the curriculum as a whole the different needs of students could be met by choosing a variety of general contexts of a more scientific, technological and social nature. In the first version curriculum the emphasis was a technological one, not too attractive for (mainly) girls. The revision of the curriculum therefore was aimed at diversifying the general contexts raised: units like *Weather Changes* (general context: nature) and *Music* (general context: culture) had to balance the more technological units like *Electrical Machines* and *Electronics*. But also minor changes in existing units appeared, like adding biographies of four physicists working at the end of the nineteenth and beginning of the twentieth century to the unit *Matter*, or – an approach the other way round – the disappearance of the operating principle of quite a number of different types of nuclear power reactor from the unit *Ionizing Radiation*.

So now the curriculum as a whole is more balanced with respect to the general contexts raised. If it is balanced enough remains an open question.

Linking physics to everyday life (at a personal and societal level) carries in itself the danger of the contents being initially timely, but not any more so a couple of years later. Therefore, we tried to choose the themes of our units taking note of long-term developments in society derived from surveys of literature and discussions with a few experts. Within the boundary condition of developing a physics curriculum this has led to the choice of issues on energy, traffic, electronics, armament, space travel and Third World aid. Next to that a relevant overall concept for dealing with quite a number of issues seemed to be the concept of risk. And also the development of physics as a discipline had to be dealt with in order to present an authentic view of physics.

However, the choice of the contexts for the units was not a completely free one. First of all we had to consider the existing nationwide examination programs. Although the project's task was to modernize and update physics curricula and to put forward proposals for changes in the examination programs, one should not get too far away from what is customary within existing physics education. Being innovative in the field of curriculum development is a good thing, but adoption and implementation of the innovative materials by the teachers must remain feasible. Secondly we had to consider the desired variety of contexts in order to accommodate to differences in students' interests.

So, the choice of themes and basic questions for the units carries in itself the character of a compromise between desirability and (to a certain extent limited) feasibility.

Relationship between Contexts and Concepts

In the first years of curriculum development within the project the focus was on developing teaching materials stimulating independent work of students and students' learning from each other's experiences. With regard to the content of the units the aim was to relate physics to everyday life phenomena in the students' immediate surroundings: knowing about the physics behind natural and technological phenomena in the students' life-world instead of using physics as one of the tools for decision making at a personal and societal level. Once teaching materials have been developed, it is difficult to change them to fit into a new set of aims, not only for reasons of limited time, but also for reasons like not putting too much pressure on trial school teachers who have grown accustomed to working with the ‘old’ materials, who have put a lot of energy, time and (school) money into organizing practicals, etc.

Therefore the integration of academic physics and STS as outlined in the previous sections is not visible in all units, and the curricula as a whole have somewhat of a hybrid character. However, the question is whether this integration is desirable in all units. Relating physics teaching to less problematic everyday life phenomena might for instance be necessary for students to be able to tackle decision making at a personal and societal level.

Concerning the units in which the above mentioned integration was worked out to a satisfactory degree, we had some problems with the first version units: abundance of aspects in and weak coherence of the units.

Most themes encompass very complicated problems or large areas of knowledge, and boundaries with other disciplines are sometimes vague. Trying to aim at completeness will be very confusing for students and teachers, and there is a danger of non-physical and non-scientific aspects dominating a unit. One of the units with this problem was the first version of *Nuclear Arms and/or Security*, which had the character of a short introduction to polemology; physics was relegated to an appendix at the end of the unit. Teachers felt uncomfortable with this unit, as they were not experienced in teaching polemology (which is not their fault!). Also the students, although a large majority of them thought that the topic of nuclear armament should be dealt with in school, felt the unit not very appropriate for physics lessons (about half of them). When revising the unit we tried to avoid this abundance of aspects by not aiming at completeness, by keeping in mind what the specific contribution of physics could be to develop an insight into the theme; other aspects should be dealt with in other school subjects (and the physics teacher might be able to encourage this to happen). So the second version of the unit dealt with the effects of nuclear explosions and the (im)possibilities of protecting oneself in such events. If students wanted to look into other aspects, the optional period at the end of the unit could be used for that.

Using the instrument of the *basic question* has been helpful in avoiding the abundance of aspects in the second version units, and has even been more helpful in strengthening the coherence of the units. When the various chapters of a unit are weakly connected to the basic question (if present at all in the first version units) and to each other, teachers easily neglect the innovative chapters and pay most attention to the traditional ones. Adapting to new content and teaching methods takes a lot of time and energy, and one has to be pushed a little bit to make the transition.

So the contextual knowledge (like the framework for thinking about the issue of risk evaluation in the unit *Ionizing Radiation*) has to be very closely connected to the physics content. But on the other hand the physics content must be associated with the contextual knowledge, that is, with the basic question. And here we come across the question: which physics concepts, laws, etc. should be taught and to what depth?

Concept Development

As long as the basic questions for the units are not clearly defined (as in most first version units), the physics content tends to be close to what is traditionally being taught, except when dealing with new physics topics (like the quark model of matter, electronics). Or, in the case of traditional topics, teachers tend to stick to the traditional, well known content and tend to go into the same depth as they used to do.

One example comes from the units *Traffic and Safety* and *Traffic*. In mechanics the traditional approach to describing motion is the use of a set of equations like $\Delta s = v_0 \cdot \Delta t + \frac{1}{2}a \cdot (\Delta t)^2$, $\Delta v = a \cdot \Delta t$ and $F = m \cdot a$. However, in order to be able to understand the way in which traffic safety devices like seat belts and crash helmets do their job, knowledge of the equations $F \cdot \Delta s = \Delta(\frac{1}{2}m \cdot v^2)$ and $F \cdot \Delta t = \Delta(m \cdot v)$ and an understanding of the concepts in these equations are perfectly suitable. Moreover, the equations represent in a very direct way the relationship between the relevant variables. For lower and average ability students there seems to be no need to burden them with the three distinct equations describing accelerated motion with the ‘help’ of an abstract concept like acceleration. And if students need any proof, the two ‘laws of motion’ stated above can be checked experimentally in both outside (real life) and laboratory conditions (which clearly shows that these equations – as well as others – are no more than approximations of reality). In this way, the physics content in the area of mechanics is reduced; but on the other hand sometimes it had to be extended. In the same area of mechanics, motion traditionally deals with point-masses moving on frictionless planes. But in order to get a firmer grip on fuel economy in traffic, dealing with real objects, a quantitative treatment of frictional forces was necessary – a topic which was not traditionally taught.

As long as it isn’t clear that a unit is dealing with *traffic safety* and *fuel economy*, in which mechanics is used as a tool to deal with practical situations in this area, the reduction and extension of physics content gets less attention from the teachers (and sometimes even from curriculum developers).

On the other hand one has to reckon with ‘outside pressures’, for example, from the school inspectorate, to keep standards high (that is, the standards of traditional teaching). Again, in many cases a compromise between the level of concept development necessary for dealing with practical situations in society and the standard level of concept development in the traditional curricula had to be reached.

One problem, however, could not be solved this way. Generally the degree of versatility students reach in applying the concepts, laws, etc. in different contexts is low: concepts developed within one specific context are not automatically used by students when solving problems in another – known or unknown – context. For lower and average ability streams this limited transfer can be accepted to a large extent, because key concepts from the fields of energy and mechanics, for example, appear in a number of units in different contexts. But this is not enough for students in pre-university streams. Their degree of versatility in manipulating concepts should be higher. A solution we found for this problem was the introduction of so-called *systematic units* in combination with the units dealt with up till this point in this chapter, to be characterized by the label of context-centered or *thematic units*.[7]

In a systematic unit concepts developed earlier in a number of thematic units act as a starting point. Concepts from different units are linked and defined more sharply in order to give students (in the pre-university stream) insight into the systematic structure of physics as a discipline (mainly in the fields of motion, energy and work, and gravitational, electric and magnetic fields). Mathematical expressions of concepts and relationships between concepts are much more sophisticated and prominent (as compared to the thematic units) in order to widen their applicability in a variety of different contexts. The innovative curriculum for the pre-university stream now consists of both thematic units (in most cases the same units used in the average ability stream) and systematic units, thus reaching a balance of aims which seems necessary for preparation for university entrance as well as preparation for citizenship.

Student Activities and Differentiation

Stimulating active involvement of students in physics lessons and recognizing the differences among students in interests, abilities and plans for the future can be met by means of introducing a variety of student activities and differentiation within the units.

While developing the first versions of units, most effort went into defining the content of a unit. Of course student activities were present in the units, like (a lot of) practicals. But, apart from that, long texts and associated questions and exercises were used far too often. During revision more attention was paid to establishing a relationship between content and student activities and to the development of a greater variety of student activities: literature research using external sources of information, practical research projects, interviewing experts, excursions, videos and some simulation games.

Different needs of students can be met not only by a variety of student activities, but also during optional periods within a unit. In first version units differentiated parts tended to be either limited to non-essential sub-topics or to be so varied that a fruitful exchange of learning experiences wasn’t feasible. And in some first version units the topics within the optional period were (far) too difficult to be studied independently, let alone to be explained by students to each other. Reporting sessions thus became problematic.

In the revised units the introduction of important concepts in the optional topics is avoided: they must be dealt with beforehand in the basic-knowledge-and-skills part of the unit. Also the topics of the differentiated chapters are chosen in such a way that they are supplementary to each other (for example, dealing with the second law of thermodynamics in either a theoretical, scientific or a practical, technological way in the unit *Energy and Quality*, or dealing with the same concept (risk) in different sectors of society in the unit *Ionizing Radiation*), thus facilitating the possibilities of students learning from each other. An extra incentive towards good quality performance of students during reporting sessions is the necessity to use the learning experiences of all groups of students during the broadening-and-deepening part of the unit.

Some Research Results about PLON

During the course of the PLON project the two research fellows had to work under high pressure from various sides. The curriculum writers wanted them to evaluate the units to get suggestions for improvement, policy people emphasized the need for research which could support their view that PLON ‘is highly successful’ or ‘doesn’t work at all’, colleagues from the educational research field would like to see if PLON experiences confirmed or refuted certain educational theories, and, of course, both fellows had their own interest areas. So difficult choices had to be made and not all needs could be fulfilled.

Evaluation of First Versions

A great deal of work was done in evaluating first versions of units. It soon became clear that the aims of first version evaluation should not be set too high. The new units were so innovative in content and teaching methods that many 'infant diseases' could be detected. For instance management problems arose: equipment wasn't available in time and in sufficient quantities or didn't meet the expectations. Also students were often not sure of what was expected from them in the activities or in preparation of end-of-unit tests. And teachers felt insecure with the new materials: some topics were brand new for them as well, and some units required teaching methods they were not familiar with. Above all, teachers often didn't know what problems they would face with the new materials regarding difficulty, time and practicability.

So, we concluded that the success of a unit could not be measured by its first version. But these first evaluations appeared to be of great use to collect ideas for revision, for teacher guides and for teacher training. The results were seldom published, partly because we thought their use would be limited to those already involved, partly because we didn't like to provide tools to those who would love to abort PLON ideas before they were mature. Many of PLON's best ideas started rather immature and it often took several tries to get them in a proper form.

A variety of methods was used for first version evaluation. Very important were the meetings with the teachers of the trial schools. After each unit we met and discussed the experiences. Teachers appeared to be very creative in finding solutions for the problems caused by the curriculum writers; they also challenged the writers on new ideas so the latter were forced to explain clearly what they were aiming at behind the problems of introduction. A second source of information was the questionnaires we presented to the students. Questions dealt with the instructiveness, usefulness, clarity and difficulty of the unit, their interest in various topics and their ideas about student activities. Finally we visited schools and observed what was going on in the classroom. Visiting schools however is very time-consuming, especially if one would like to observe all lessons in one class about one unit. Therefore, this source of information was used to a lesser extent.

As an example we will describe results of an evaluation study on the use of the first version of *Water for Tanzania*. Six classes were involved. A teacher meeting was held after use of the unit, teachers and students (N = 106) filled in questionnaires and lessons were observed by PLON staff members and trainee teachers. In general this unit was highly appreciated by teachers and students, especially by the girls. Students enjoyed the lessons, in particular constructing and testing the various pumps.

However, two problems were noted: one with the introduction of the unit and one with the simulation game.

The unit starts with an introduction about the country and life in a village. A considerable part of the students didn't like this part and had problems with getting acquainted with life in a Tanzanian village. As judgments of students differed strongly between classes, this seemed mainly due to the way teachers introduced this section of the unit. One suggestion made was to back-up teacher activities in the teacher's guide. Another was to include student activities in which they would get more involved: that would make the introduction less dependent on the teacher's input.

The second problem noted had to do with the simulation game. Students had difficulties in setting proper requirements to the pumps. And in the decision-making stage of the simulation game they got so involved in 'their' pump that a thoughtful balancing of pros and cons did not take place. Students just acted as 'salesmen' of their pump. Constructing a pump led clearly to an identification with the pump which counteracted their roles as evaluators. This result led to the suggestion to set external requirements to the pumps and to ask students each to evaluate one pump on this set of requirements. In the second version of the unit *Water for Tanzania* this suggestion was followed.

Evaluation of Second Versions

Once the first versions were revised and the 'infant diseases' were cured a new round of evaluation started. A great deal of noise was now eliminated, so we tried to get a better insight into the impact of the units on students' learning and on their attitudes towards various topics. For this kind of research a distinction could be made between evaluation of units and curriculum evaluation. The former was aimed at studying learning of a particular physics topic in the context set by the unit. The latter kind of research paid attention to the effects of the curriculum as a whole. Results of this kind of research seemed to be of more interest to others, so more of it has been published, however, often in Dutch. Here we will describe some of the results of second version evaluation of both these levels.

At the unit level two differences from the first version evaluation results were remarkable. One is that some units which were highly criticized by students on the first version became rather popular in the second version. An example of such a unit is the senior unit *Traffic* in which mechanics is taught in the context of traffic. About two-thirds of the students seemed to dislike the first version, mainly because they did not know what was expected of them both in activities and in preparation for tests. Two years later the second version became one of the most popular units. On the main ideas of the unit no changes were made: the same concepts were taught in the context of traffic. But the instructions for the activities were better, the main concepts were properly introduced and a collection of test questions on traffic situations was included. A second difference with the first version evaluation results was a less significant difference between classes. This might be explained with the argument that the confusing first versions demanded more from the teachers in terms of clarification of what was expected and/or that teachers felt more at ease with the unit after having taught the unit before. We haven't been able yet to find out which of these points is most important.

Evaluation of second versions of the units resulted in some more questions in need of clarification. Let us take, for example, the unit *Ionizing Radiation*. In first and second version evaluations it appeared to be a very popular unit, especially the medical parts of it with the girls. In the latter evaluation study pre- and post-unit measurement was done regarding the use of concepts in arguing about controversial statements regarding applications of ionizing radiation. It appeared that hardly any physics was used in arguing about the dumping of radioactive waste in the sea, a fiercely debated topic in the Netherlands. On the acceptability of food irradiation, a less publicly-known topic, we detected afterwards a better use of topics dealt with in the unit. But at the same time it became clear that students had misconceptions about radiation which did not change very much. For instance, students used the word ‘radiation’ where an expert would use ‘radioactive substances’. So one of the questions which arose was what ideas students do have about radiation before instruction. It was decided to study this question in a new research program (see next section).

In one of the studies at the curriculum level we asked students their opinion about the various units. In this study 191 students filled in a questionnaire at the end of a two-year PLON course in senior secondary education (average ability stream).

The results show that students prefer some units more than others. Popular units are those which relate to daily life or specific interest areas of students, for instance the units *Traffic*, *Music*, *Weather Changes* (boys) and *Ionizing Radiation* (girls). Students seemed to be less fond of units which are either theoretical or technological, such as *Matter*, *Energy and Quality*, *Electronics* and *Electrical Machines* (girls).

On the other hand students' responses showed more variety in answering the question: ‘From which two units did you learn most?’ Here their judgments are more spread over the units, especially those of the boys. It was also rather surprising that for some units answers were not in accordance with general preferences mentioned above. So 41 per cent of the boys found *Ionizing Radiation* very instructive; the same qualification was given by 23 per cent of the girls to *Electronics*.

In general, students appreciated the physics lessons with PLON materials. They were especially positive about the student activities and the applied character of the physics. According to them these characteristics should get even more attention and especially students' individual contribution to the lessons should be increased.

Some Current Research Programs about PLON

After the formal end to the curriculum development work within PLON several research projects have been started to study more in depth the learning of particular physics concepts and curriculum effects. Regarding concepts the work has been concentrated on ‘force’, ‘energy’ and ‘ionizing radiation’. In the research project on ‘ionizing radiation’, for example, two points are particularly interesting for those involved in STS education.

The first point is: what particular content should be chosen if the aim is that students should be able to use physics in daily life situations? Often STS materials suffer from an abundance of concepts, facts and processes, and from a chaotic variety of situations in which science plays a smaller or larger role. But by what criteria are they chosen? How can decisions be made to include some applications and leave out others, and to deal with many concepts and processes superficially instead of with a few concepts at greater depth? The answers to these questions cannot come from teachers and curriculum writers alone, as they could hardly be expected to be familiar with so many STS areas.

We have involved some fifty radiation experts in trying to find an answer using the experience of these experts in a variety of professional fields: health, power and other industrial companies, civil service, research establishments and environmental organizations. Currently a three-round Delphi study is being carried out. Of course, it is not the intention to let experts decide what is suitable for science education: they are not qualified to take all necessary aspects into consideration. But we do think that their experience should be made use of. STS education cannot mature in isolation from society.

The second point of interest for STS education has also to do with the de-isolation of science education. From many studies we know that students do have ideas about concepts and processes which have in science a particular meaning. In many areas of physics we have an idea of the kind of pre-concepts students have. But we do not know much about the source of these pre-concepts nor about the daily life situations in which these pre-concepts lead to unfounded conclusions with serious consequences. We could all give some examples of this, but as far as we know a systematic study has not yet occurred. However, it is not unlikely that STS teaching would promote clashes between thinking in 'personal' and 'scientific' domains. Therefore, in our ionizing radiation research program we study the use of scientific concepts in the media: radio, TV, newspapers and magazines, and consult experts on the following kind of questions: which meanings are given to words sounding familiar to scientists and the public, how do these meanings relate to each other, what are the most essential differences, do these differences depend on the particular situations, and what consequences does this have, for instance for an assessment of the risks of ionizing radiation? We hope to be able to use the results to rewrite the unit *Ionizing Radiation* in the future and to write a new teachers' guide.

Apart from this kind of research studies are also carried out at the curriculum level. In one project a longitudinal study is done to detect causes for the change of attitude of girls towards physics during the first two years of obligatory physics instruction. A comparison is made between the effects of using the PLON curriculum and an academic curriculum. Another study concentrates on the impact of two important characteristics of PLON curricula: active involvement of students and physics learning in a daily life context. The effects of both learning environment characteristics on students' motivation and cognitive learning outcomes are being investigated.

In summary we could conclude that the experiences with the PLON curricula have resulted in a number of questions on which answers are required if we want to improve the quality of our curriculum materials in future. Finding these answers will use a great deal of our time and energy in the coming years.

Lessons to Be Drawn

It would be very premature to draw, in 1988, final conclusions about the impact of the PLON project on science education, particularly on the teaching of physics. Processes of change in education take a long time and are influenced by many factors from inside and outside education, such as teachers' salaries, class size, structure of education, job opportunities, teacher training, new examination programs, etc. Innovators' feelings often drift between hope and fear.

At present only students at a limited number of schools (twenty-five) are allowed to take the experimental PLON examinations, which differ from the nationwide final examinations (as the obvious result of the project's task of modernizing and updating physics education). Administrators' fears of the number of schools opting for the PLON examinations (and the teaching materials) getting 'out-of-hand' have put some serious restraints on the dissemination of the teaching materials. However, there are some hopeful signs. PLON experiences have greatly influenced the discussion on new examination programs for physics. Not all programs have been finalized yet, but the new examination program for the lower ability stream clearly incorporates many PLON ideas regarding content and contexts. Also in the drafts for the examination programs for the average ability and pre-university streams much attention is paid to learning in personal, technological and social contexts. This will allow all schools in future to change physics education. Moreover, although the use of PLON materials in classrooms is limited, infusion of PLON ideas in recently published traditional physics textbooks is visible. Students graduating from the teacher training colleges are now familiar with PLON ideas and teaching materials.

However, how big the actual changes in many schools will be is yet unclear. Much will depend on textbook writers and on the enthusiasm of teachers. Recent increases of class size and number of teaching periods, and decreases in both salaries and number of students, are not favorable to changes in the classroom. Unfortunately, curriculum innovators are rather powerless regarding these trends.

Returning from politics to more familiar fields, we conclude that PLON has been able to draw a great deal of attention to alternative content and teaching methods for physics education. However, the project's area has been very wide: complete curricula have been developed for various streams in both junior and senior secondary education, a variety of aims was set and innovation regarded content, methods and differentiation. As might have been predicted, width cannot be combined with great depth. Now we know where more depth is required and so we concentrate our efforts on curricula for special groups (low ability students, high ability students) and special topics (environmental science). We have also learned how important concept development is in teaching physics in context. We hope with research in this field to lay the foundations for further improvement of science education in future.

Notes

1 These bodies have published policy statements as follows: (a) (1981) *Education through Science*, Association for Science Education, Hatfield; (b) (1982) *Science-Technology-Society: Science Education for the 1980s – An NSTA Position Statement*, National Science Teachers Association, Washington DC; (c) (1984) *Science for Every Student: Educating Canadians for Tomorrow's World – Report 36*, Science Council of Canada, Ottawa; (d) (1983) *Recommended Statement of 16+ National Criteria for Science*, GCE and CSE Boards Joint Council for 16+ National Criteria, Manchester.

2 For example: (a) (1978) *Integrated Science Education Worldwide*, ICASE Conference, Nijmegen (the Netherlands); (b) (1980) *World Trends in Science Education*, Halifax, Atlantic Institute of Education; (c) (1981) *UNESCO Congress on Science and Technology Education and National Development*, Paris, UNESCO; (d) (1982) *Second Conference on Science, Society and Education*, Leusden (the Netherlands); (e) (1982) *World Trends in Science and Technology Education*, Nottingham, Trent Polytechnic; (f) (1985) *World Trends in Science and Technology Education*, Brisbane, College of Advanced Education; (g) (1987) *Science and Technology Education and the Quality of Life*, Kiel, IPN.

3 Some current examples of these are: (a) LEWIS, J. (Ed.) (1981), *Science in Society*, London, Heinemann Educational / The Association for Science Education; (b) SOLOMON, J. (1983) *Science in a Social Context*, Oxford, Basil Blackwell / The Association for Science Education; (c) EIJKELHOF, H.M.C., BOEKER, E., RAAT, J.H. and WIJNBEEK, N.J. (1981) *Physics in Society*, Amsterdam, VU.

4 Descriptions of other units are: (a) LIJNSE, P.L. (1983) 'Energy and Quality', paper presented at the Conference 'Entropy in the School', Balaton (Hungary); (b) EIJKELHOF, H.M.C., KORTLAND, J. and VAN DER LOO, F.A. (1984) 'Physics and nuclear weapons: A suitable topic for the classroom?', *Physics Education*, 19, pp. 11-15; (c) EIJKELHOF, H.M.C. (1985) 'Ethics in the classroom – Goals and experiences' in GOSLING, D. and MUSSCHENGA, B. (Eds.) *Science Education and Ethical Values*, Geneva, pp. 68-78; (d) EIJKELHOF, H.M.C. and VERHAGEN, P. (1985) 'A thematic approach to physics curriculum development for senior high schools' in LIJNSE, P.L. (Ed.) *The Many Faces of Teaching and Learning Mechanics*, Utrecht (the Netherlands), GIREP, pp. 411-421; (e) VAN GENDEREN, D. (1985) *Traffic – A thematic approach to mechanics in grade 10*, see 4d, pp. 384-389; (f) KORTLAND, J. (1988) *Curriculum Emphases in the PLON Physics Curriculum*, proceedings of the Third International Symposium on World Trends in Science and Technology Education, Brisbane.

5 EIJKELHOF, H.M.C. and KORTLAND, J. (1986) 'The context of physics education' in HARRISON, G.B. (Ed.) *World Trends in Science and Technology Education*, Nottingham, pp. 79-81.

6 AIKENHEAD, G.S. (1985) 'Collective decision making in the social context of science', *Science Education*, 69, pp. 453-475.

7 DEKKER, J.A. and VAN DER VALK, A.E. (1986) 'Pre-university physics presented in a thematic and systematic way – Experiences with a Dutch physics curriculum development project', *European Journal of Science Education*, 8(2), pp. 145-153.